Network Effects on Behavior: How Do Mechanisms Matter?

Paul DiMaggio
New York University

Filiz Garip
Cornell University

Network effect

is the effect on ego of alters' behavior

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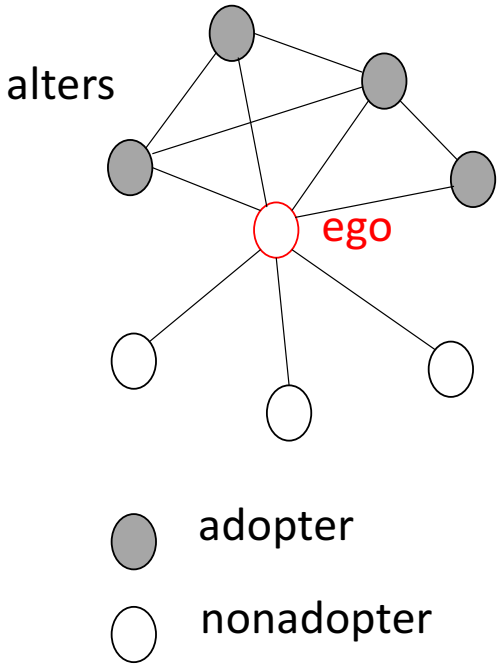

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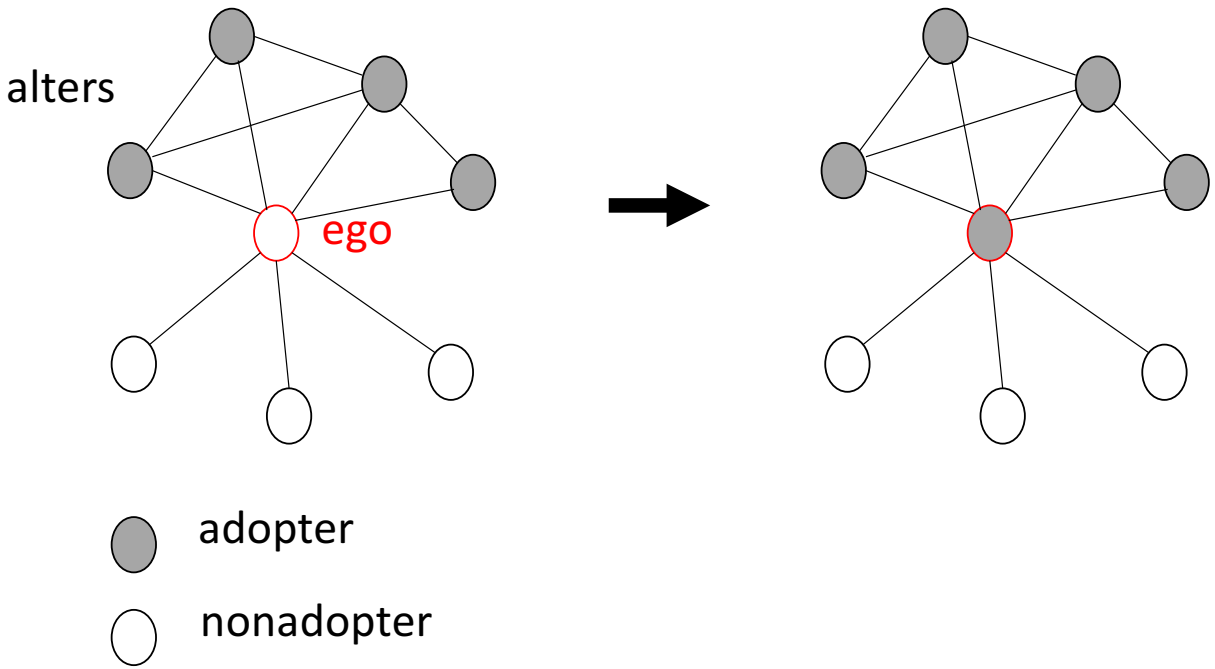

Mechanisms underlying network effects are important to identify.

Different mechanisms might lead to different levels of adoption and to different levels of inequality between groups.

Prior work

Network effects in education, health and technology use can cumulate to higher levels of social inequality.

DiMaggio and Garip (2011, AJS)

For network effects to exacerbate inequality:

- the practice should be beneficial,
- adoption should be more likely among the advantaged,
- adoption should be more likely if peers have adopted,
- networks should be homophilous.

What we do in this paper:

- Define a typology of mechanisms for network effects,
- Express each mechanism mathematically,
- Build a computational model of adoption,
- Vary levels of network homophily,
- Examine differences among mechanisms in
    - the level of adoption,
    - the level of intergroup inequality.

Characteristics of Practices

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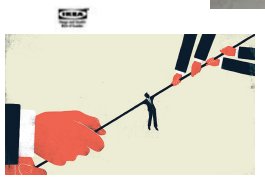
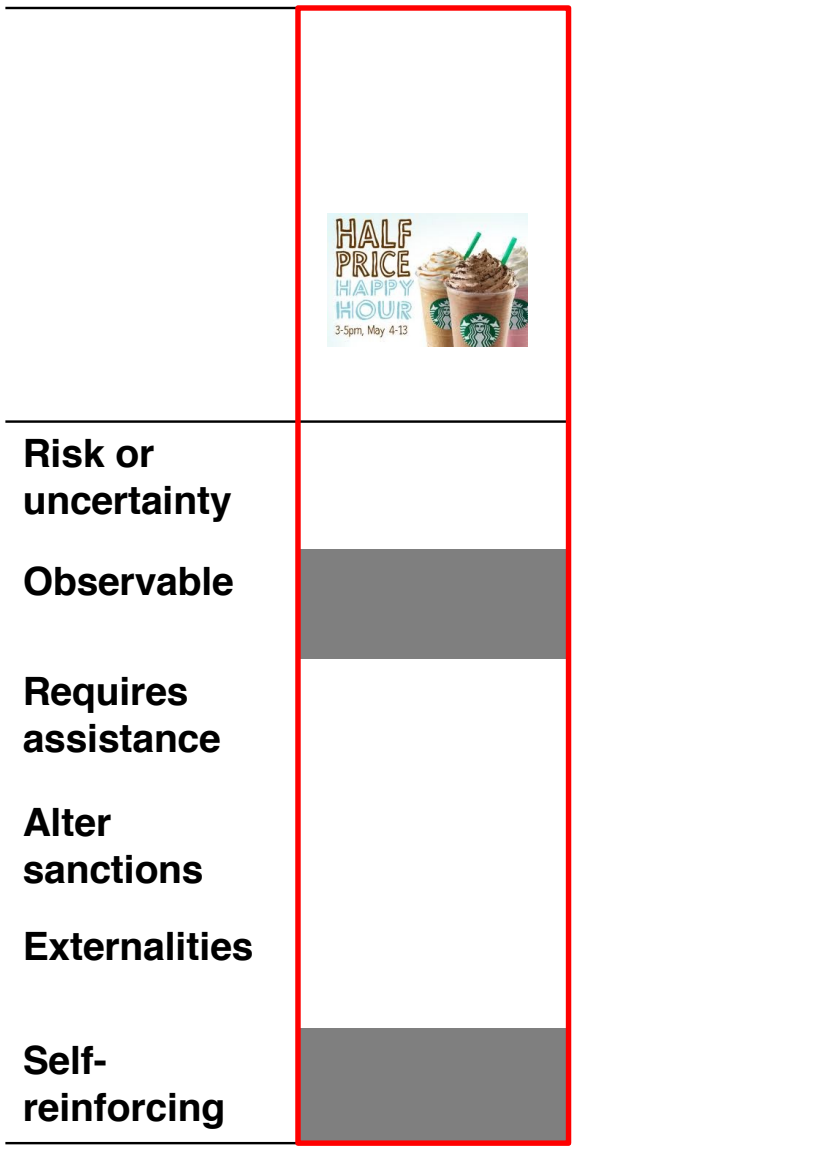
- Is choice easy to implement or does it require assistance?
- Do alters apply sanctions?
- Is adoption characterized by network externalities?
- Is the behavior self-reinforcing or does it require continued support?



Typology of Mechanisms



Simple contagion

When behaviors are uncomplicated, safe, observable, and self-reinforcing.

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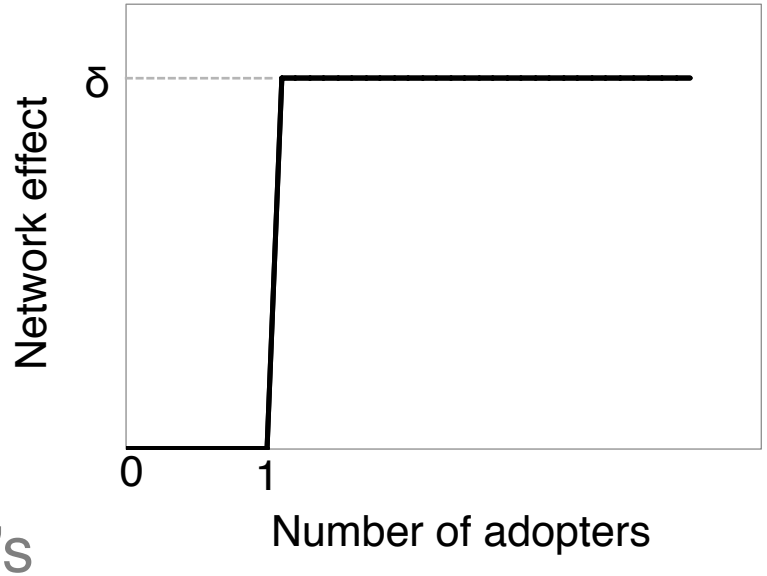
Network effect is given by

δ if $na_{it-1} \geq 1$

0 otherwise.



δ (delta) a scalar

na_{it-1} no of adopters in individual i's network at time t-1

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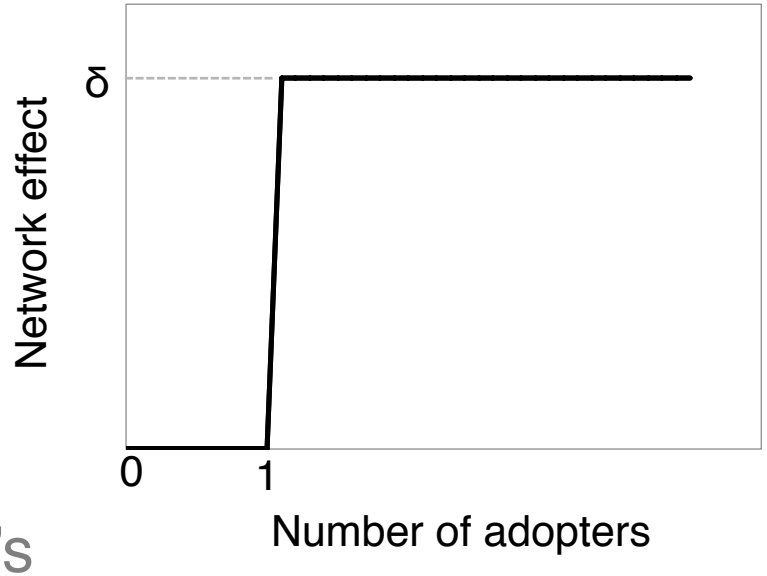

