Cost of Large-Scale Transitions: Introducing Targeted Incentives

Future of Energy (2024-12-09)

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Computational Science Lab

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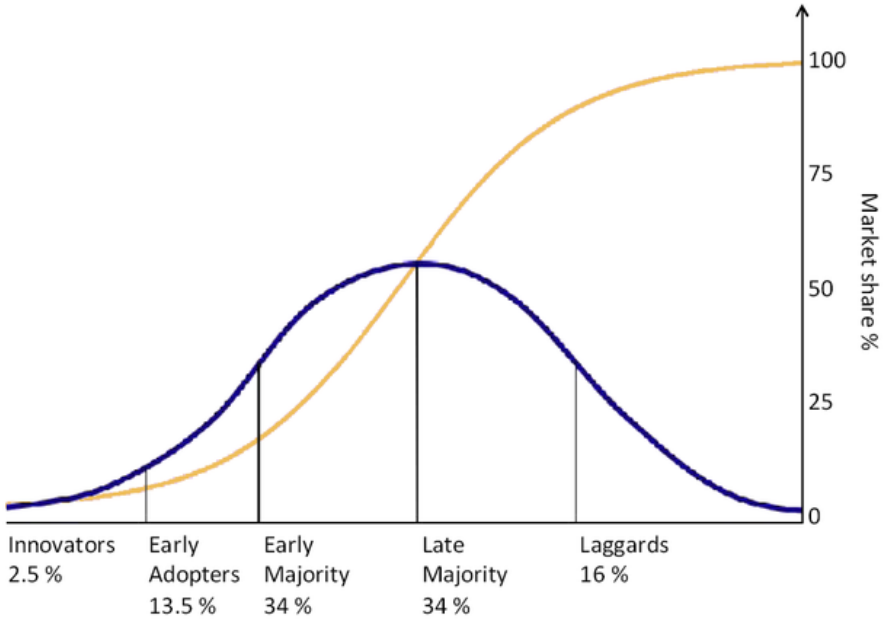
The energy transition is both a supply- and demand-side challenge

- Oversupply/underdemand leads to cheap prices and increased risks for bankruptcy in production side
- Undersupply/overdemand leads to increased prices which prevent adoption

- Today we'll focus on evolution of demand under exogenously varying conditions

Traditional technology adoption processes and models

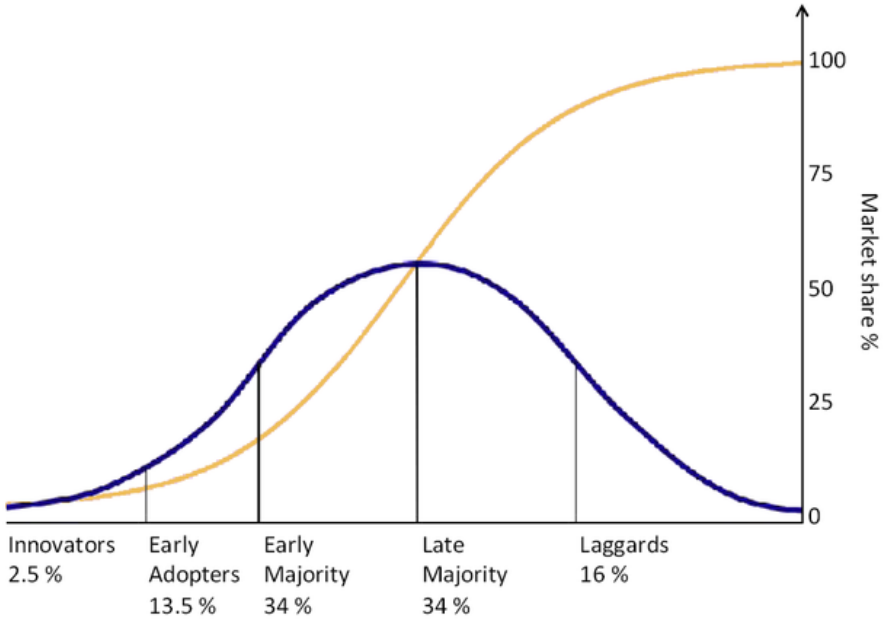
- The adoption of technology has conceptually divided the population in different types of individuals:
  - Innovators
  - Early adopters
  - Early majority
  - Late majority
  - Laggards



Traditional technology adoption – Bass diffusion model

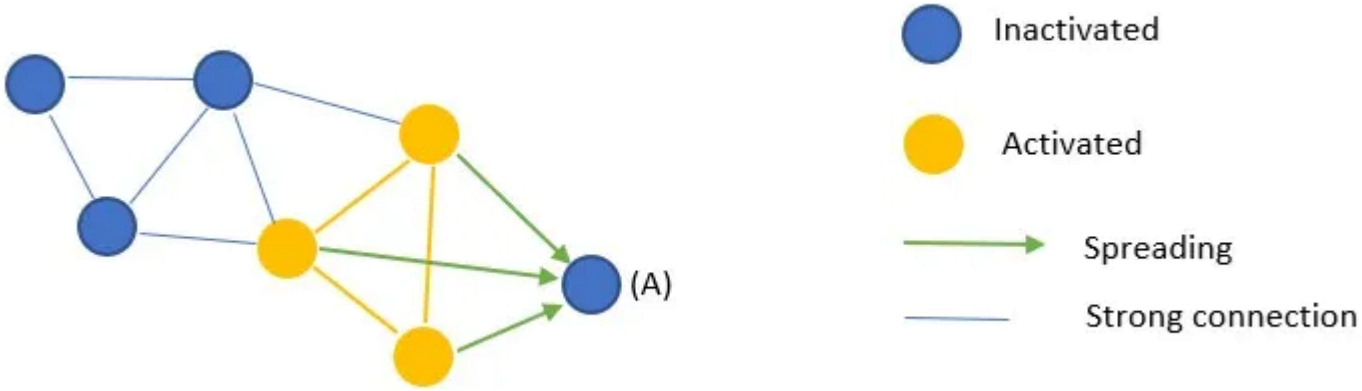
- The adoption of technology has a basic model, X is fraction of adopters:
  - $\frac{dX}{dt} = q\,X(1-X)$

- Two issues:
  - The propagation process
  - Where are the innovators?



