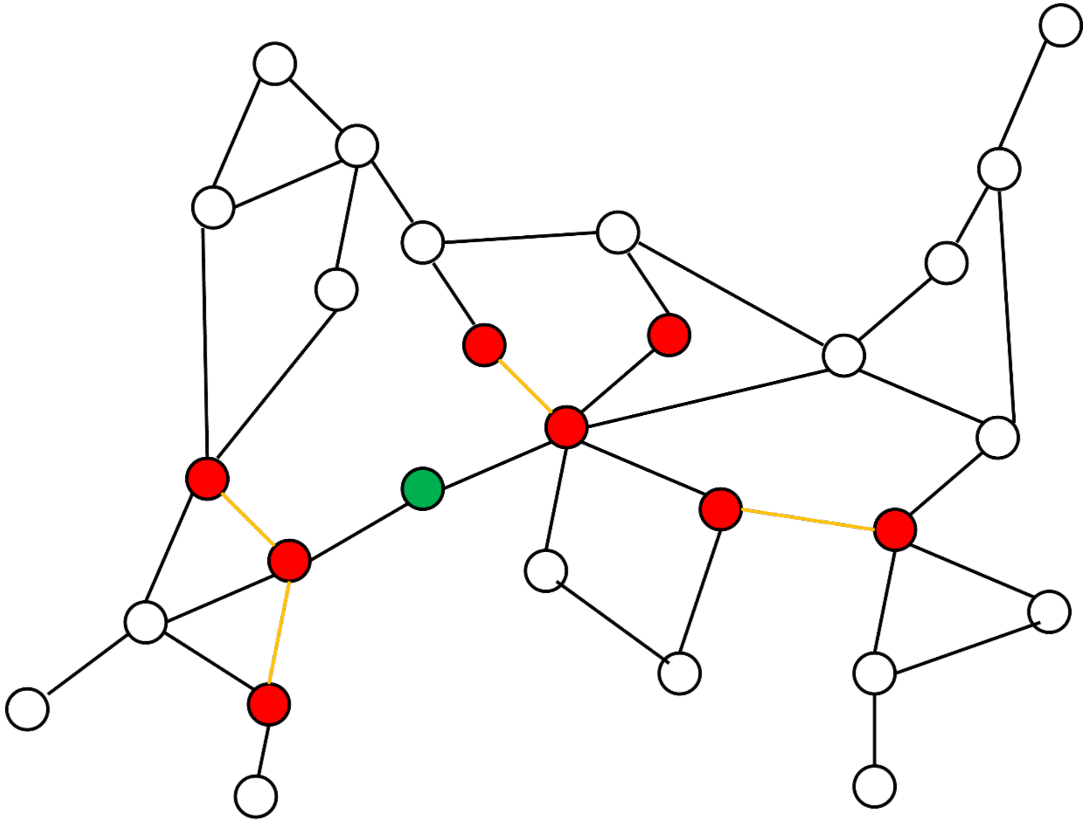
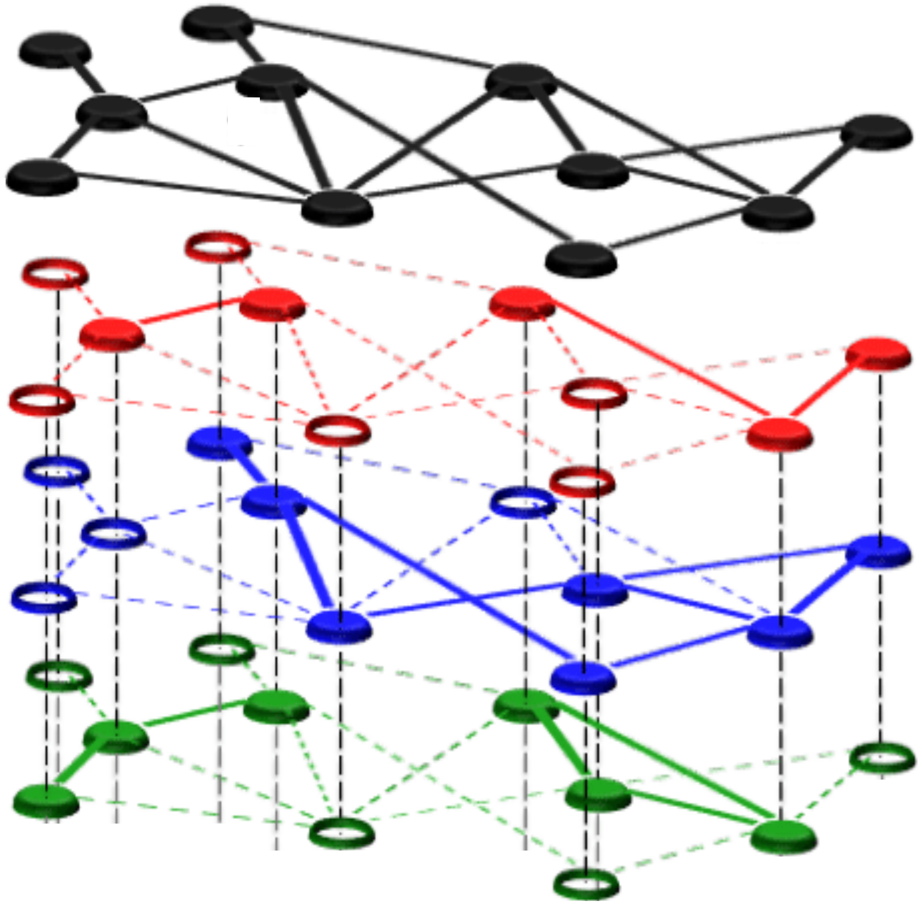
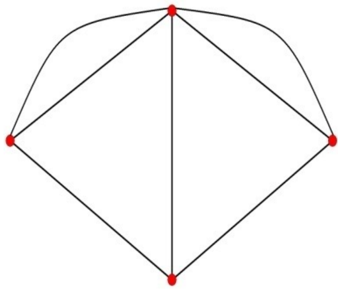
Multiplexing In Networks and Diffusion