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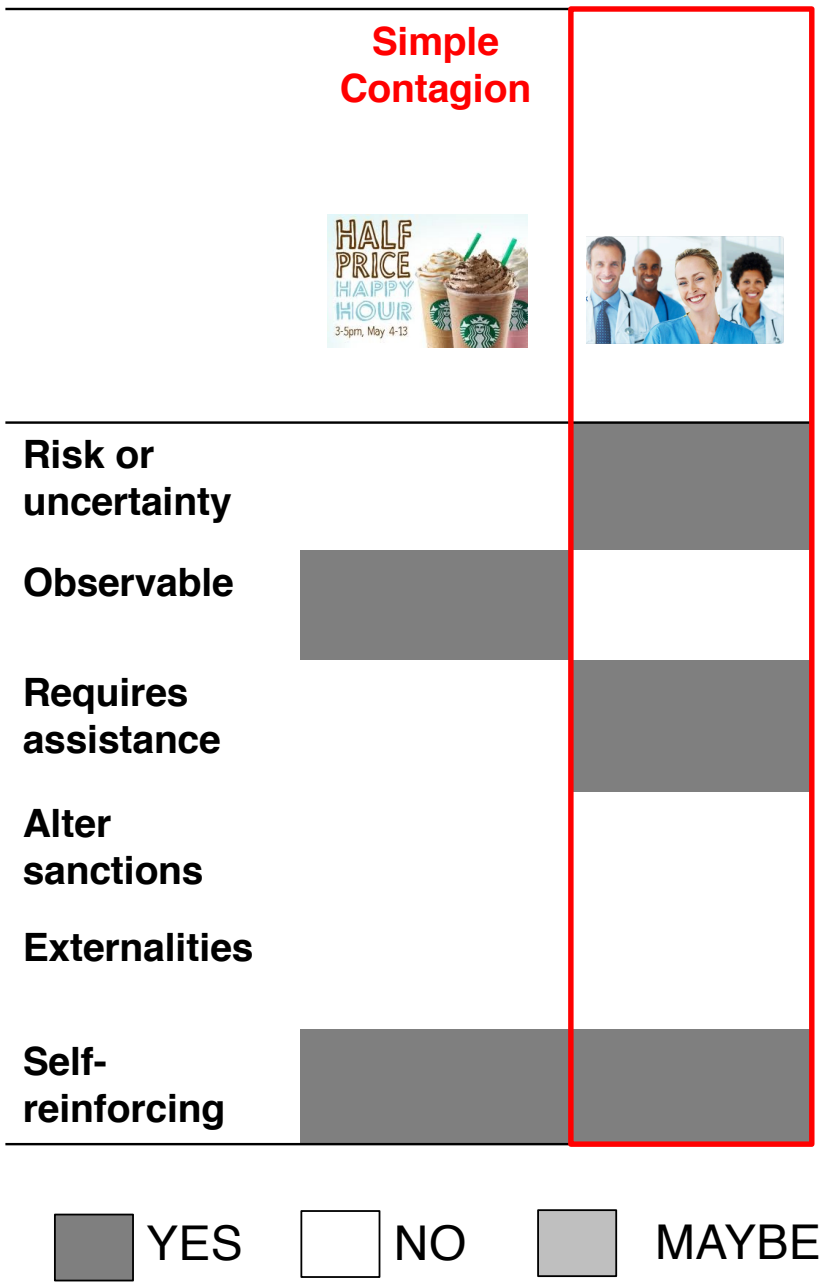
Strong and weak ties are equally useful.

Typology of Mechanisms



Social facilitation

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$\delta \times \log(na_{it-1} \geq 1)$ if $na_{it-1} \geq \tau$

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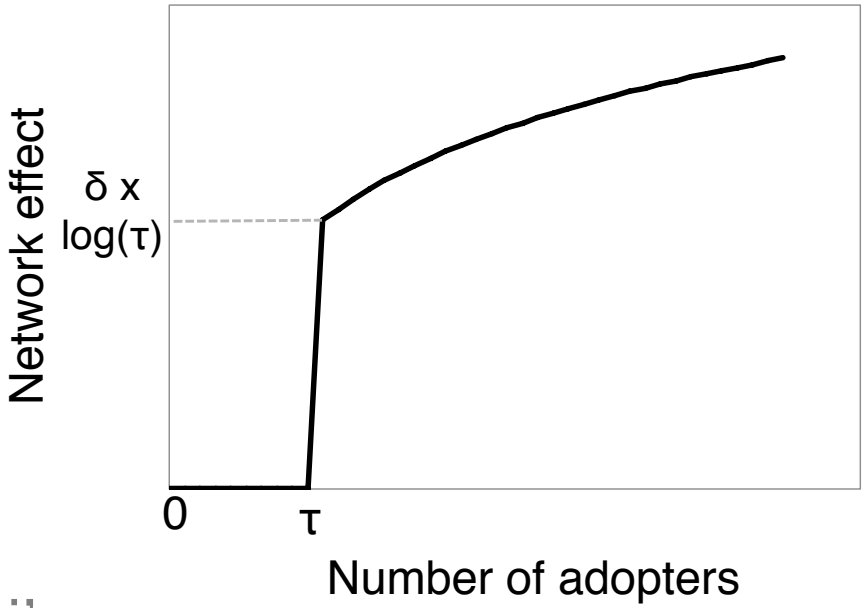

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τ (tau) threshold for network effect

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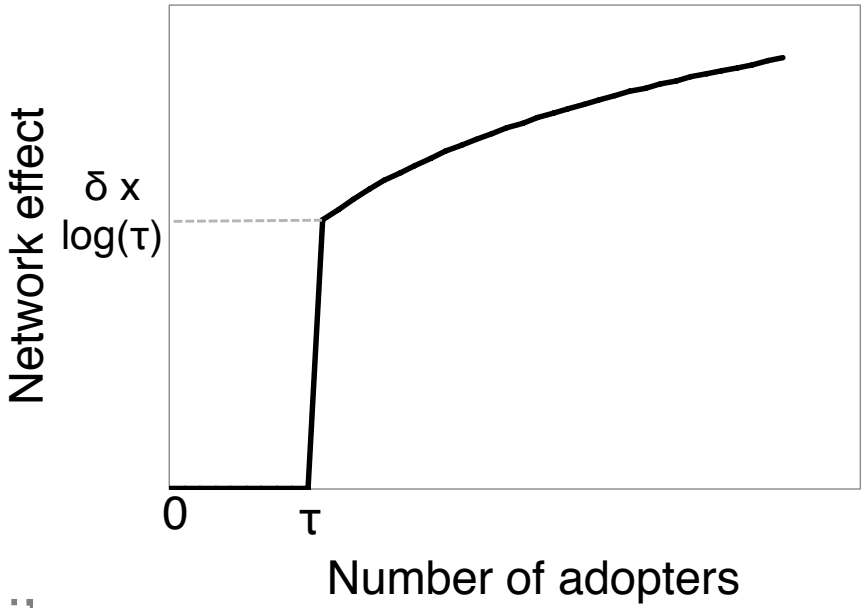

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Only strong ties matter.

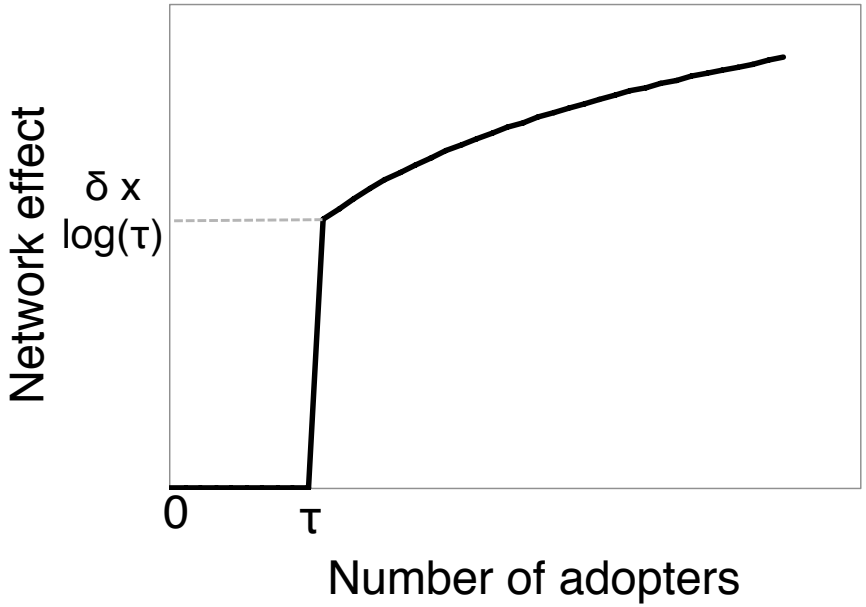
Typology of Mechanisms

	Simple Contagion	Social Facilitation	Social Observation
			
Risk or uncertainty			
Observable			
Requires assistance			
Alter sanctions			
Externalities			
Self-reinforcing			

YES NO MAYBE

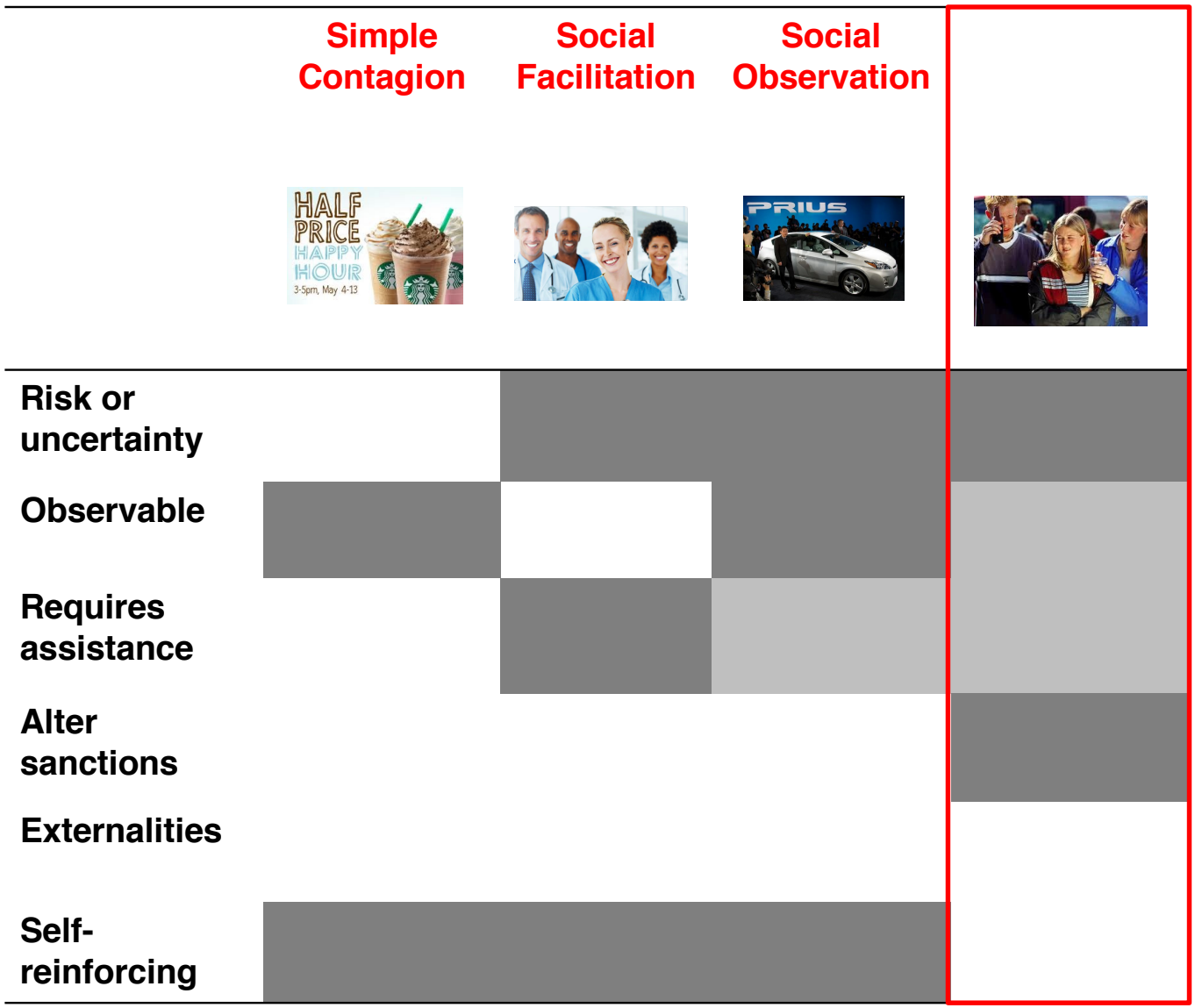
Social observation

Network effect is identical in form to social facilitation.



But, here, both strong and weak ties matter.

Typology of Mechanisms



Normative influence with consensus

When prior adopters provide positive or negative sanctions to persuade the adoption of uncertain behaviors and non-adopters are indifferent.