Complex Contagion and the Weakness of Long Ties

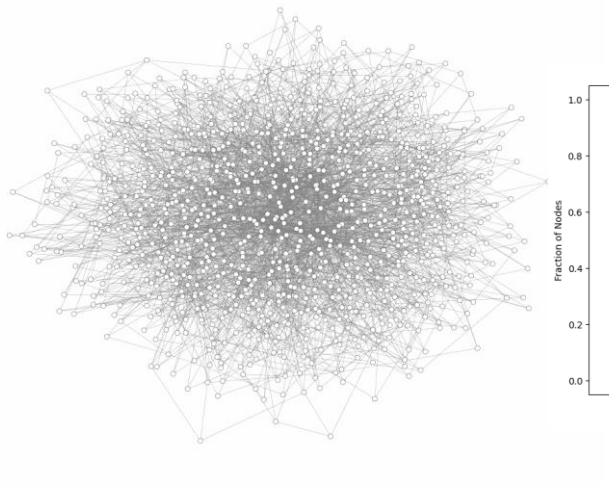
- **Information and disease spread as “simple contagions,” requiring only one contact for transmission**
- **Behaviors typically spread as “complex contagions,” requiring multiples sources of reinforcement to induce adoption**

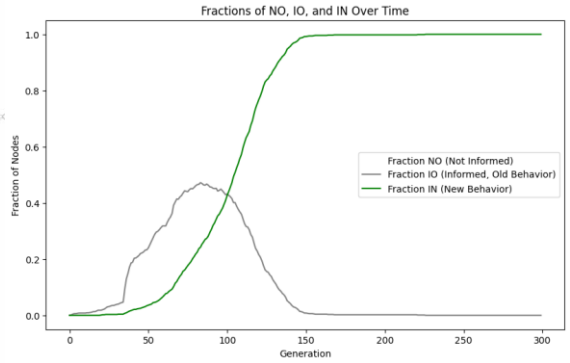


Centola, D., & Macy, M. (2007). Complex contagions and the weakness of long ties. *American journal of Sociology*, *113*(3), 702-734.

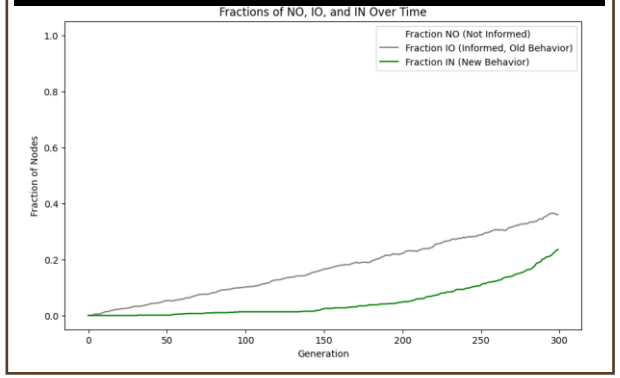
Complex Contagion and the Weakness of Long Ties

local information diffusion

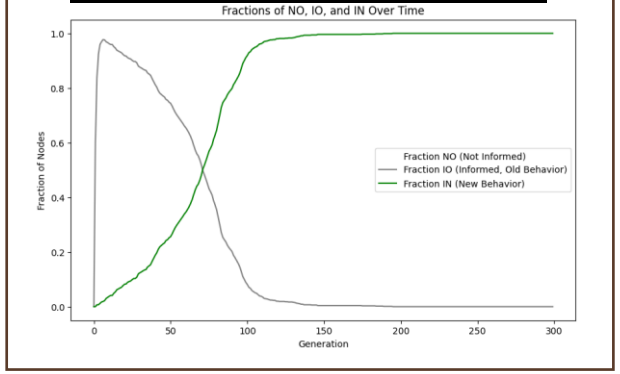




local, low-visibility information diffusion

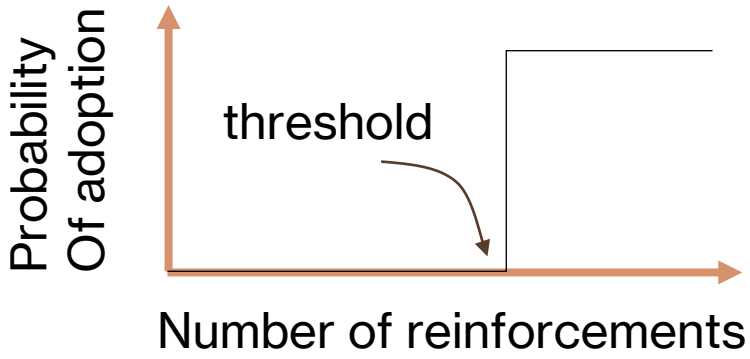


global information diffusion



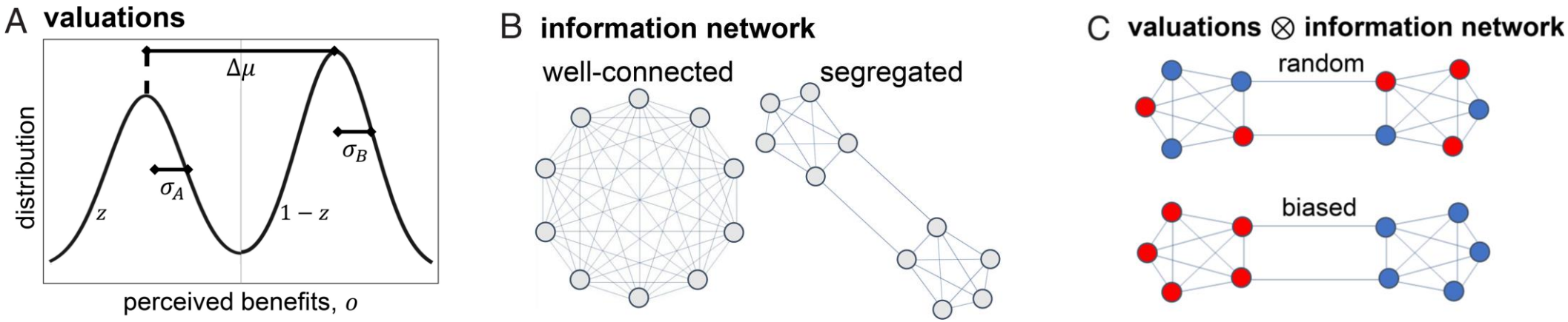
Complex Contagion and the Threshold model

- **Granovetter** (1978)**.** The threshold approach shares features with Schelling's (e.g., 1969, 1971) segregation model and the "theory of critical mass," a sociological approach to the study of collective action problems (Marwell and Oliver 1993).



Key reference:
Gravilets The dynamics of injunctive social norms | Evolutionary Human Sciences | Cambridge Core
A network-based microfoundation of Granovetter's threshold model for social tipping | Scientific Reports

How does the composition of a population affect collective behavior?



- "An Experimental Study of Homophily in the Adoption of Health Behavior." Damon Centola (2011)
  - Homophily significantly increased overall adoption of a new health behavior, especially among those most in need of it.
- Segregation and clustering of preferences erode socially beneficial coordination, Vasconcelos (2021)

How to model human behavior, then?