Chandrasekhar, Chaudhary, Golub, Jackson

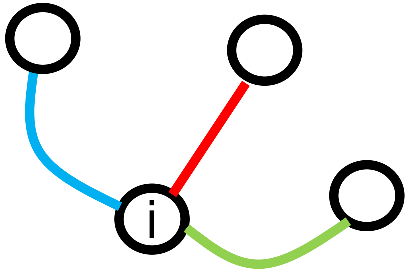
LNMB



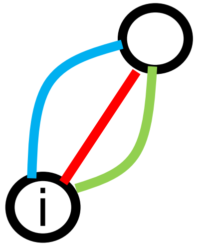
- Data collected to test theory
- Provides new unanticipated empirical effects
- New theoretical questions, requiring new models
- New predictions for the data…

``Multiplexed" Networks

- Compare two people:
  - One has different friends for different purposes



  - Another person does everything with the same friend



``Multiplexed'' Networks

- Compare two people:
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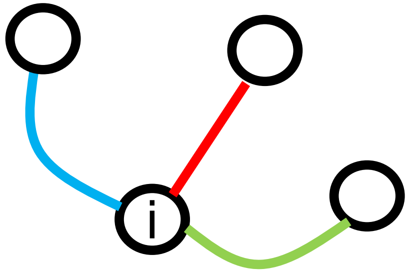

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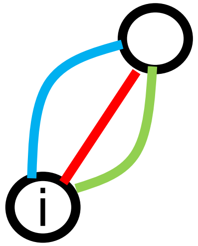
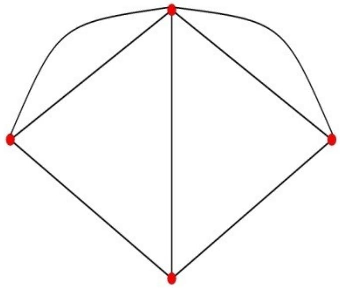


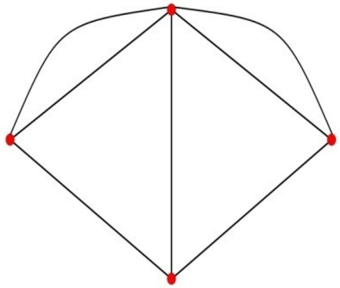
- Which is more susceptible to contagion?
- Which is more likely to adopt a behavior/new technology?