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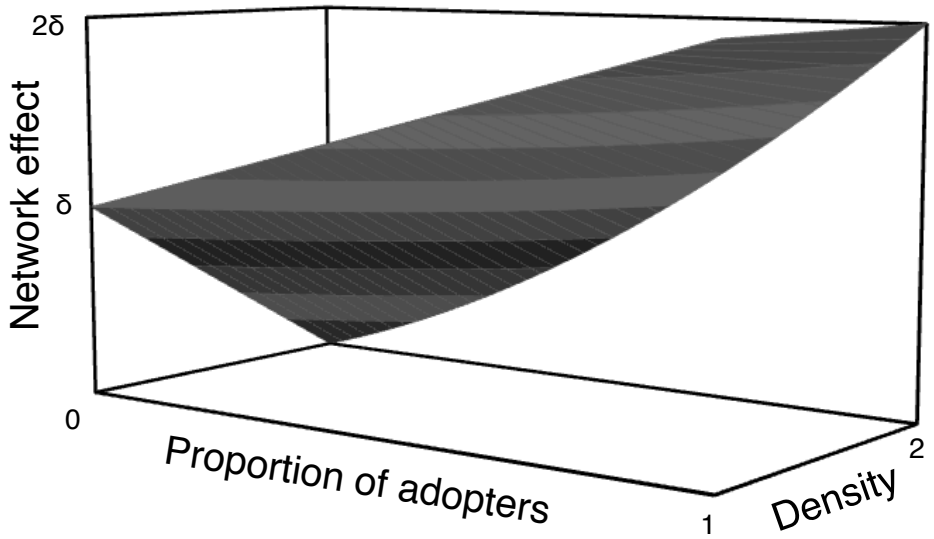
Network effect is expressed as

$$\delta \times pa_{it-1} \times da_{it-1}$$



δ (delta) a scalar

pa_{it-1} proportion of adopters in individual i's network at time t-1 [0,1]

da_{it-1} density of ties among adopters in individual i's network at time t-1 [1,2]

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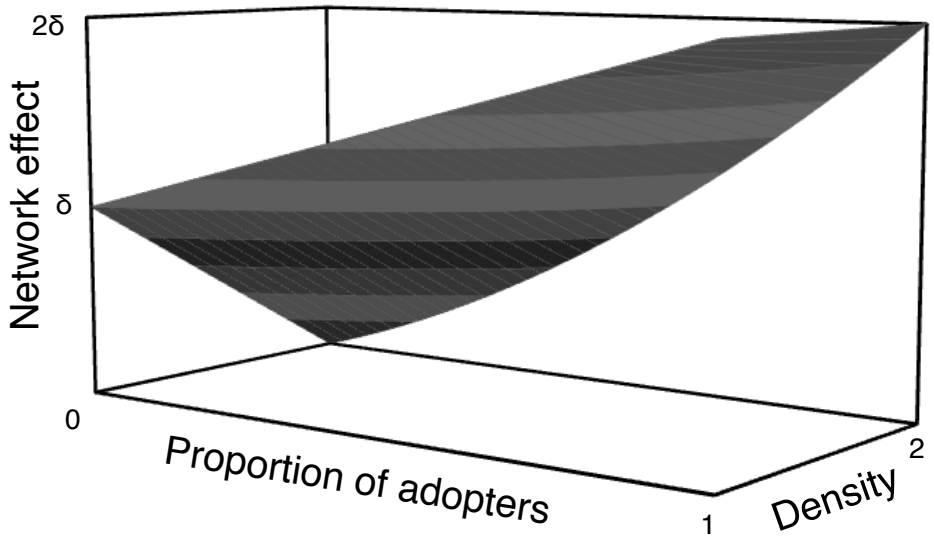

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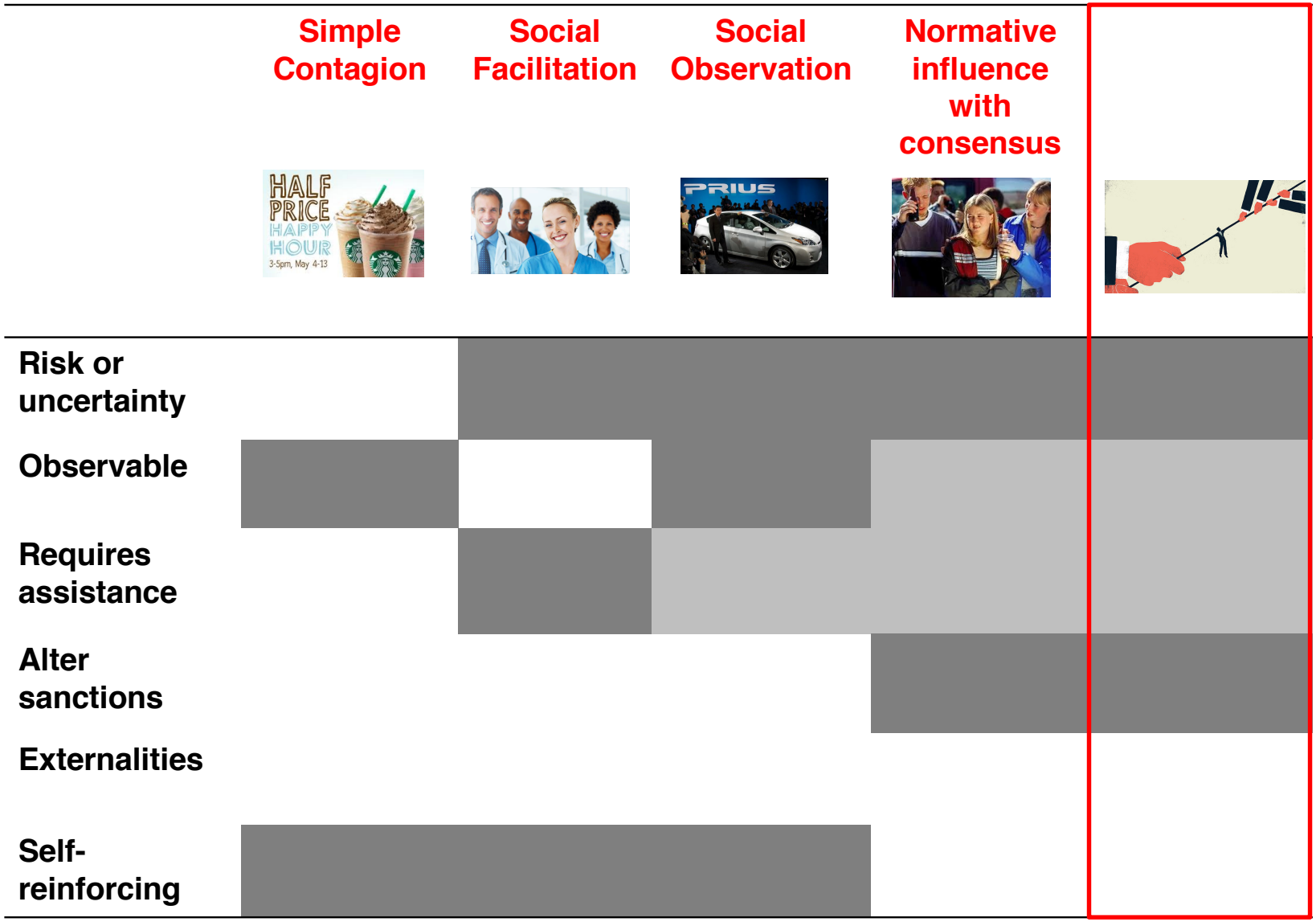

Normative influence with dissensus

Prior adopters and non-adopters compete for influence.

Network effect is expressed as

$$\delta \times \frac{pa_{it-1}}{pn_{it-1}} \times \frac{da_{it-1}}{dn_{it-1}}$$

δ	(delta) a scalar
pa_{it-1}	proportion of adopters in individual i's network at time t-1 [0,1]
pn_{it-1}	proportion of non-adopters in individual i's network at time t-1 [0,1]
da_{it-1}	density of ties among adopters in individual i's network at time t-1 [1,2]
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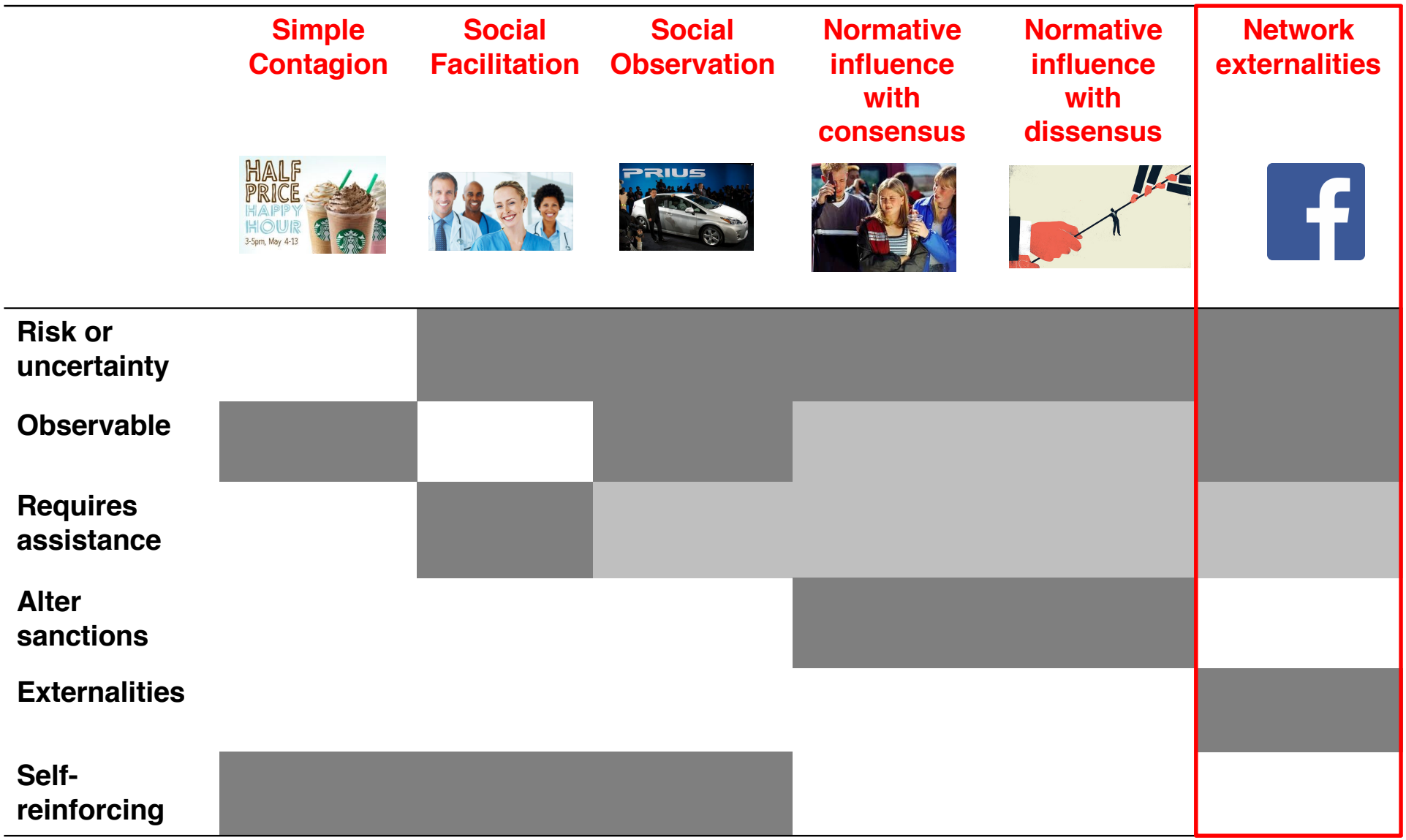

Network externalities

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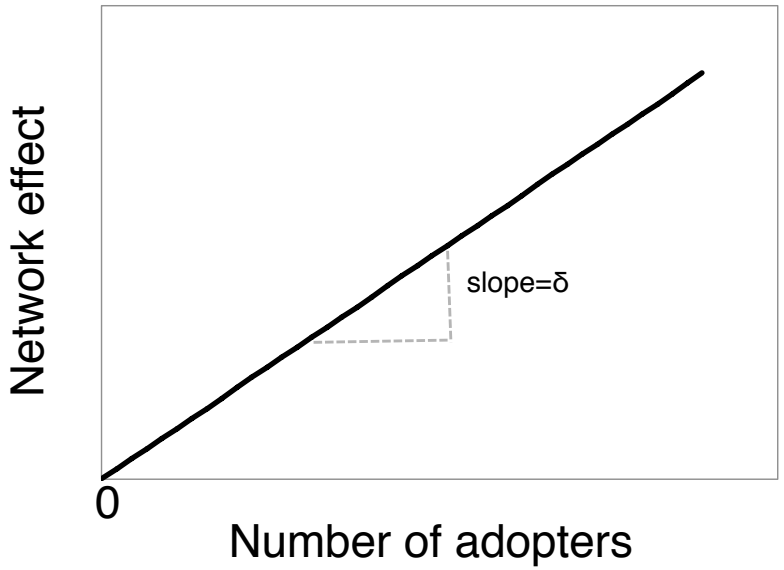

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na_{it-1} no of adopters in individual i's network at time t-1 [0,1]