Behavior adoption has looked at individual level factors

- How does an agent respond to their current and past environment? In terms of
  - Costs
  - Health benefits
  - Quality of living space
  - Current behavior

Behavior adoption has looked at individual level factors

costs A

benefits A

value of option A

Behavior adoption has looked at individual level factors

price A
…

social status A
…

costs A

benefits A

value of option A

Behavior adoption has looked at individual level factors

price A
…

social status A
…

price B
…

social status B
…

costs A

benefits A

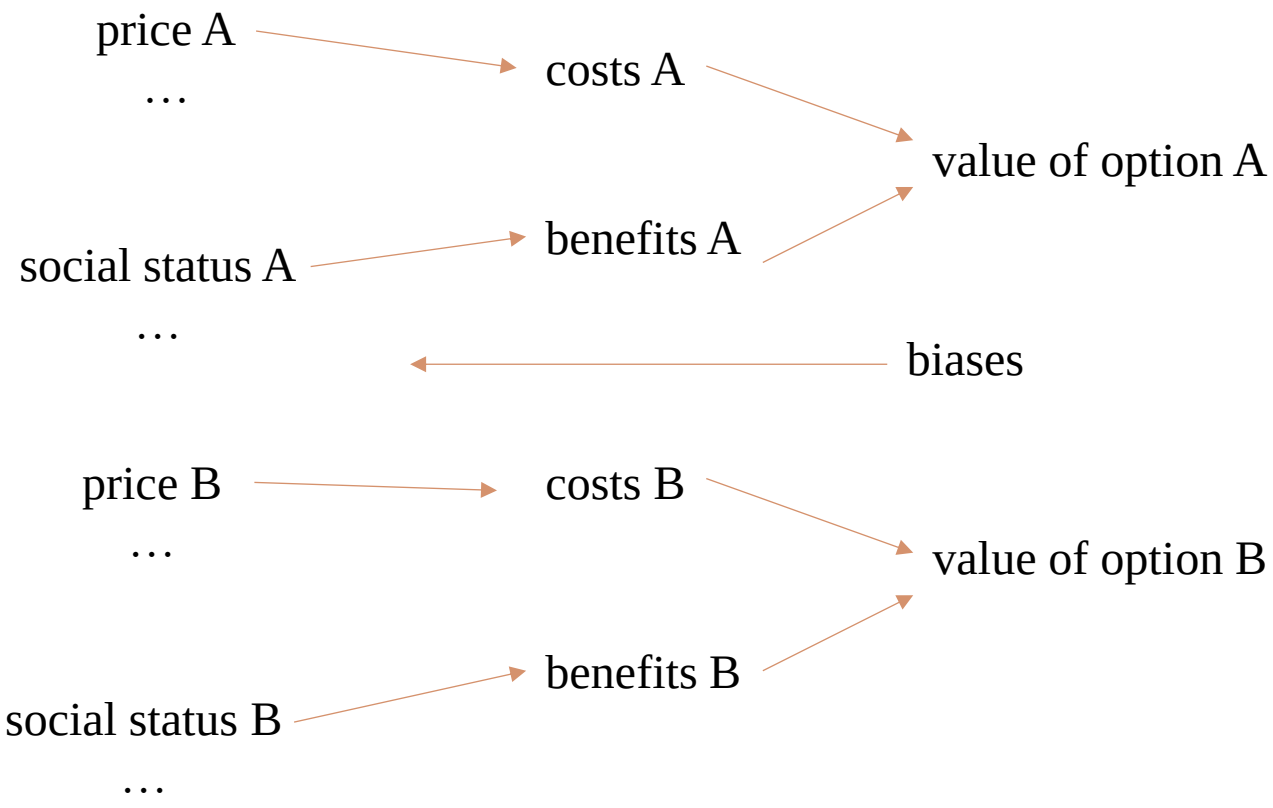
costs B

benefits B

value of option A

value of option B

Behavior adoption has looked at individual level factors



Behavior adoption has looked at individual level factors

price A
…

social status A
…

price B
…

social status B
…

costs A

benefits A

costs B

benefits B

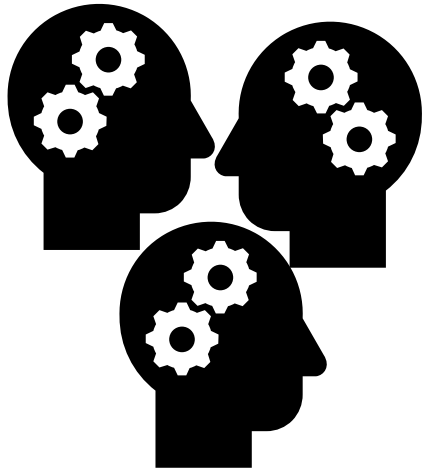
value of option A

value of option B

biases

decision

Social feedback



their decisions

price A

…

costs A

value of option A

social status A

…

benefits A

biases

decision

price B

…

costs B

value of option B

social status B

…

benefits B

Social feedback

Utility of A = *features of A* × *valuation of those features* + *social influence of A*

Utility of B = *features of B* × *valuation of those features* + *social influence of B*

Spiral of silence and cultural lag

PNAS nexus

PNAS Nexus, 2024, **3**, pgae302

https://doi.org/10.1093/pnasnexus/pgae302
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Research Report

Anticonformists catalyze societal transitions and facilitate the expression of evolving preferences

Dhruv Mittal [a,*], Sara M. Constantino [b,c,d,e] and Vítor V. Vasconcelos [a,f,*]

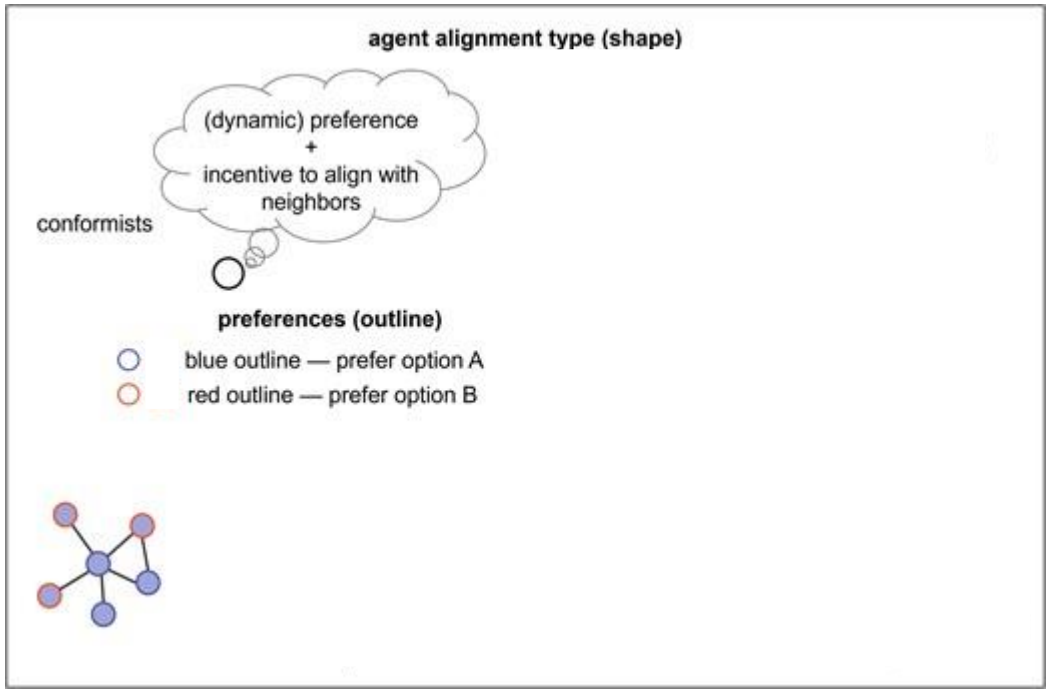
Population of N individuals

- Each individual, i, has a set of preferences derived from the comparison between the properties of the two products, A and B. This results in a utility difference between A and B per individual, ΔU_i
- The properties of the products can be decomposed in two elements, intrinsic, o_i^A and o_i^B, and social, dependent on the numbers of adopters $\#_A$ and $\#_B$:
  - $\Delta U_i = \underbrace{o_i^A - o_i^B}_{\text{intrinsic}} + \underbrace{w(\#_A - \#_B)}_{\text{social}}$
- When described from the individual point of view and as a function of their neighborhood, we get a threshold model,