Outline



- Empirical background multiplexing
- How do multiple layers affect diffusion (in an RCT)?
- Theory on how multiplexing impacts diffusion (simple, complex)

Background - Microfinance

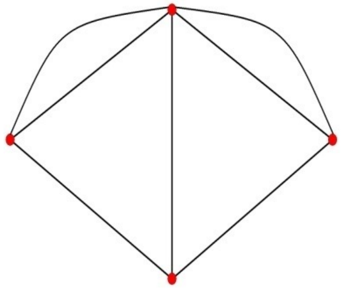


BCDJ 2013, 2019

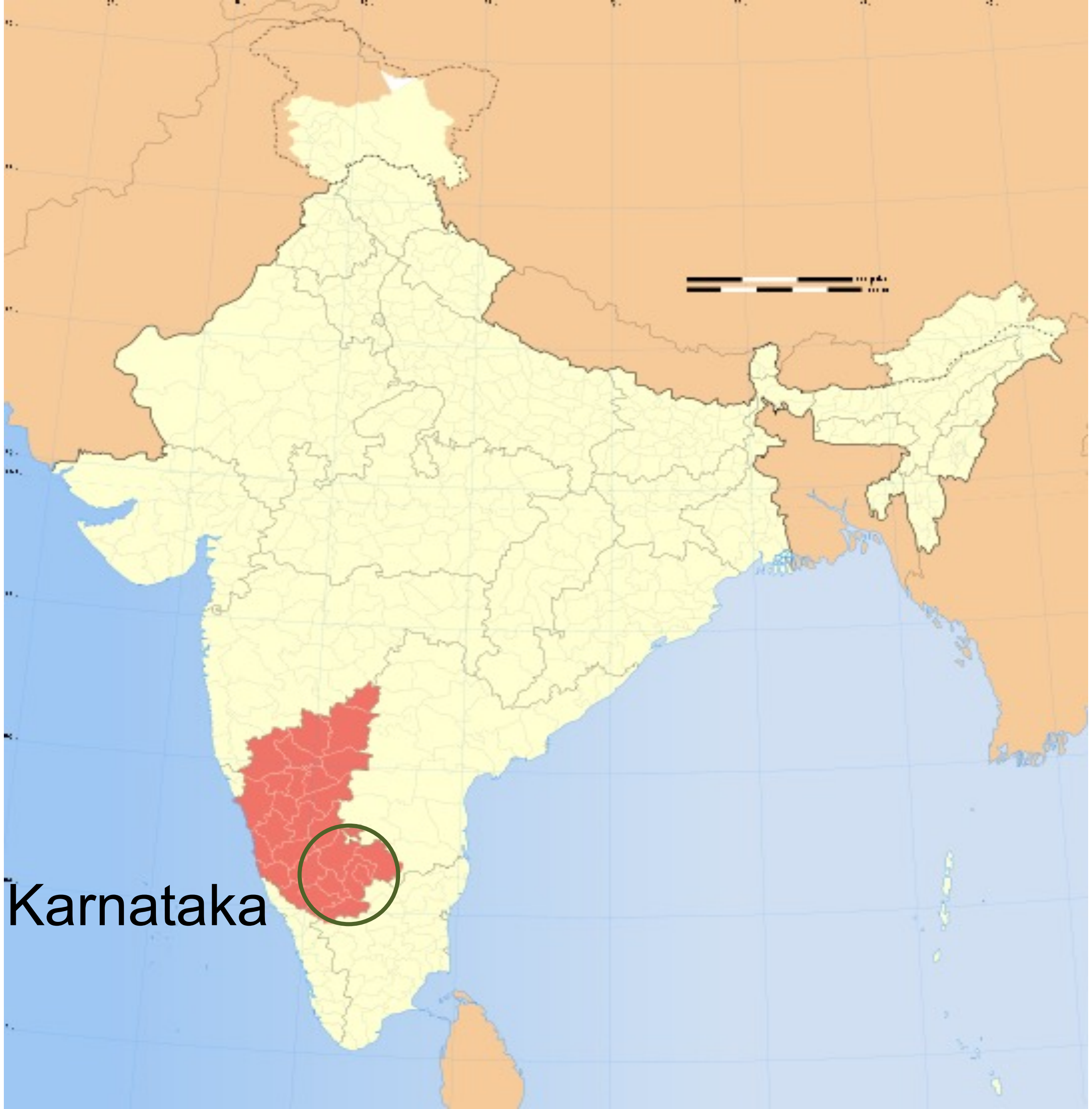
Dramatically different participation in microfinance across villages

