Network Effects on Behavior: How Do Mechanisms Matter?

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New York University

Filiz Garip
Cornell University
Network effect
is the effect on ego of alters’ behavior
Network effect

is the effect on ego of alters’ behavior
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is the effect on ego of alters’ behavior
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

• Does the choice to adopt entail risk or uncertainty?
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• Is the behavior readily observable or difficult to observe?
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• Is choice easy to implement or does it require assistance?
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• Is adoption characterized by network externalities?
Characteristics of Practices

- Does the choice to adopt entail risk or uncertainty?
- Is the behavior readily observable or difficult to observe?
- 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

<table>
<thead>
<tr>
<th>Risk or uncertainty</th>
<th>Observable</th>
<th>Requires assistance</th>
<th>Alter sanctions</th>
<th>Externalities</th>
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- **Risk or uncertainty**
- **Observable**
- **Requires assistance**
- **Alter sanctions**
- **Externalities**
- **Self-reinforcing**

- **YES**
- **NO**
- **MAYBE**
Simple contagion

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

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

Network effect is given by

\[ \delta \]

if \( n_{a_{it-1}} \geq 1 \)

0 otherwise.

\( \delta \) (delta) a scalar

\( n_{a_{it-1}} \) no of adopters in individual i’s network at time t-1
Simple contagion

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

Network effect is given by

\[ \delta \text{ if } na_{it-1} \geq 1 \]

\[ 0 \text{ otherwise.} \]

\( \delta \) (delta) a scalar

\( na_{it-1} \) no of adopters in individual i’s network at time t-1

Strong and weak ties are equally useful.
Typology of Mechanisms

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<tr>
<td>YES</td>
<td>NO</td>
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**Legend:**
- **YES**: Indicates the presence of the mechanism.
- **NO**: Indicates the absence of the mechanism.
- **MAYBE**: Indicates uncertainty or potential presence.
Social facilitation

When thick information or assistance are needed for adoption of uncertain, hard to observe, difficult to implement but self-reinforcing behaviors.
Social facilitation

When thick information or assistance are needed for adoption of uncertain, hard to observe, difficult to implement but self-reinforcing behaviors.

Network effect is given by

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

$$0 \text{ otherwise.}$$

$\delta$ (delta) a scalar

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

$\tau$ (tau) threshold for network effect
Social facilitation

When thick information or assistance are needed for adoption of uncertain, hard to observe, difficult to implement but self-reinforcing behaviors.

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0 \text{ otherwise.} \]

\[ \delta \text{ (delta) a scalar} \]
\[ na_{it-1} \text{ no of adopters in individual i’s network at time t-1} \]
\[ \tau \text{ (tau) threshold for network effect} \]

Only strong ties matter.
# Typology of Mechanisms

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Social observation

Network effect is identical in form to social facilitation.

But, here, both strong and weak ties matter.
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Normative influence with consensus

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

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

Network effect is expressed as

\[ \delta \times pa_{it-1} \times da_{it-1} \]

- \( \delta \) (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 \([1,2]\)
Normative influence with consensus

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

Network effect is expressed as

\[ \delta \times p_{\text{a}_{it-1}} \times d_{\text{a}_{it-1}} \]

\( \delta \) (delta) a scalar

\( p_{\text{a}_{it-1}} \) proportion of adopters in individual i’s network at time t-1 [0,1]

\( d_{\text{a}_{it-1}} \) density of ties among adopters in individual i’s network at time t-1 [1,2]

Both strong and weak ties matter, but strong ties are more important than weak ties.
## Typology of Mechanisms

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</tr>
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<tbody>
<tr>
<td>Observable</td>
<td>●</td>
<td>□</td>
<td>□</td>
<td>□</td>
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<tr>
<td>Requires assistance</td>
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<td>□</td>
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- YES
- NO
- MAYBE
Normative influence with dissensus

Prior adopters and non-adopters compete for influence.

Network effect is expressed as

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

\( \delta \) (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]

\( dn_{it-1} \) density of ties among adopters in individual i’s network at time t-1 [1,2]
## Typology of Mechanisms

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<th>Network externalities</th>
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<tbody>
<tr>
<td><img src="image1" alt="Simple Contagion Image" /></td>
<td><img src="image2" alt="Social Facilitation Image" /></td>
<td><img src="image3" alt="Social Observation Image" /></td>
<td><img src="image4" alt="Normative Influence with Consensus Image" /></td>
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<td><img src="image8" alt="Observable" /></td>
<td><img src="image9" alt="Requires Assistance" /></td>
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<td><img src="image11" alt="Externalities" /></td>
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- **YES**
- **NO**
- **MAYBE**
Network externalities

When the value of practice to ego increases as more alters adopt.
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Network effect is given by

\[ \delta \times n_{ait-1} \]

\( \delta \) (delta) a scalar

\( n_{ait-1} \) no of adopters in individual i’s network at time t-1 [0,1]
Network externalities

When the value of practice to ego increases as more alters adopt.