- but now we can talk about alignment with preferences.
- It can describe different types of incentives: conformity and non-conformity

Social feedback leads to emergent phenomena

- Individuals respond to they social environment
- Anti-conformists see (some) incentives to miscoordinate with others



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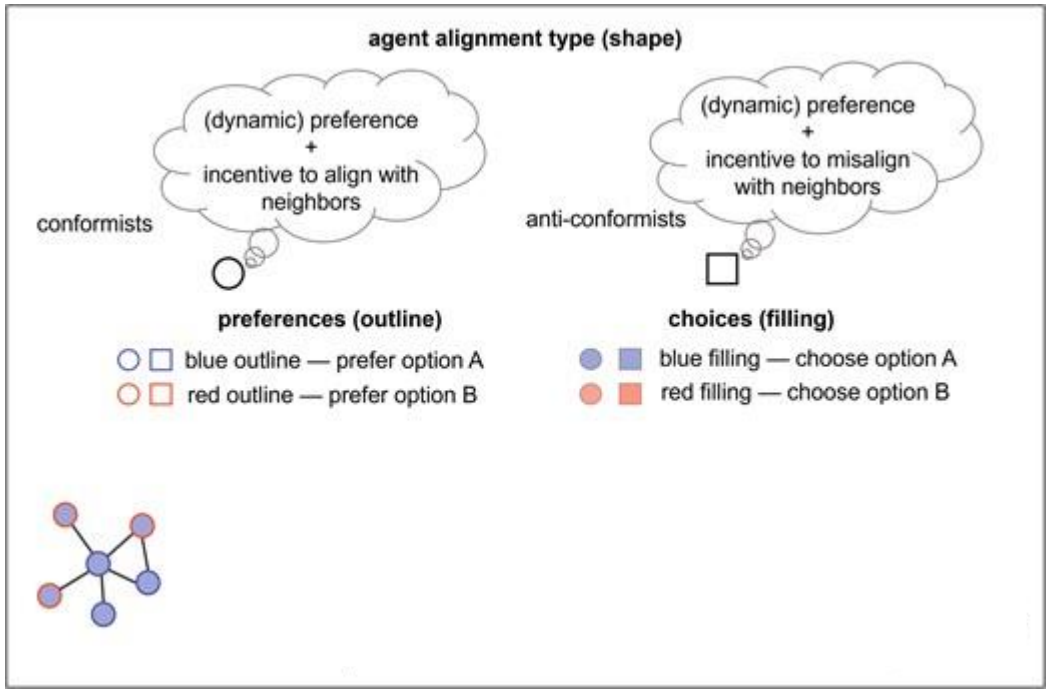

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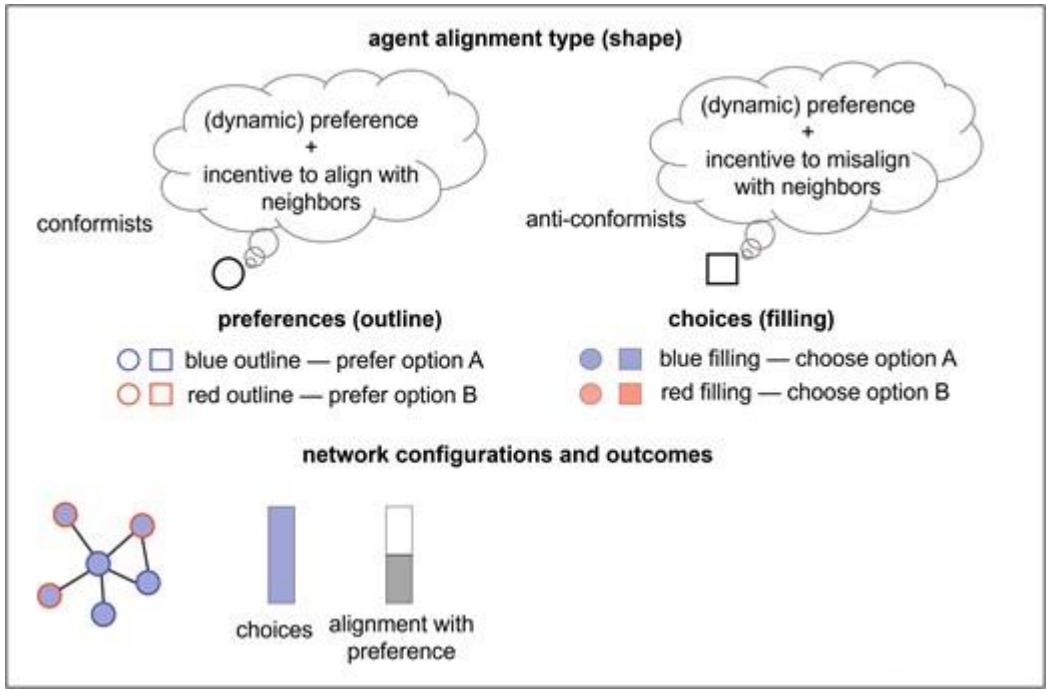

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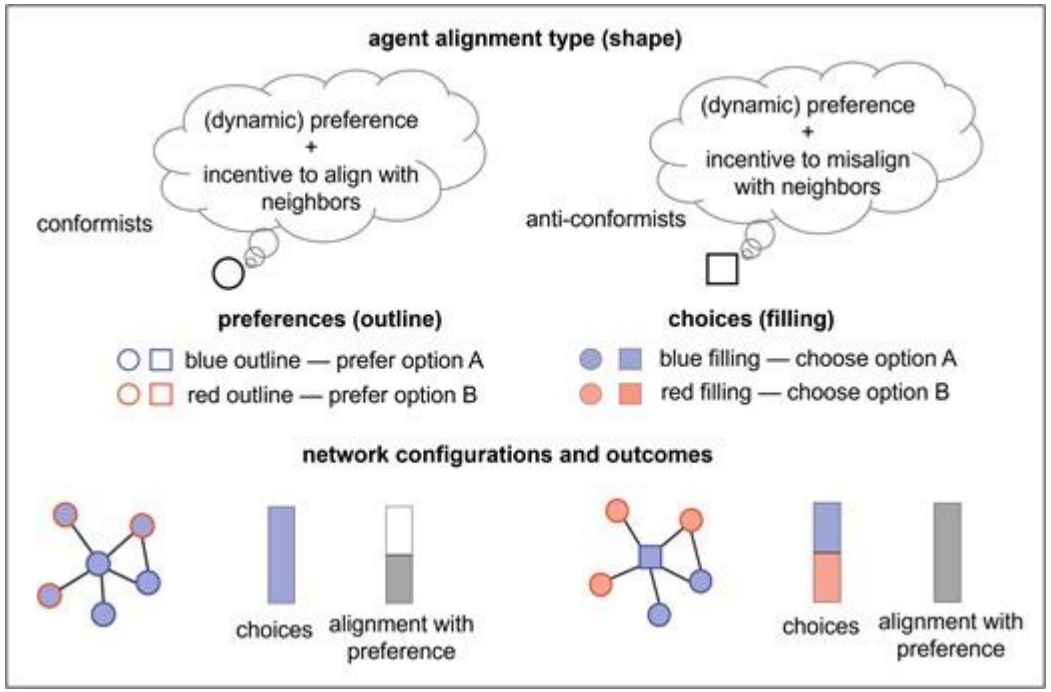