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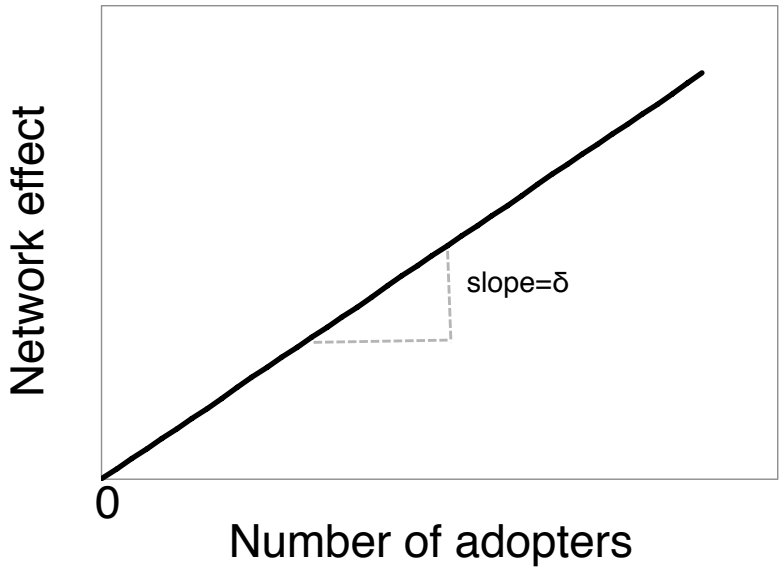

Network effect is given by

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δ (delta) a scalar

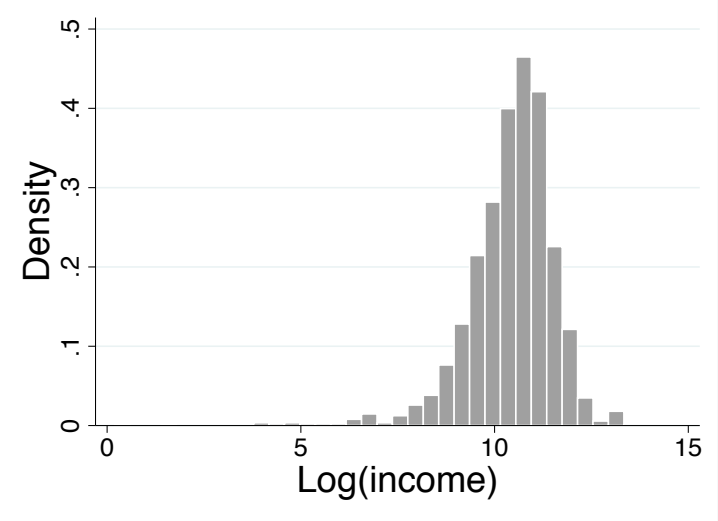
na_{it-1} no of adopters in individual i's network at time t-1 [0,1]

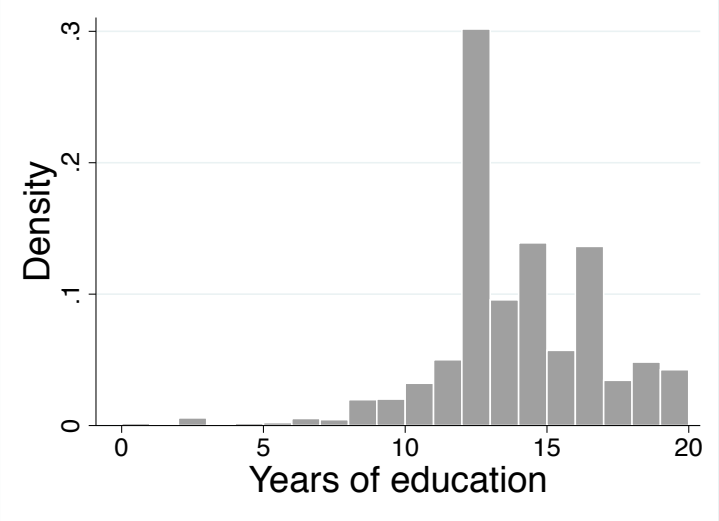
Both strong and weak ties matter, but strong ties are more important than weak ties.

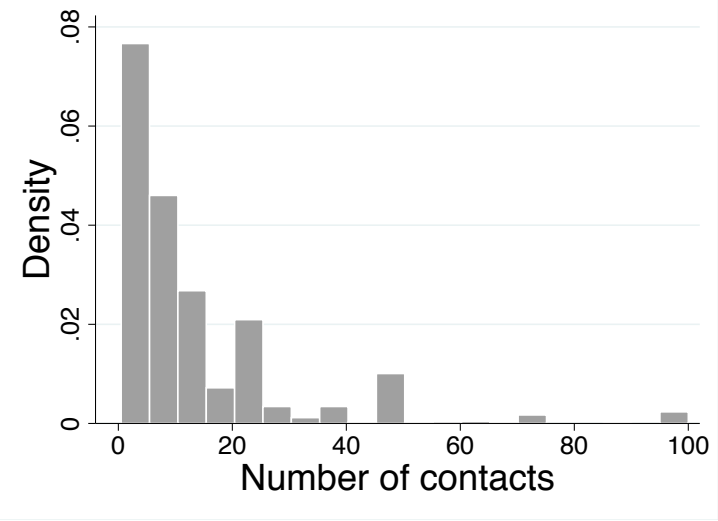
Are these mechanisms distinct in their implications?

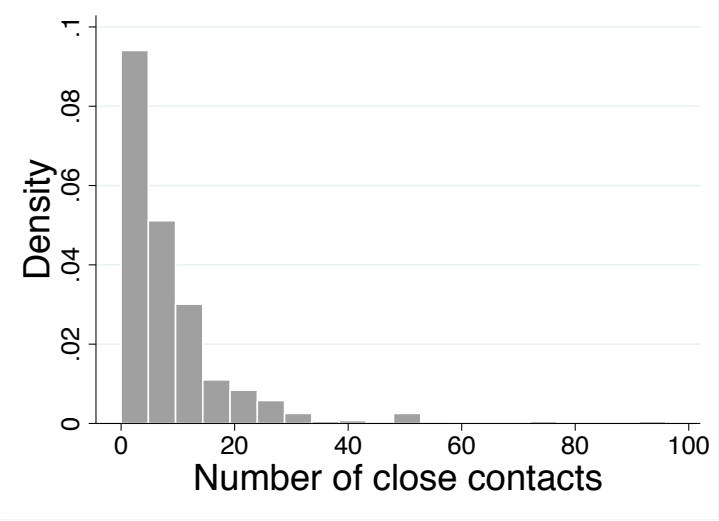
Modeling mechanisms for network effects

Agents' **race**, **income**, **education** and **network size** sampled from GSS (*N*=2,237).









Average characteristics by race in the GSS

Characteristics	Whites	Blacks
Income	56,449	36,878
Years of education	14	13
Number of contacts	30	18
Number of close contacts	9	5
N	1,901 (85%)	336 (15%)

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Reservation price model

$$r_{it} = \underbrace{\alpha \cdot y_i^{\gamma}}_{\text{Income effect}} + \underbrace{\beta \cdot e_i}_{\text{Education effect}} + \delta \cdot f\left(a_{it-1}\right) + \varepsilon_{it}$$

Economides & Himmelberg (1995)

y_i income of individual i

e_i education of individual i

γ (gamma) exponent of income (0,1)

α (alpha) scalar for income effect

β (beta) scalar for education effect

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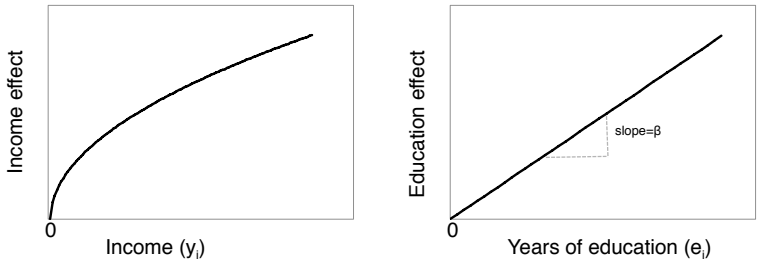

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δ (delta) scalar for network effect

$f(a_{it-1})$ function for the network effect where a_{it-1} is an adoption outcome in individual i's network at time t-1

ε_{it} (epsilon) random perturbation for individual i at time t

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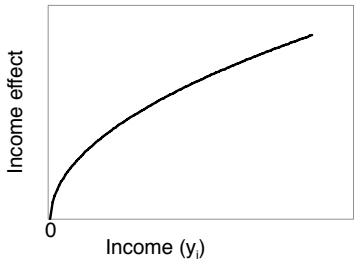
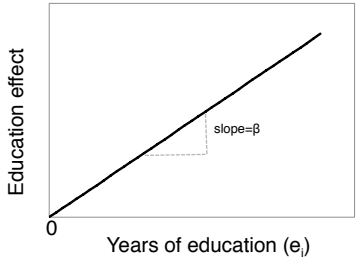
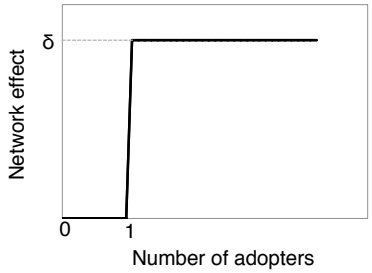
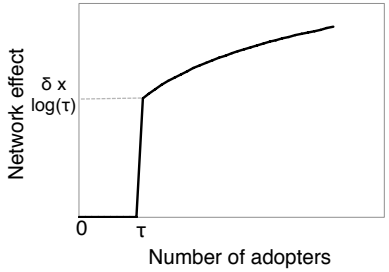


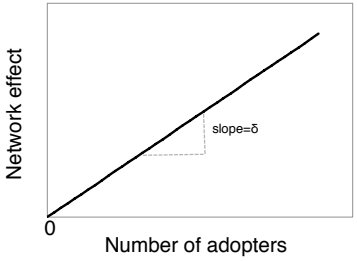




Simple contagion



Social facilitation



Network externalities

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y_i	income of individual i
e_i	education of individual i
γ	(gamma) exponent of income (0,1)
α	(alpha) scalar for income effect
β	(beta) scalar for education effect
δ	(delta) scalar for education effect
$f(a_{it-1})$	function for the network effect where a_{it-1} is an adoption outcome in individual i's network at time t-1
ε_{it}	(epsilon) random perturbation for individual i at time t

Modeling mechanisms for network effects

Agents' **race**, **income**, **education** and **network size** sampled from GSS (*N*=2,237).

Agents have a **reservation price** that increases with income, education and prior adopters in network.

The practice itself has a price which declines with the number of adopters.

Price of a new practice

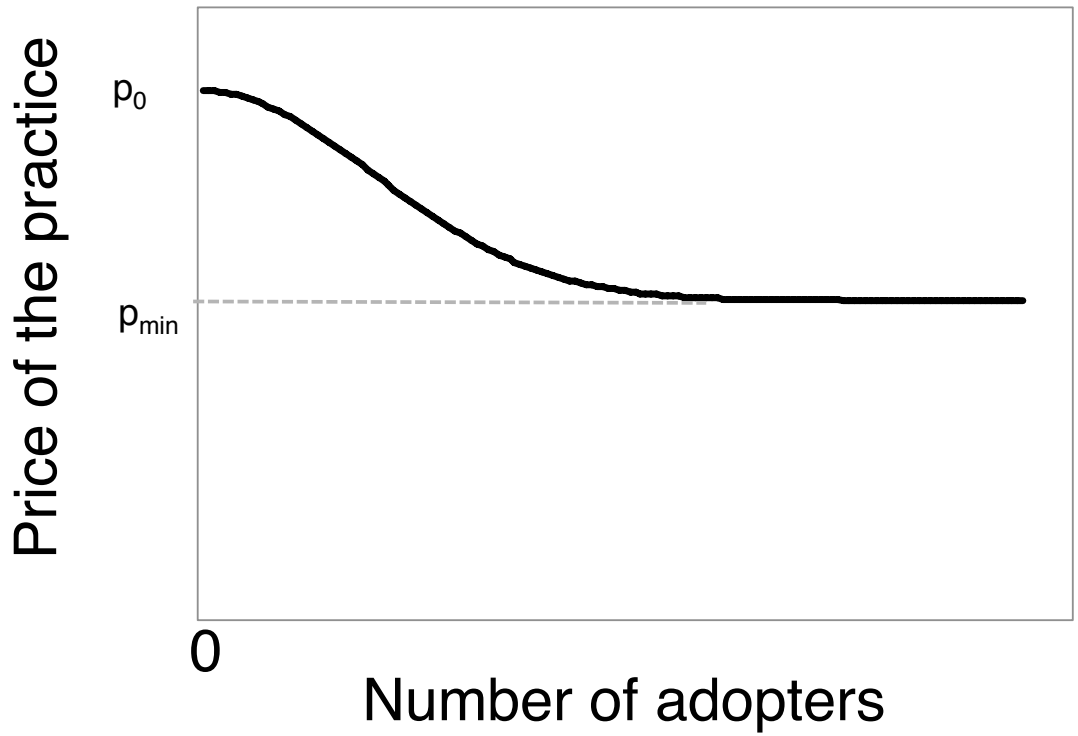
$$p_t = p_{t-1} + k \cdot n_{t-1} \cdot \left(p_{\min} - p_{t-1} \right)$$

Speed of reversion

Price decline component

p_t	price at time *t*
p_{min}	equilibrium price
n_{it-1}	number of adopters in network at time *t-1*
k	multiplicative constant

Price of a new practice



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The practice itself has a price which declines with the number of adopters.