Network effect is given by

$$\delta \times na_{it-1}$$

$\delta$ (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

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Whites</th>
<th>Blacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Income</td>
<td>56,449</td>
<td>36,878</td>
</tr>
<tr>
<td>Years of education</td>
<td>14</td>
<td>13</td>
</tr>
<tr>
<td>Number of contacts</td>
<td>30</td>
<td>18</td>
</tr>
<tr>
<td>Number of close contacts</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>N</td>
<td>1,901 (85%)</td>
<td>336 (15%)</td>
</tr>
</tbody>
</table>
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.
Reservation price model

\[ r_{it} = \alpha \cdot y_i^\gamma + \beta \cdot e_i + \delta \cdot f(a_{it-1}) + \varepsilon_{it} \]

- \( y_i \): income of individual i
- \( e_i \): education of individual i
- \( \gamma \): (gamma) exponent of income (0,1)
- \( \alpha \): (alpha) scalar for income effect
- \( \beta \): (beta) scalar for education effect

Economides & Himmelberg (1995)
Reservation price model

\[ r_{it} = \alpha \cdot y_i^\gamma + \beta \cdot e_i + \delta \cdot f(a_{it-1}) + \varepsilon_{it} \]

- Income effect
- Education effect

Income effect

Education effect

Income (\(y_i\))

Years of education (\(e_i\))
Reservation price model

\[ r_{it} = \alpha \cdot y_i^\gamma + \beta \cdot e_i + \delta \cdot f(a_{it-1}) + \varepsilon_{it} \]

- **Income effect**
- **Education effect**
- **Network effect** (varies by mechanism)

- **\( y_i \)**: Income of individual \( i \)
- **\( e_i \)**: Education of individual \( i \)
- **\( \gamma \)**: (Gamma) exponent of income (0,1)
- **\( \alpha \)**: (Alpha) scalar for income effect
- **\( \beta \)**: (Beta) scalar for education effect
- **\( \delta \)**: (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 \( t-1 \)
- **\( \varepsilon_{it} \)**: (Epsilon) random perturbation for individual \( i \) at time \( t \)
Reservation price model

\[ r_{it} = \alpha \cdot y_i^\gamma + \beta \cdot e_i + \delta \cdot f(a_{it-1}) + \epsilon_{it} \]

- **Income effect**
- **Education effect**
- **Network effect** (varies by mechanism)

---

**Simple contagion**

**Social facilitation**

**Network externalities**
Reservation price model

\[ r_{it} = \alpha \cdot y_i^\gamma + \beta \cdot e_i + \delta \cdot f(a_{it-1}) + \varepsilon_{it} \]

- Income effect
- Education effect
- Network effect
- Error term

\( y_i \) income of individual i
\( e_i \) education of individual i
\( \gamma \) (gamma) exponent of income (0,1)
\( \alpha \) (alpha) scalar for income effect
\( \beta \) (beta) scalar for education effect
\( \delta \) (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
\( \varepsilon_{it} \) (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

\[ p_t = p_{t-1} + k \cdot n_{t-1} \cdot (p_{\text{min}} - p_{t-1}) \]

- **Price decline component**
  - Speed of reversion

- **Symbols**:
  - \( p_t \): price at time \( t \)
  - \( p_{\text{min}} \): equilibrium price
  - \( n_{t-1} \): number of adopters in network at time \( t-1 \)
  - \( k \): multiplicative constant
Price of a new practice

![Graph showing the price of a new practice as a function of the number of adopters. The price decreases as the number of adopters increases, approaching a minimum price $p_{\text{min}}$.](image)

- $p_0$: Initial price of the practice
- $p_{\text{min}}$: Minimum price as the number of adopters increases.
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.

Agents adopt if reservation price \(\geq\) 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

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

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

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

Each dyad has a degree of social distance.

Each agent has in-group and out-group members based on social distance.
Generating networks with homophily

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

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

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

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
Homophily = 1

Race categories

- white
- black
Computational model

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

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

At each time period $t$ in 1:150,

- identify the adopters (reservation price $\geq$ price of the practice),

- update network adoption rates, reservation prices and the price of the practice.
**Computational model**

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

Establish ties with a chosen degree of homophily $h \in [0,1]$

At each time period $t$ in $1:150$,

- identify the adopters (reservation price $\geq$ 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

Time

Proportion of Adopters

Contagion
Facilitation
Consensus
Dissensus
Externalities
Observation
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

Time

Proportion of Adopters

- Contagion
- Facilitation
- Consensus
- Dissensus
- Externalities
- Observation

0 50 100 150
Diffusion with homophily = 0.5

Proportion of Adopters vs Time

- 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
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 Race

- Odds ratio (white-to-black)
- Contagion
- Consensus
- Facilitation
- Observation
- Externalities
- Dissensus

- h=0
- h=0.25
- h=0.50
- h=0.75
- h=1
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?