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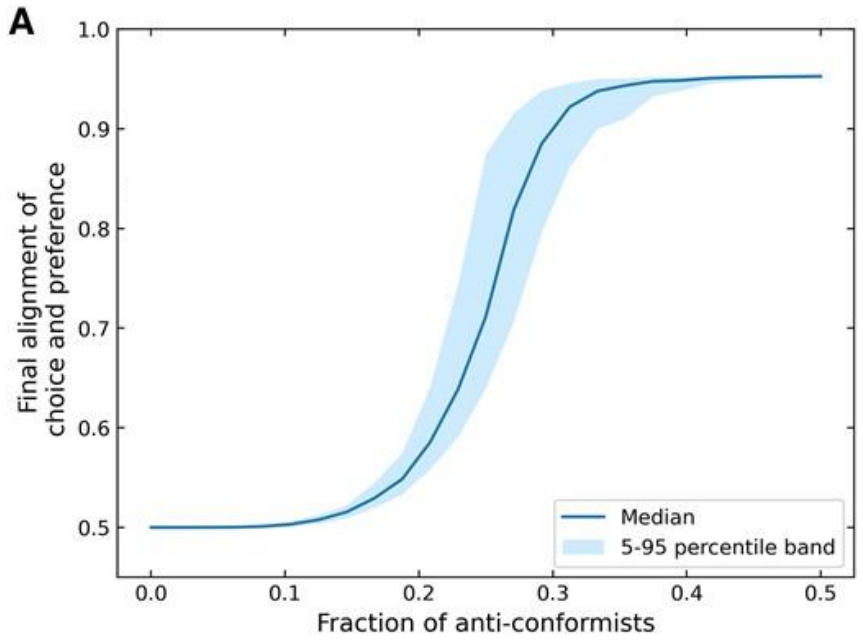
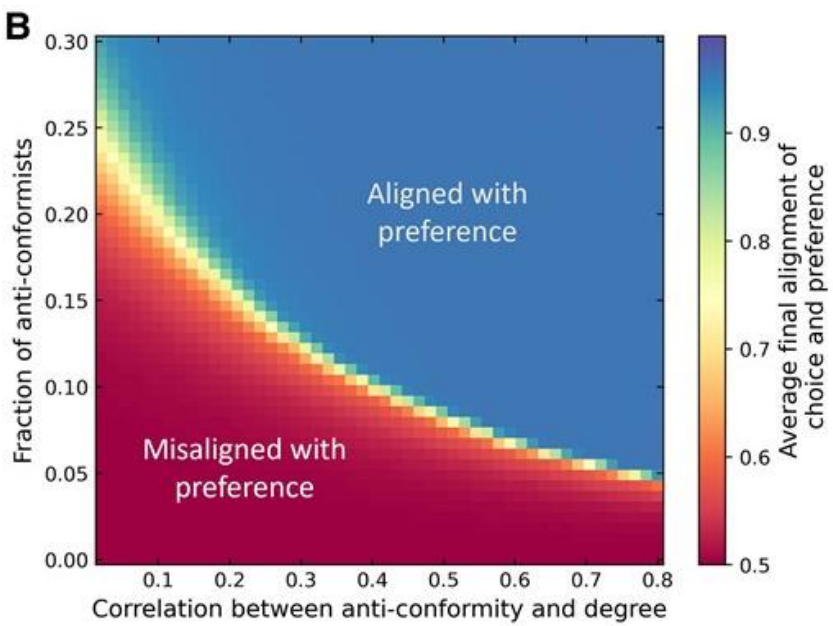
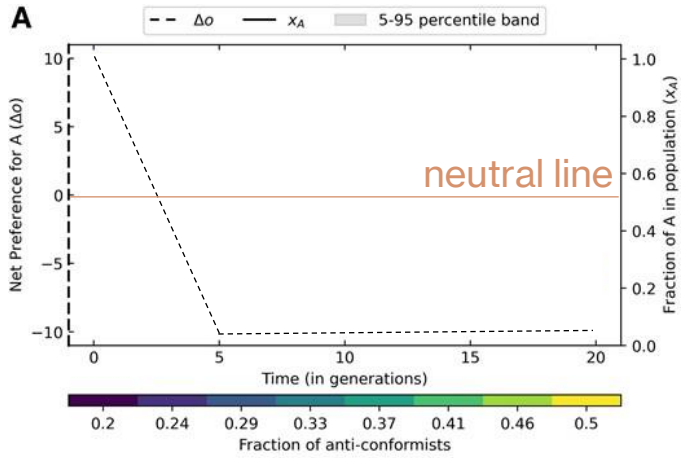




Cultural Lag in dynamic environments

Decaying preferences

anti-conformists



Conclusion

- Conformity pressures lead the system to deadlocks in non-preferred states
- The system can “tip,” showing the patters of technology adoption based on microscopic decision
- Anticonformists catalyze such societal transitions
- They also facilitate the expression of evolving preferences (such as decaying prices or economic cycles)

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Targeting heuristics for cost-optimized institutional incentives in heterogeneous networked populations

Dhruv Mittal, Fátima González-Novo López, Sara Constantino, Shaul Shalvi, Xiaoji Chen, & Vítor V. Vasconcelos

Where to intervene?