Agents adopt if **reservation price ≥ price of the practice**.

Agents adopt due to a combination of (a) increasing reservation price and (b) decreasing price of the practice.

Generating networks with homophily

Each agent has a target number of ties (weak + strong).

Generating networks with homophily

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Each dyad has a degree of **social distance**.

Social distance = Euclidean distance with respect to income, education and race

Each characteristic standardized to (0,1) range and weighted by its relative homophily in the GSS data.

Generating networks with homophily

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Each agent has in-group and out-group members based on social distance.

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Ties are established such that **homophily** bias occurs with a given probability.

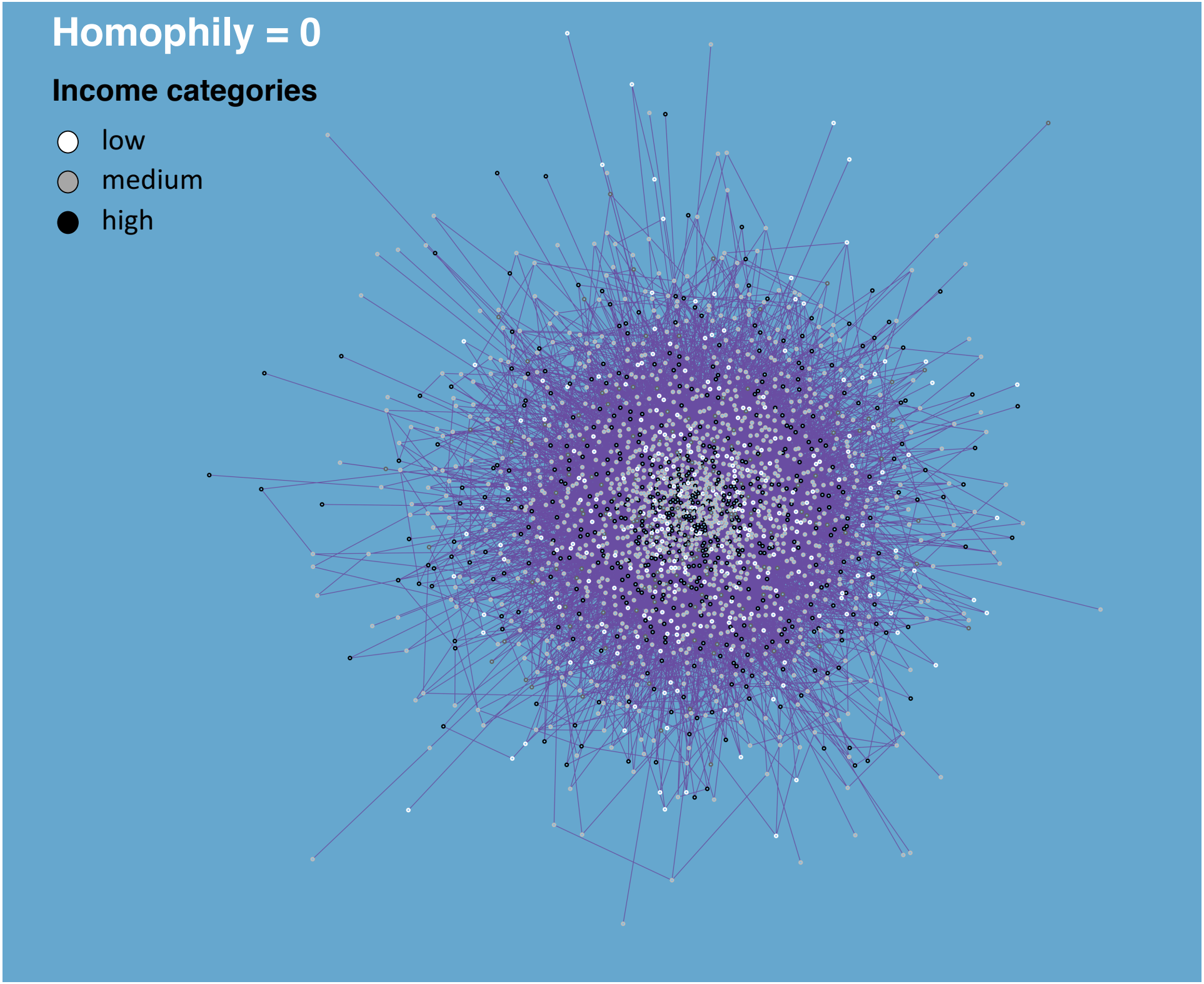
$$P(T) = h + [1- h]. P_R(T)$$ Skvoretz (1990)

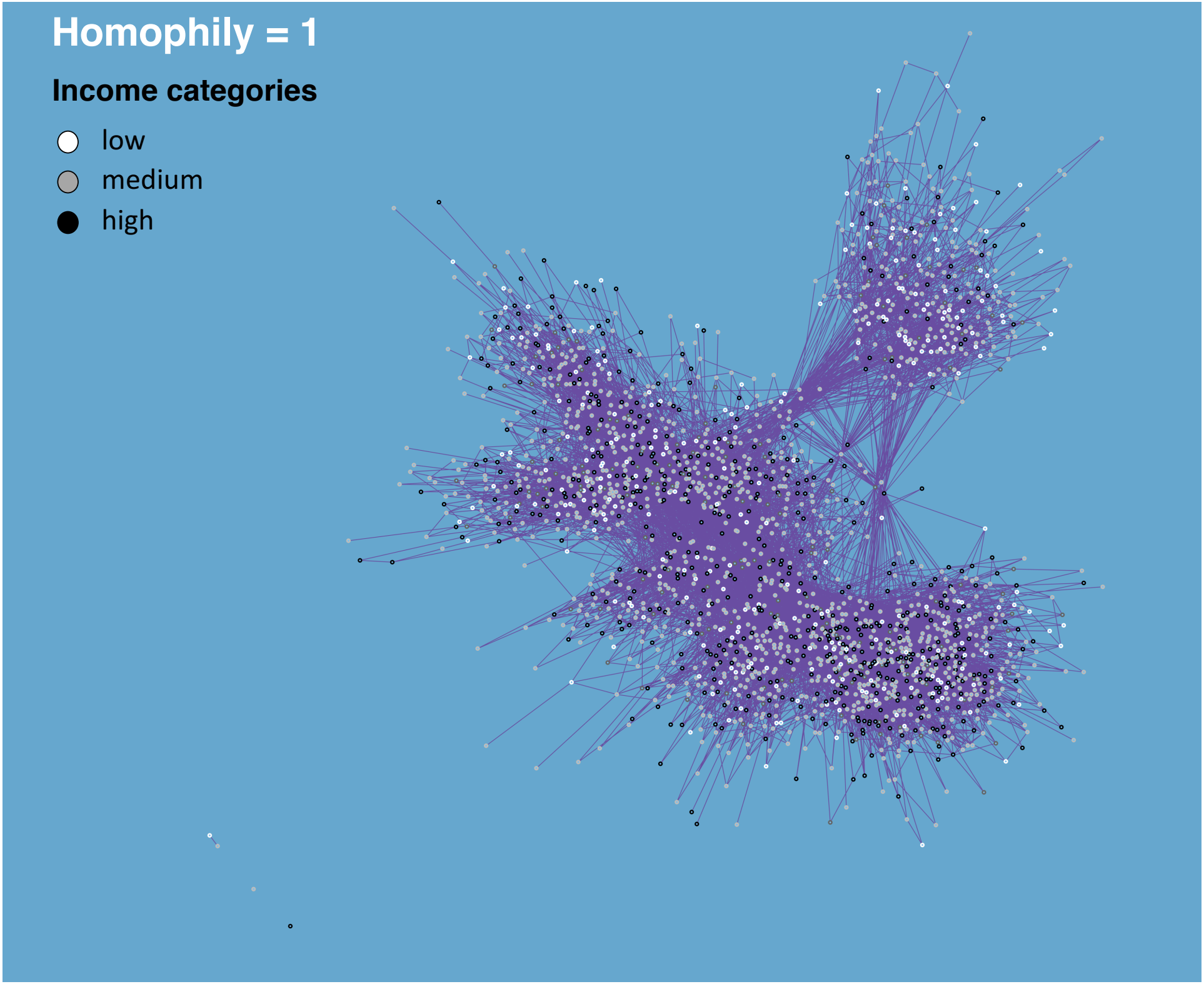
$P(T)$	probability of an in-group tie
$P_R(T)$	probability of a random tie
h	probability of homophily bias