1. Agent using a traditional, polluting technology

2. No social pressure on the agent to change strategies

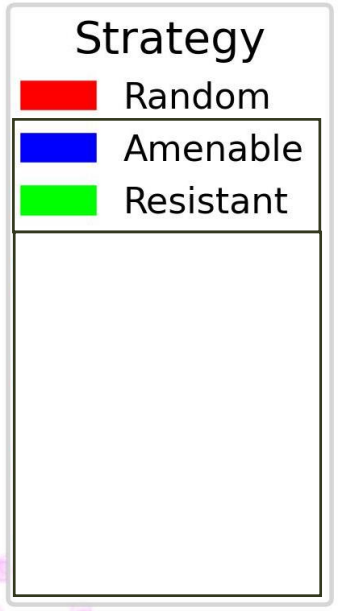
3. Institution provides incentives to encourage norm change

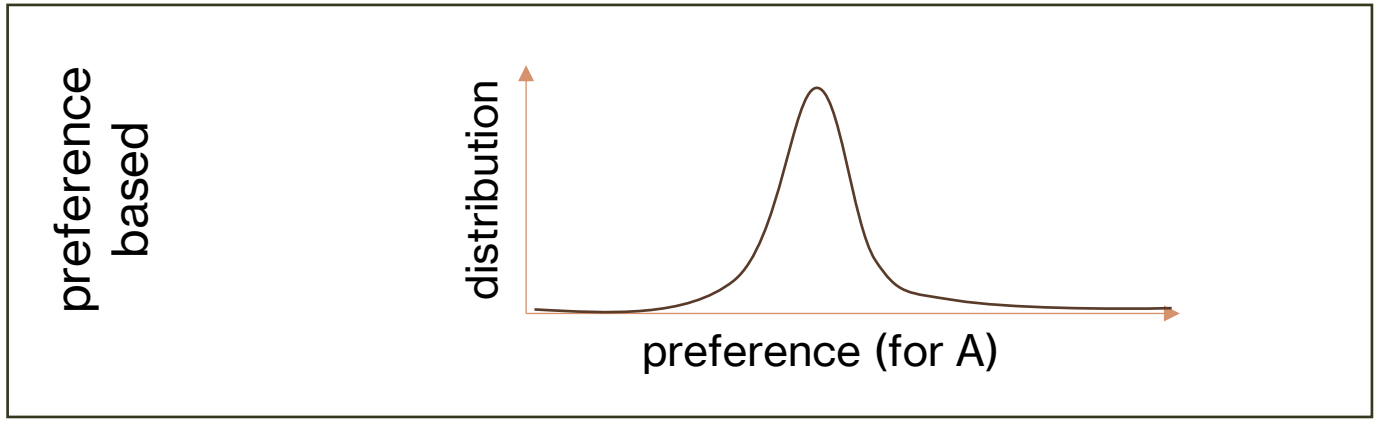
4. Agent is aware of this incentive program and decides to apply for it

5. Institution evaluates case and grants the necessary incentive

6. Agent adopts greener technology which influences neighbors' attitudes towards it

Where to intervene?





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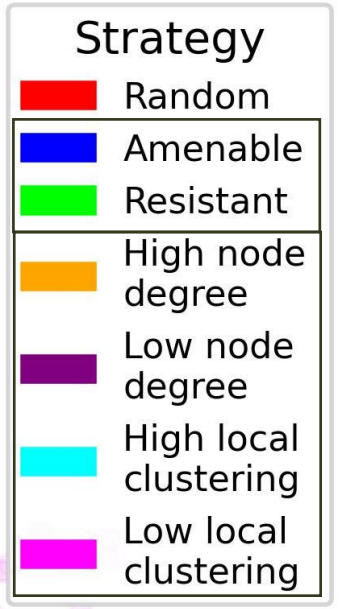

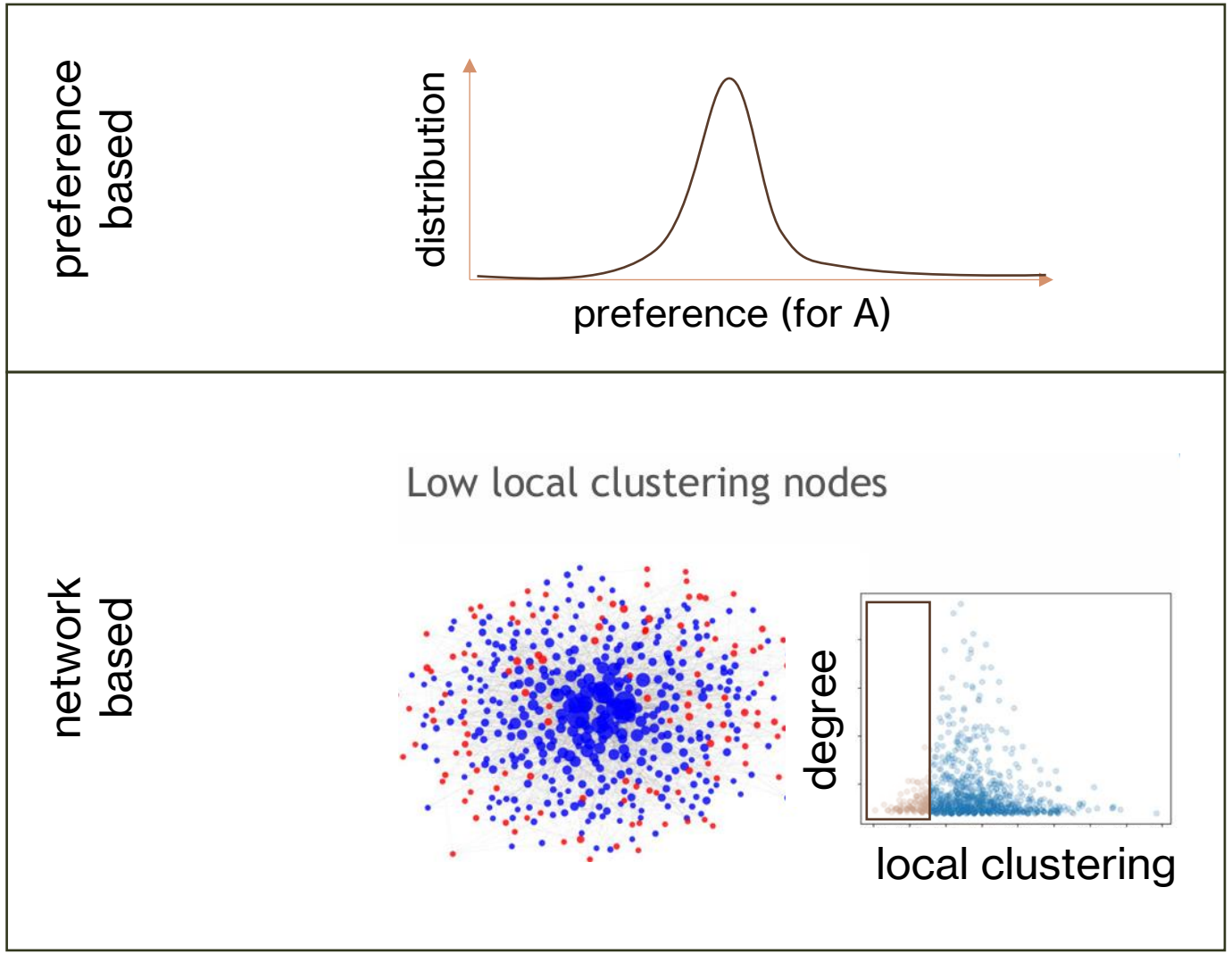

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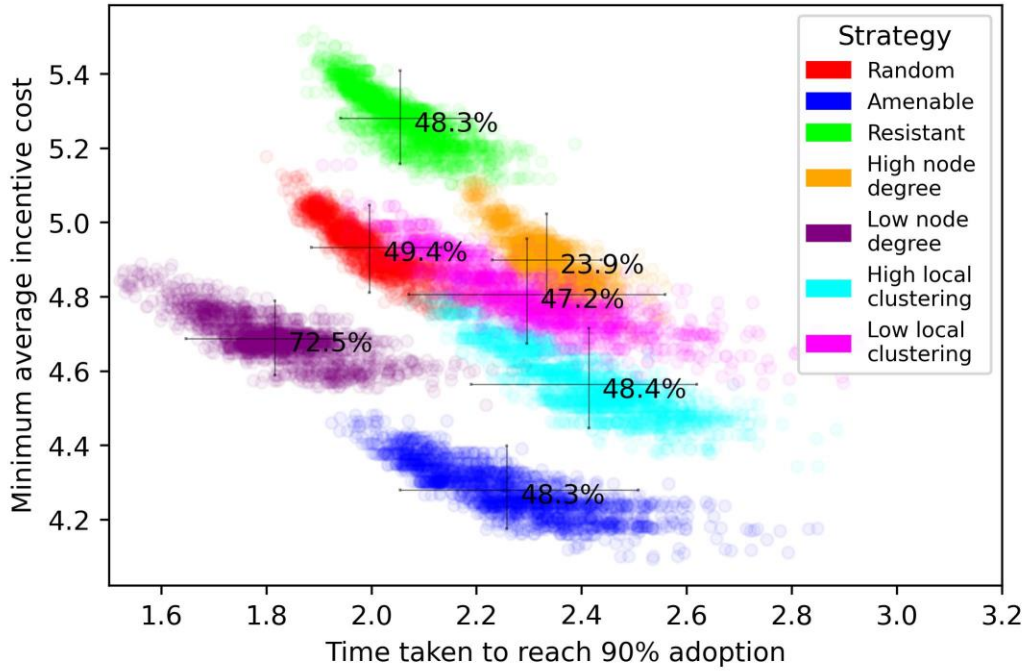


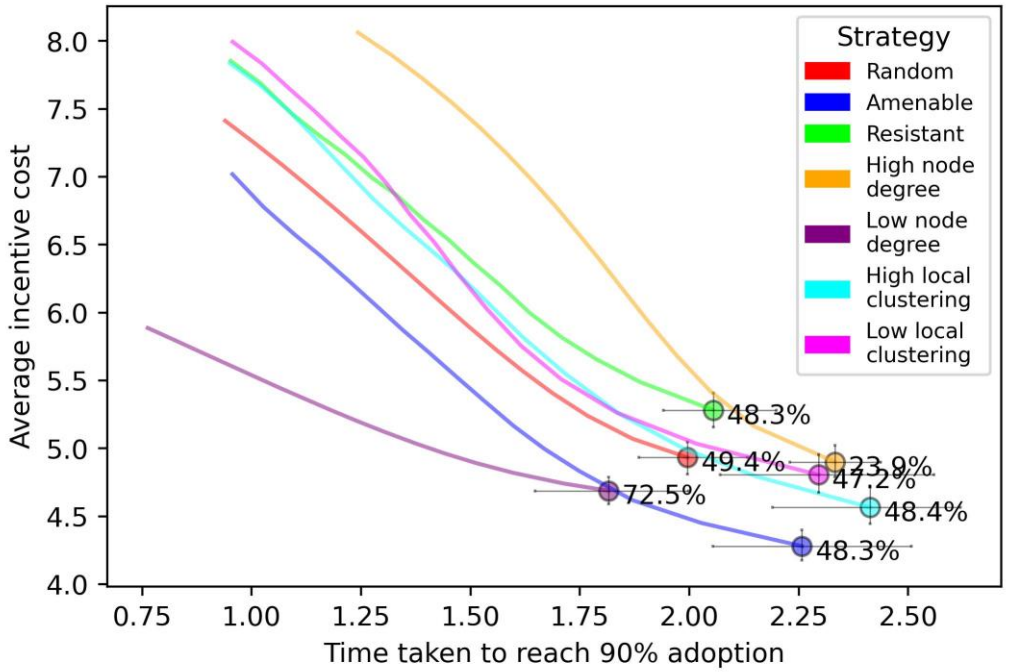
Setup:

- Heterogeneous network (N=1000)
- Unimodal preferences ($\mu=0$, $\sigma>0$)

Results:

- Targeting amenable individuals is optimal on expectation
- Different realizations have different costs and different timing
- A lower minimal incentive is associated with longer time within a strategy
- Targeting low degree nodes is associated with faster cascades (at average costs)

Where to intervene?



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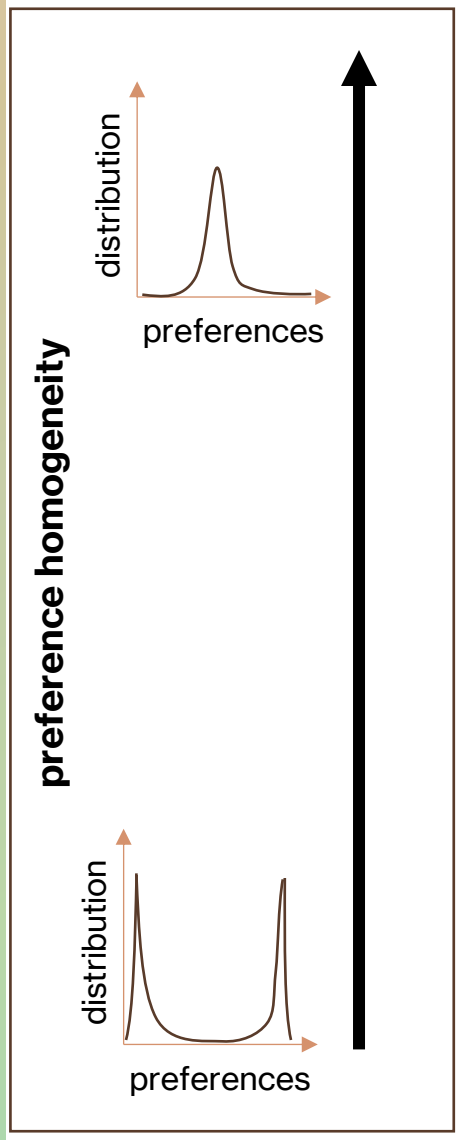
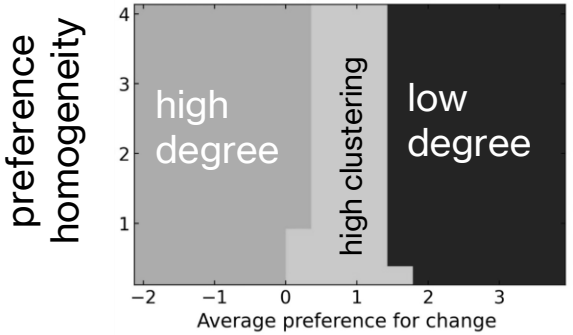
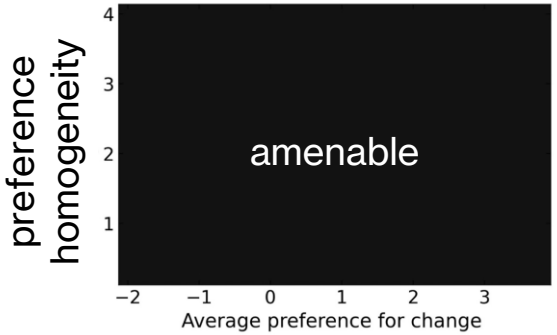
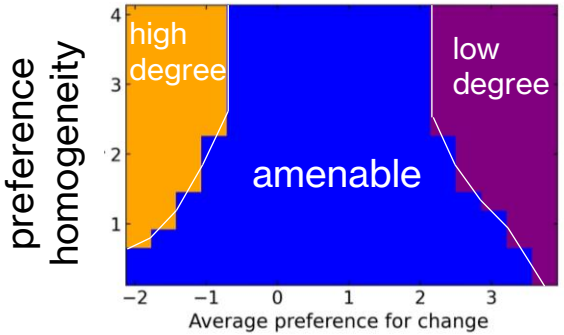