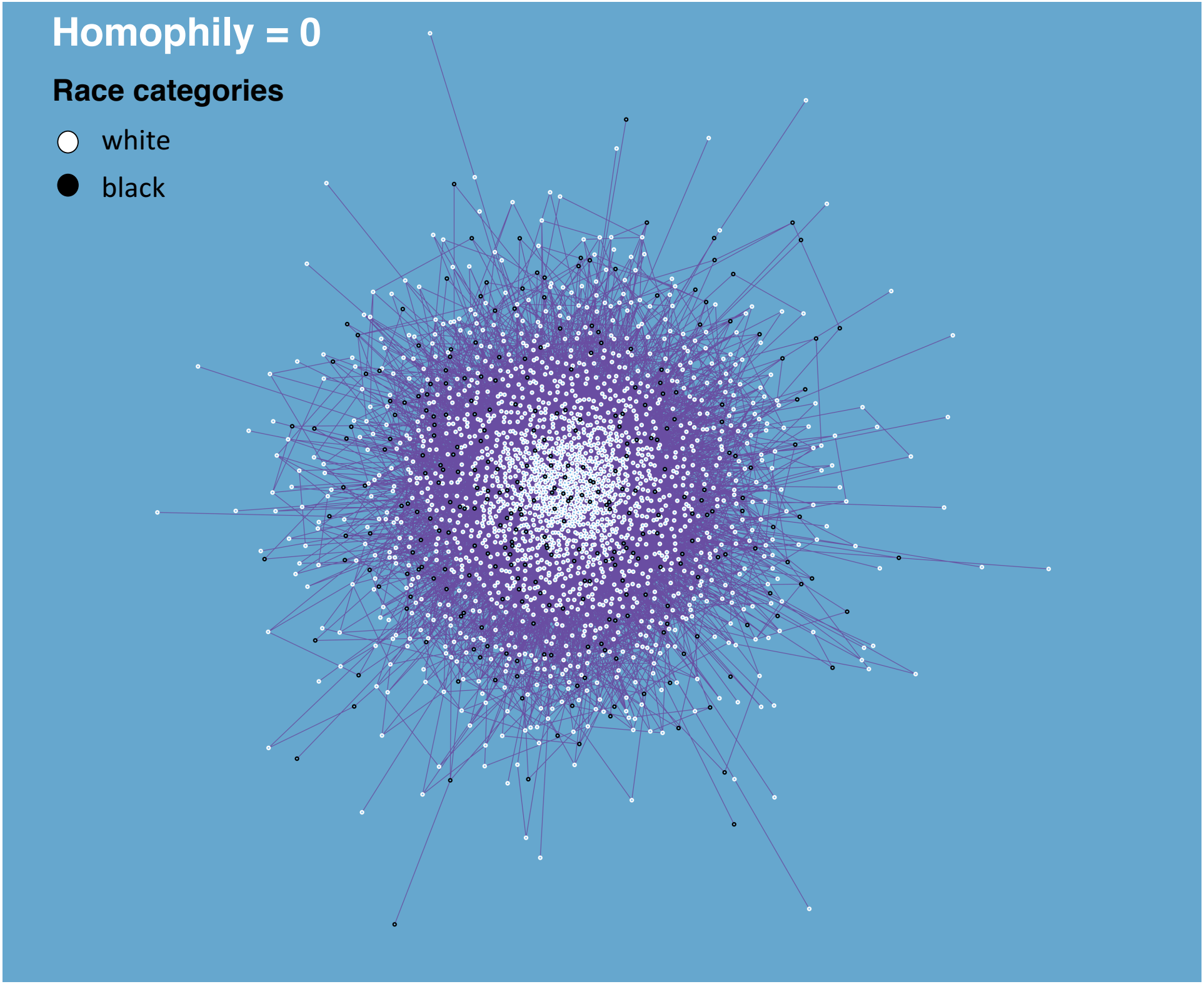
Computational model

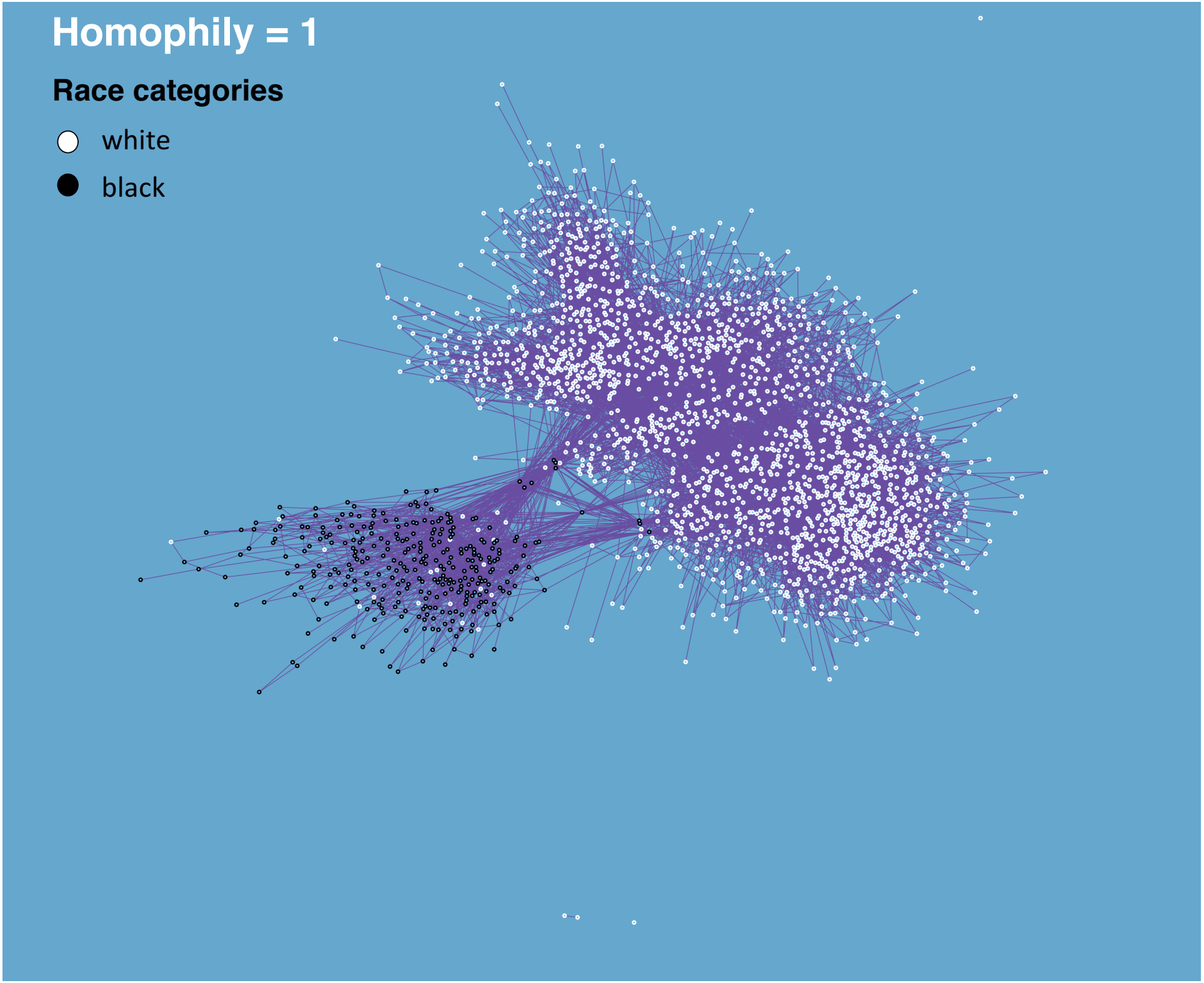
Start with the GSS data (N=2,237)

Establish ties with a chosen degree of homophily *h* [0,1]


Homophily = 0
Income categories
low
medium
high


Homophily = 1
Income categories
low
medium
high


Homophily = 0
Race categories
white
black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At each time period t in 1:150,

identify the adopters (reservation price ≥ price of the practice),

update network adoption rates, reservation prices and the price of the practice.

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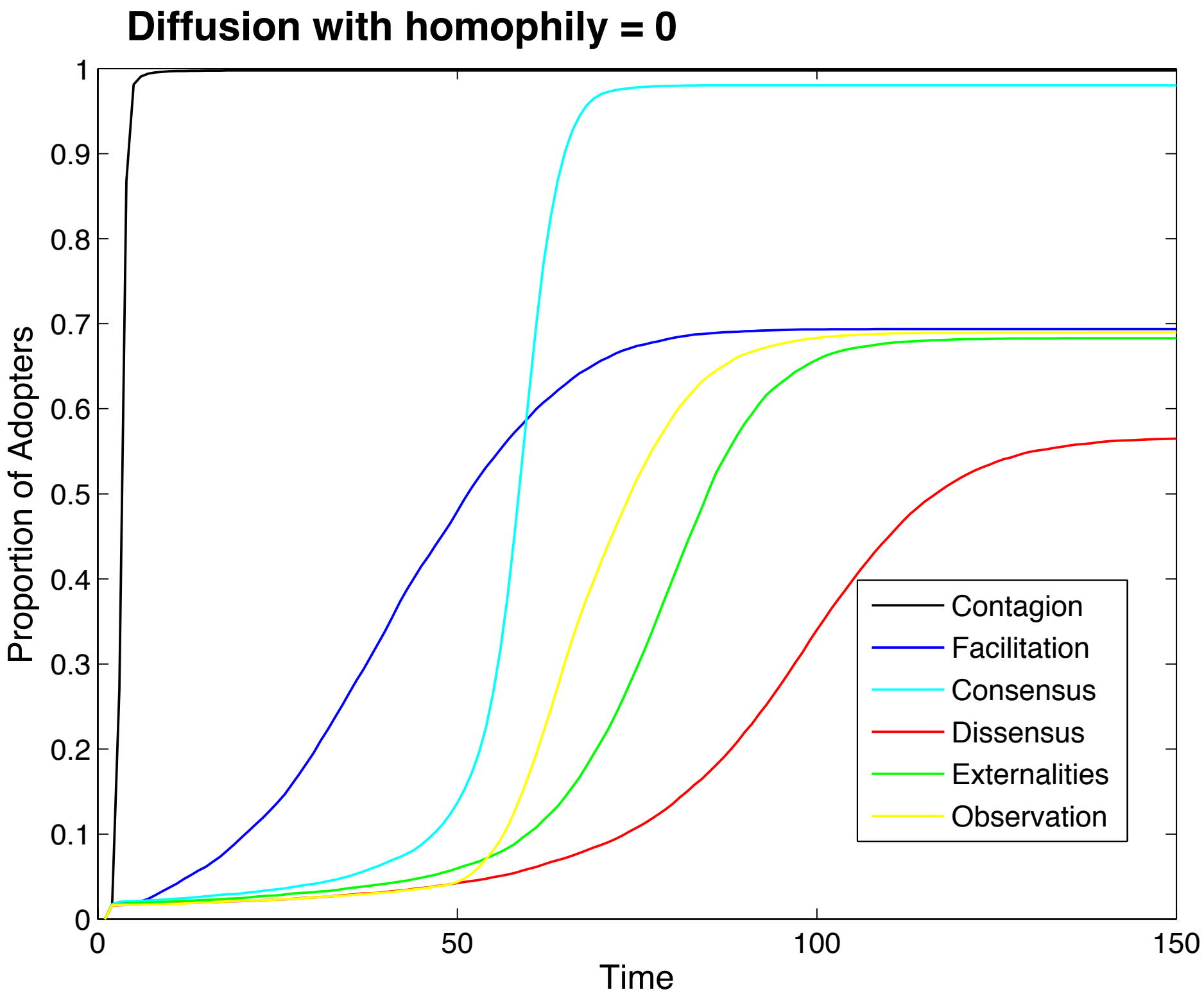
At each time period t in 1:150,

identify the adopters (reservation price ≥ price of the practice),

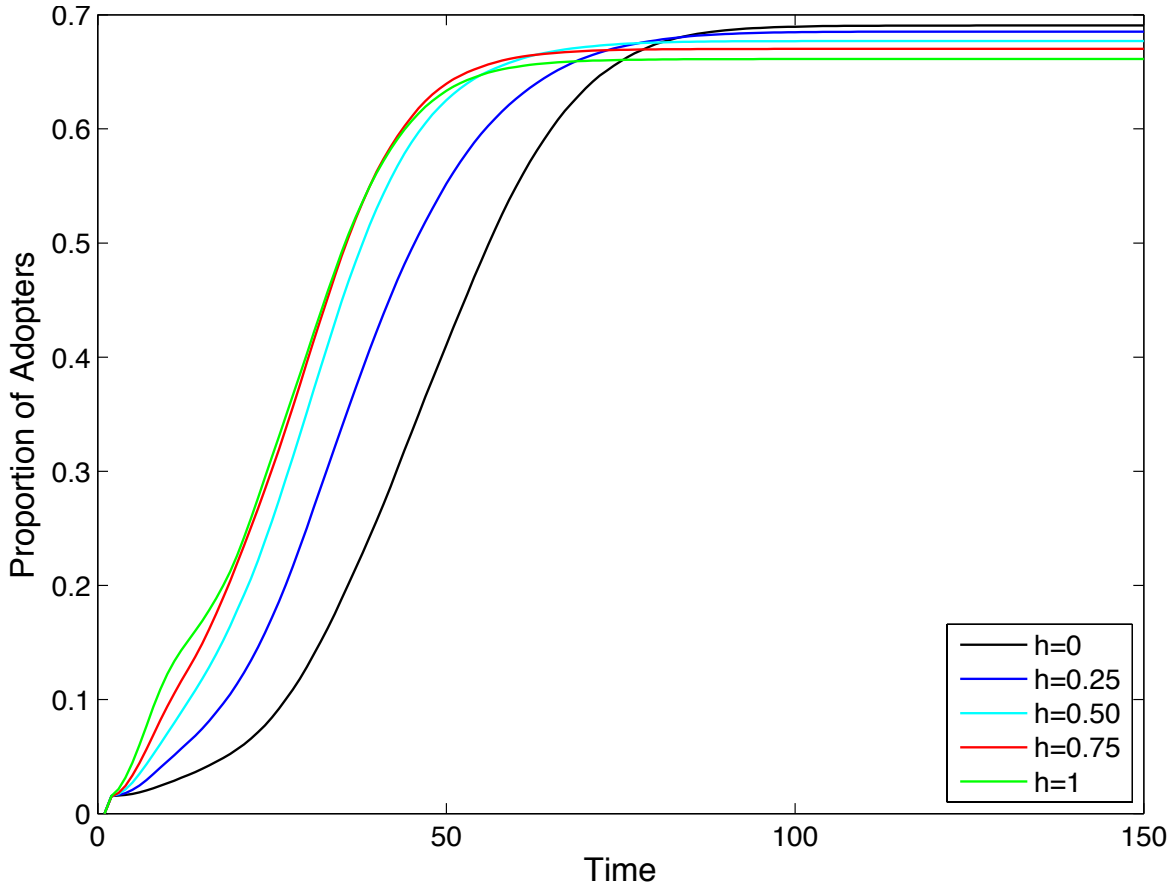
update network adoption rates, reservation prices and the price of the practice.

For each degree of homophily (0, 0.25, 0.50, 0.75, 1), consider six mechanisms for network effects:

simple contagion
social facilitation
social observation
normative influence with consensus
normative influence with dissensus
network externalities


Diffusion with homophily = 0
Proportion of Adopters
Time
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
Contagion
Facilitation
Consensus
Dissensus
Externalities
Observation

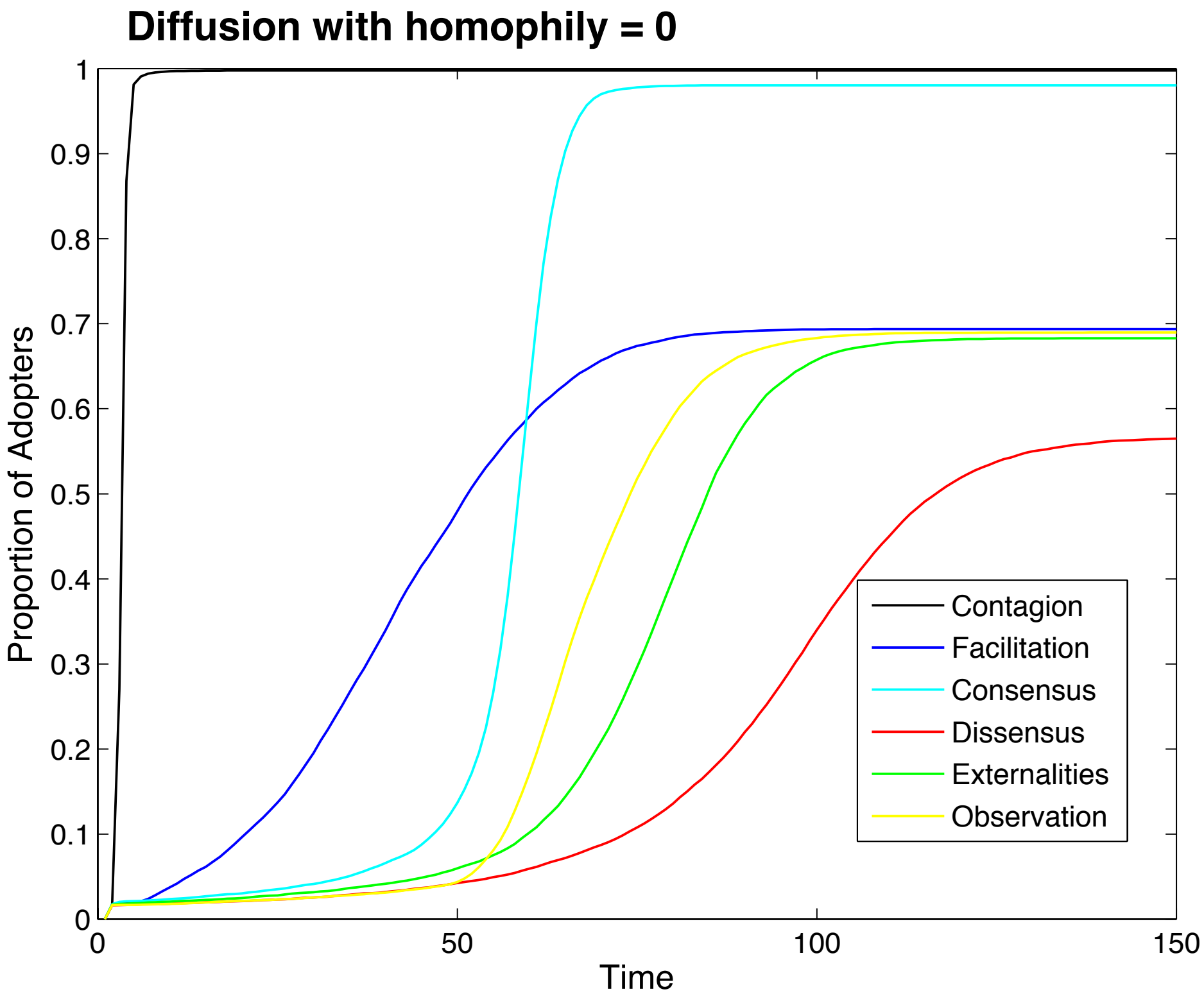
Diffusion with social facilitation and varying levels of homophily

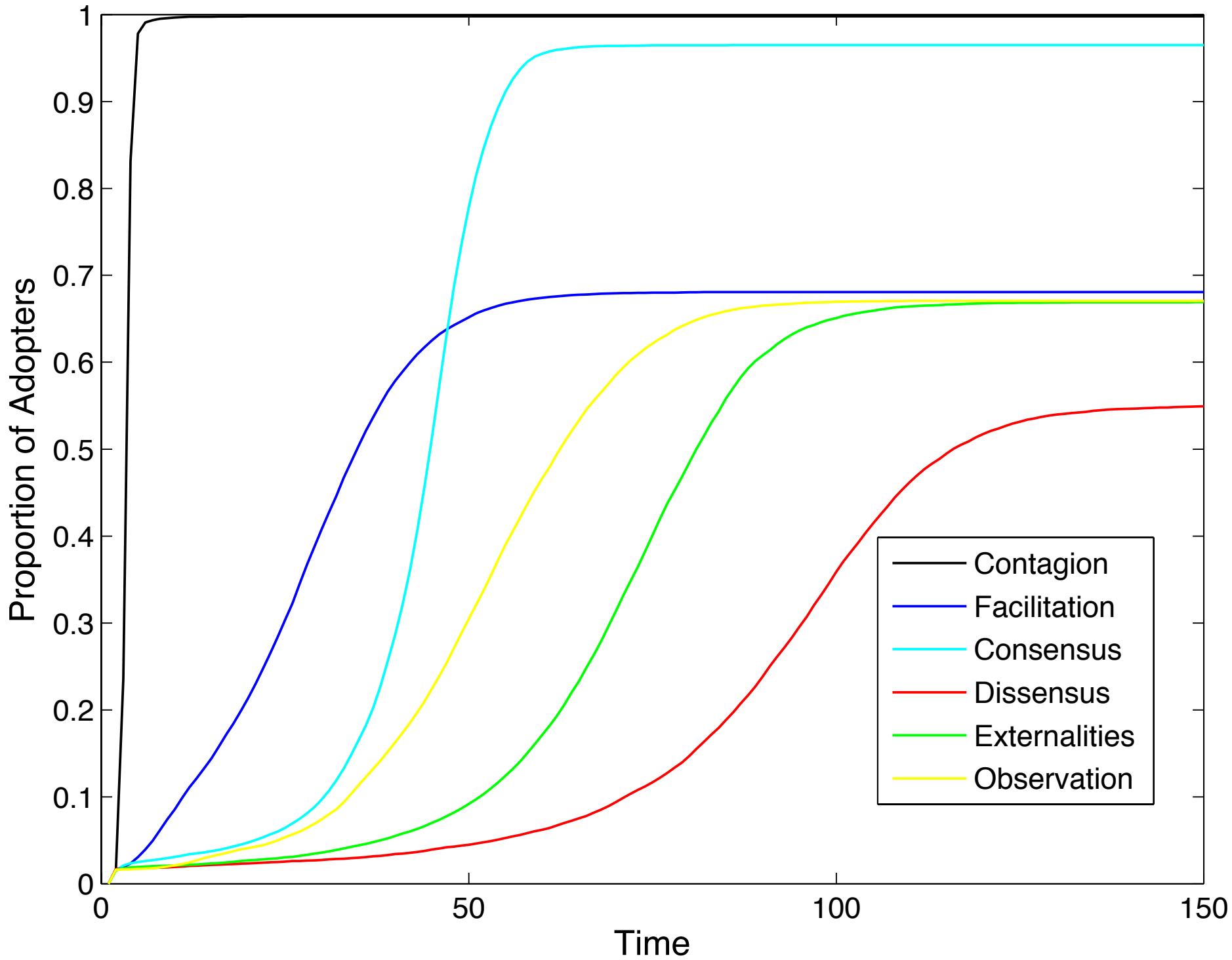


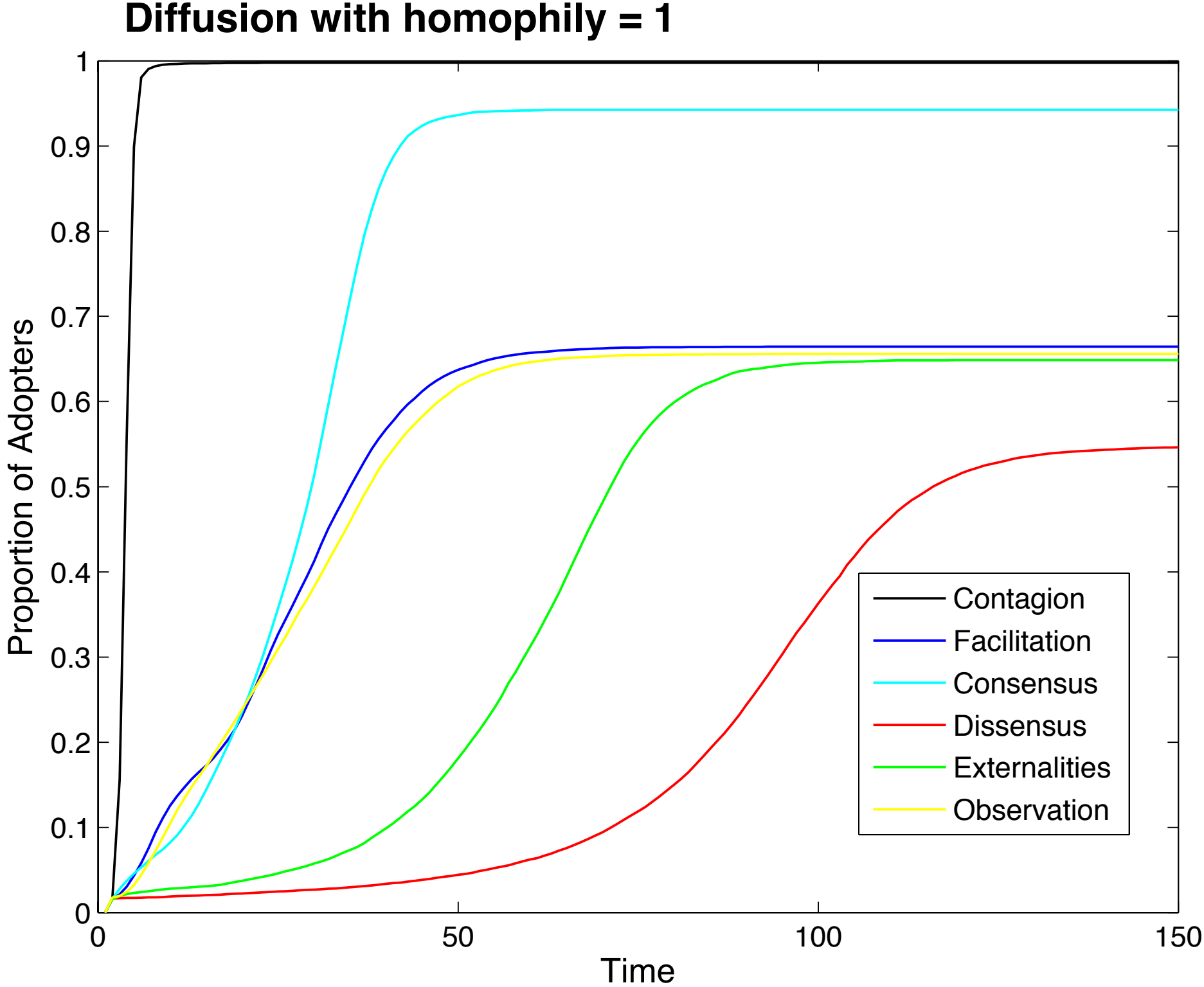
Homophily increases the adoption rate, but decreases the overall adoption level.

The effect of homophily on the adoption rate is nonlinear, high at first and lower later on.

The effect of homophily on the adoption level is linear.


Diffusion with homophily = 0
Proportion of Adopters
Time
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
Contagion
Facilitation
Consensus
Dissensus
Externalities
Observation


Diffusion with homophily = 0.5
Proportion of Adopters
Time
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
Contagion
Facilitation
Consensus
Dissensus
Externalities
Observation


Diffusion with homophily = 1
Proportion of Adopters
Time
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
Contagion
Facilitation
Consensus
Dissensus
Externalities
Observation

Equilibrium adoption levels

(from high to low, for all homophily levels)