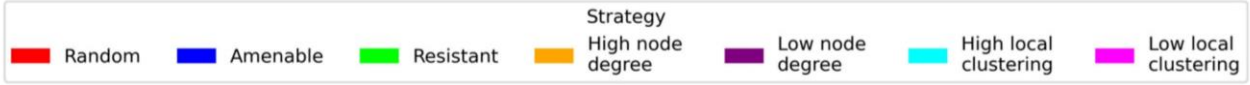
Information about network



Information about preferences







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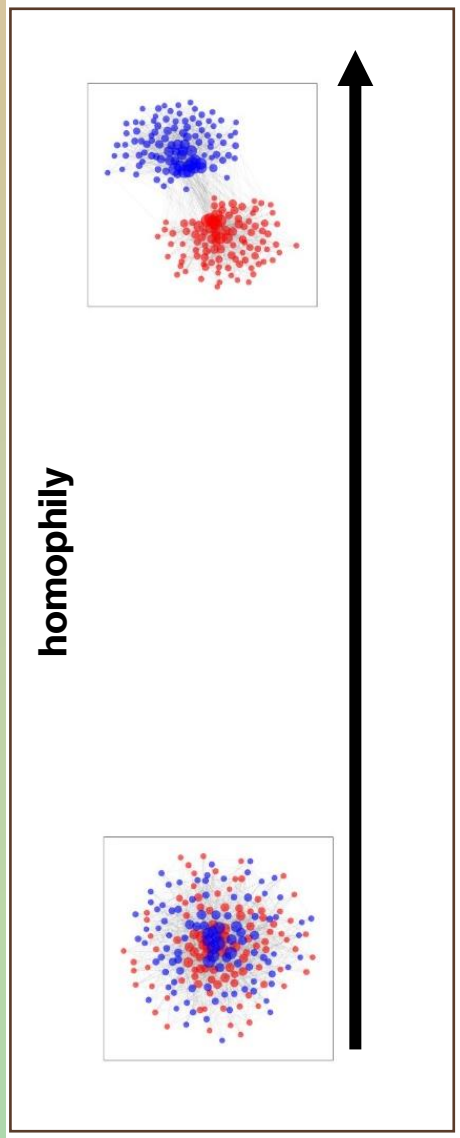
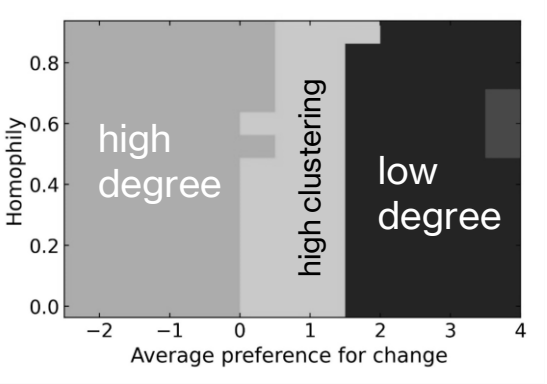
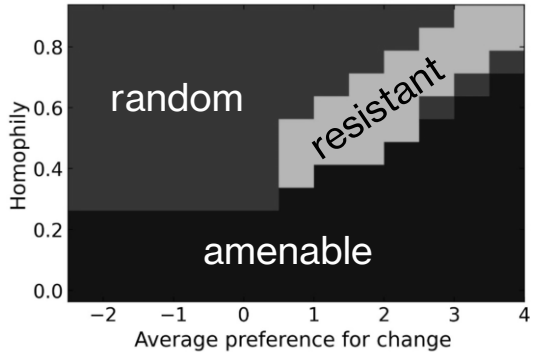
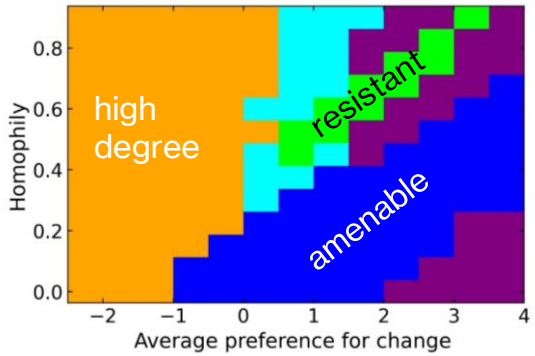


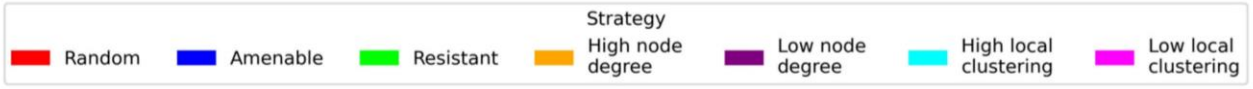
Information about network



Information about preferences







Current state

- Theory shows when and how populations can generate self-sustained change
    - The conditions are highly diverse, population and scale-dependent
- Where to intervene depends populations' underlying preferences and their distribution, information availability and its flows (networks), and individuals' susceptibility to others
- Thus, different issues will have different best solutions, depending on where they lie on this spectrum

Next steps

- At POLDER we have started a project with RIVM covering technology adoption and theory of social tipping
- We have proposed a project on Climate Attitudes and polarization of climate policy support using identical tools
- We have proposed a project to look at the adoption of plant-based diets

- Use conjoint experiments to assess individuals' preferences and dependence on neighborhoods, connecting to existing elements on CBS data
- Use ERGMs to test dynamical behaviors of link formation for the coevolution of networks and behavior

Thank you!

Outputs:

- Mittal, D., Constantino, S., & Vasconcelos, V. V. (2024). Anticonformists catalyze societal transitions and facilitate the expression of evolving preferences. PNAS nexus, 3(8), pgae302.
- González-Novo López, F. (2024). Thesis MSc Computational Science: “Heuristic strategies for cost-optimized institutional incentives in heterogeneous networked populations.” Supervision and Assessment: Mittal, D., Vasconcelos, V.V., Shalvi, S.
- Mittal, D., GN López, F., Constantino, S., Shalvi, S., Chen, X., & Vasconcelos, V.V. (upcoming). Targeting heuristics for cost-optimized institutional incentives in heterogeneous networked populations.

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