Contagion

Consensus

Facilitation = Observation = Externalities

Dissensus

Consensus ≈ Contagion in equilibrium adoption

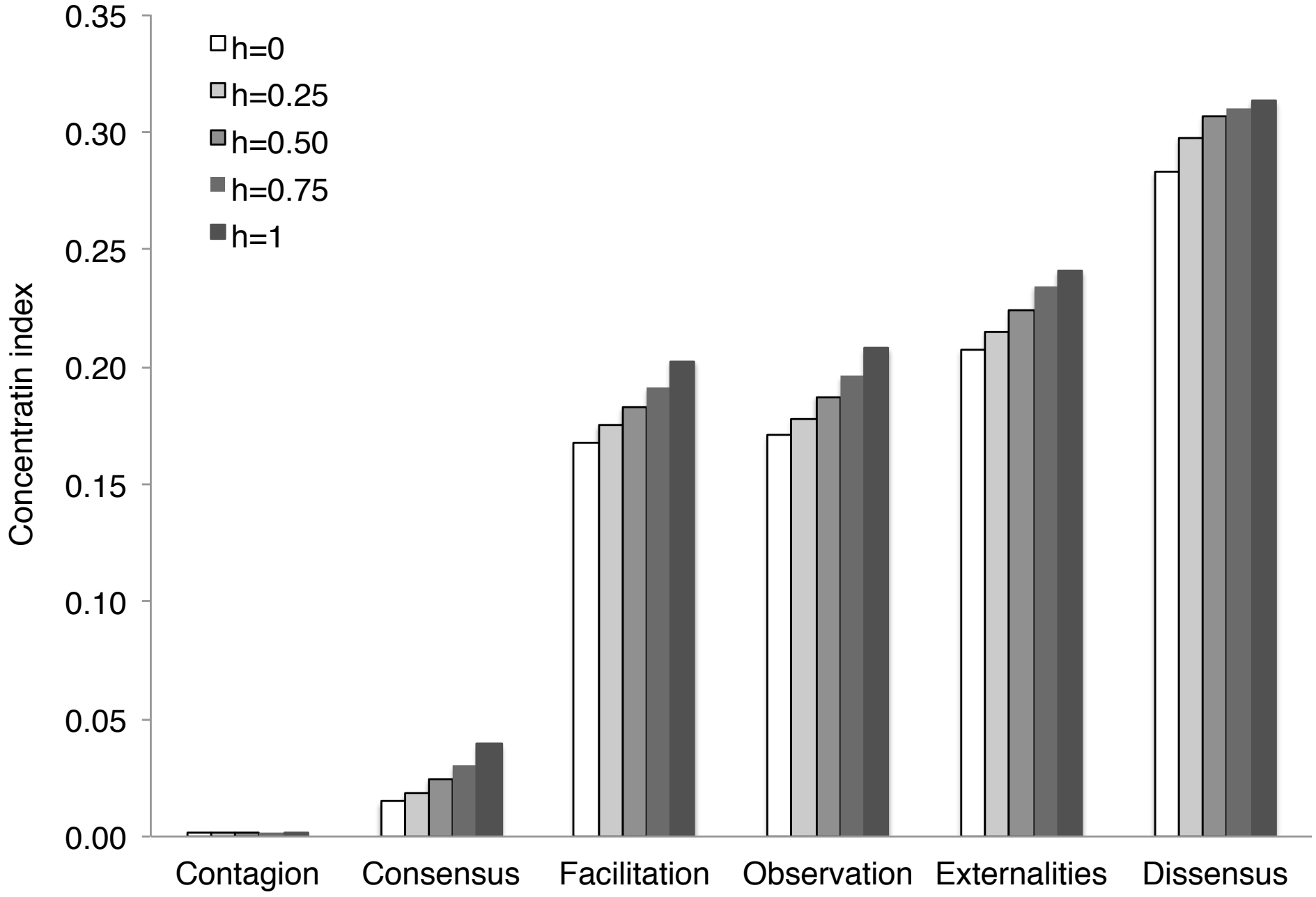
Networks are almost as effective in inducing generally approved norms through rewards and sanctions as they are in disseminating information efficiently.

Inter-group inequality in adoption

Concentration index for income and education

Odds ratio for race

Inequality in Adoption by Income



Inter-group inequality in adoption by income

(from high to low, for all homophily levels)

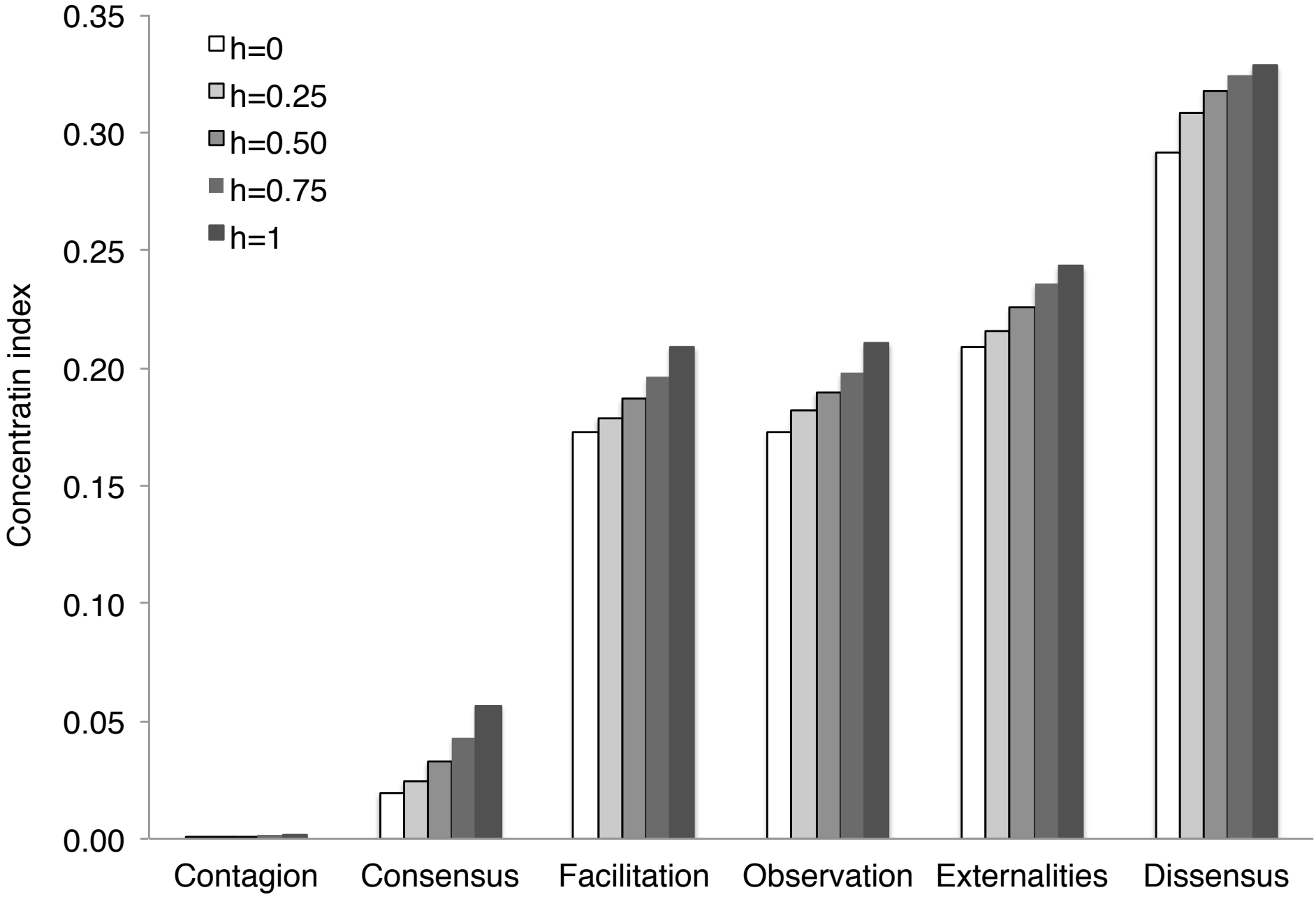
Dissensus

Facilitation = Observation = Externalities

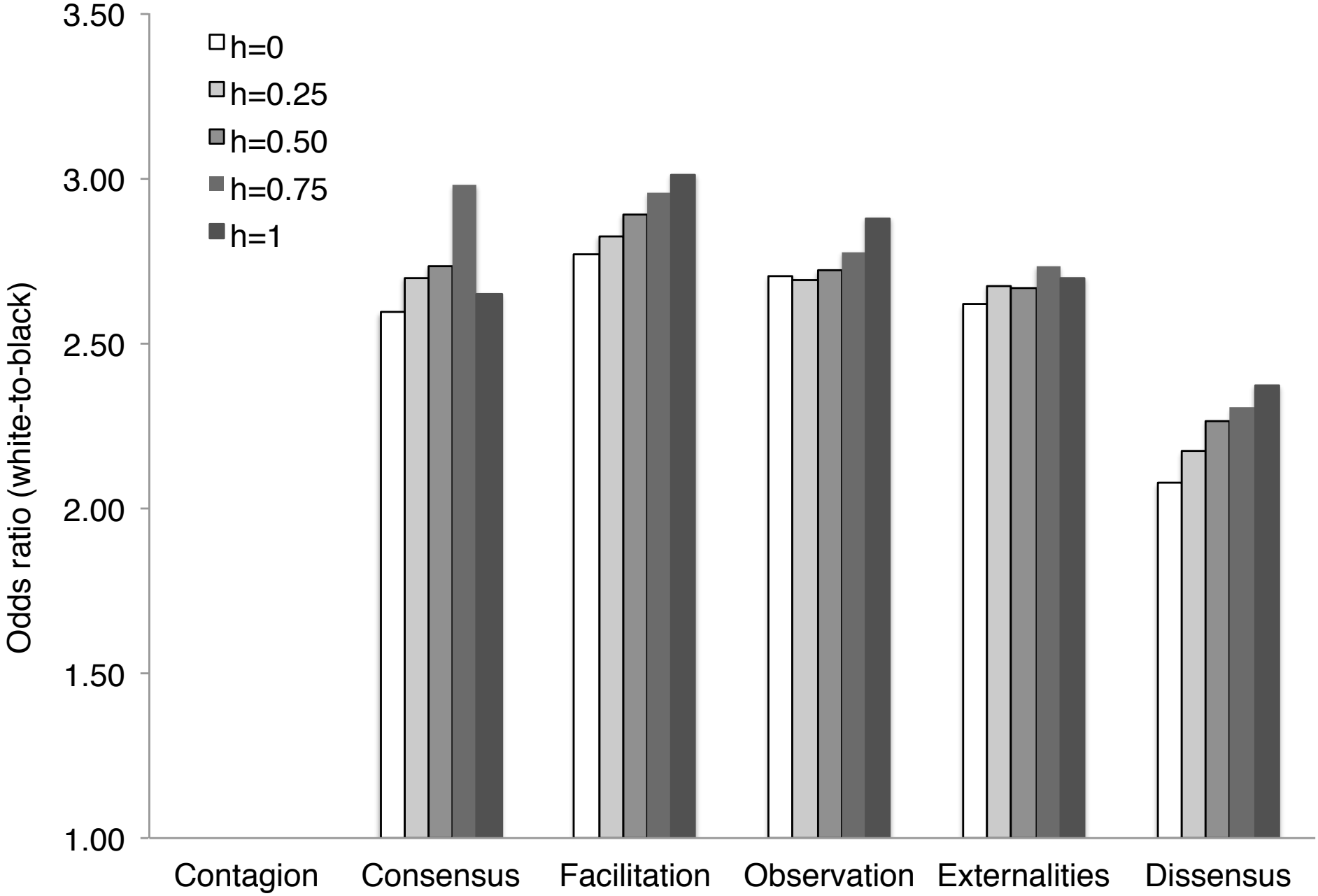
Consensus

Contagion

Inequality in Adoption by Education



Inequality in Adoption by Race



Inequality in adoption by race is pervasive – more so than that by income or education.

It is impervious to mechanisms underlying network effects.

Inequality in adoption by race is pervasive – more so than that by income or education.

It is impervious to mechanisms underlying network effects.

This is because race is highly correlated with income, education, network size and composition, creating a situation of concentrated disadvantage for blacks.

Summary of findings

Adoption level of a practice, or the inter-group inequality in its adoption, depends on the mechanism through which peers exert influence.

Summary of findings

Adoption level….

… is **highest** for practices:

that can be transmitted with a single contact, or

that can be enforced through peer pressure in dense networks.

…is **lower** for practices

that require confirmation from multiple contacts, or

that carry network externalities.

…is **lowest** for practices

with competing alternatives across which peer influence is split.

Summary of findings

Income or education-based inequality in adoption….

… is **lowest** for practices:

that can be transmitted with a single contact, or

that can be enforced through peer pressure in dense networks.

…is **higher** for practices

that require confirmation from multiple contacts, or

that carry network externalities.

…is **highest** for practices

with competing alternatives across which peer influence is split.

Summary of findings

Racial inequality in adoption….

… is **lowest** for practices:

that can be transmitted with a single contact, or

… but is about **equally high** for all others.

Implications

Findings shed light onto empirical patterns:

Large inequalities by socio-economic status in healthy behaviors (exercising, dieting, not smoking, etc.) that require persistent peer involvement but that are not consistently supported in the population (i.e., behaviors subject to normative influence with dissensus) (Pampel et al. 2010, Christakis and Fowler 2008).

Implications

Findings shed light onto empirical patterns:

Relatively smaller gaps by socio-economic status in practices subject to threshold effects (e.g., migrating for work) or those with externalities (e.g., joining online communities) (Garip 2008, DiMaggio and Garip 2011).

Implications

Findings shed light onto empirical patterns:

> And **persistent differences by race** in various practices ranging from using the Internet to finding a job to quitting smoking (DiMaggio et al. 2004, Smith 2004).

Future directions

Can we use the ‘fingerprint’ of each mechanism (i.e., the distinctive functional form) to differentiate between alternative mechanisms in real-life data?

What happens with ‘hybrid’ mechanisms?