Collected data in Karnataka India 75 villages to test theories of diffusion

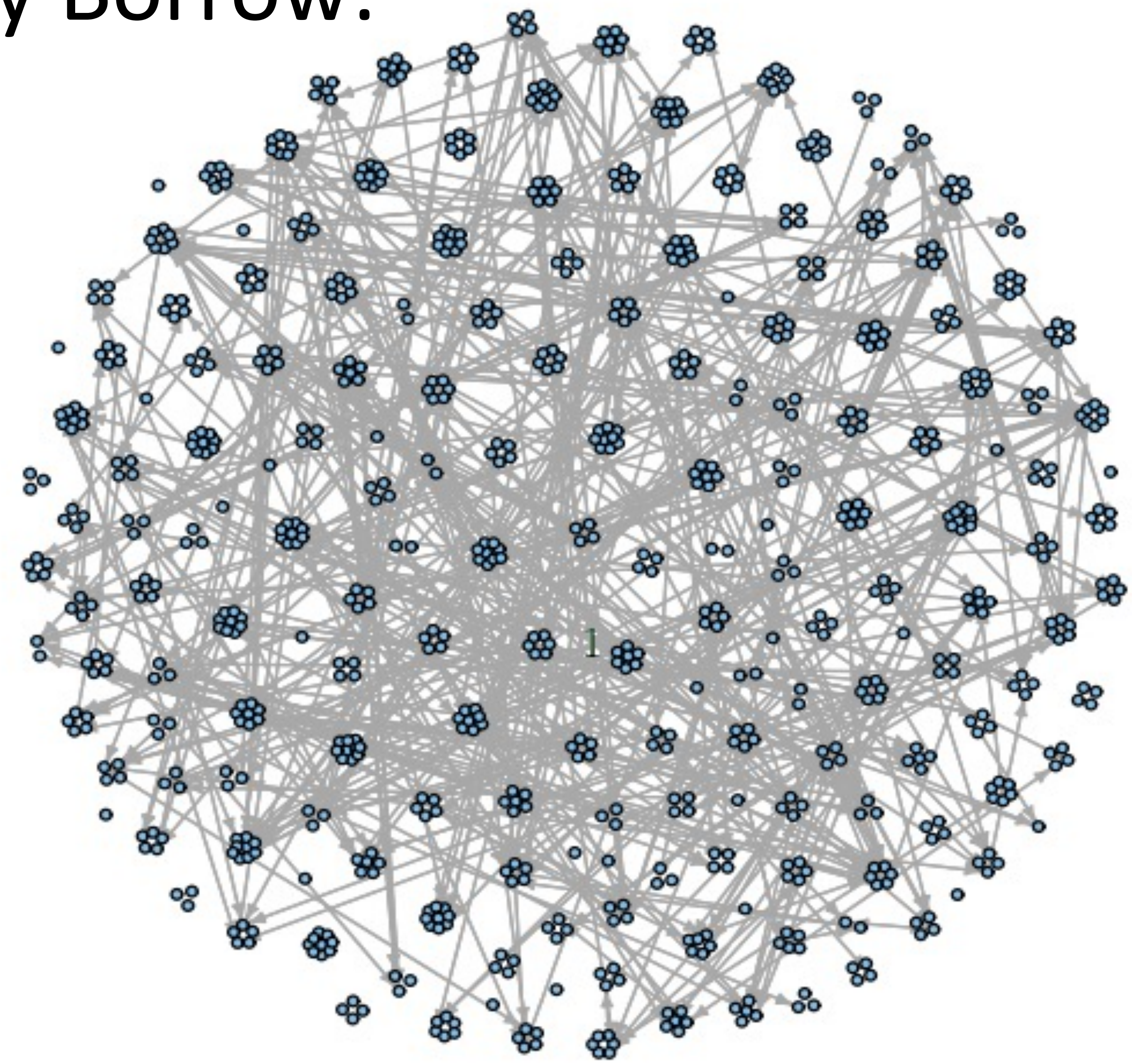
Timeline

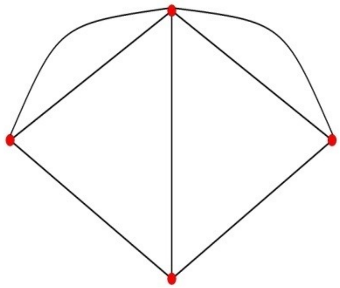


- 2006   We surveyed 75 villages that the bank intended to enter
- 2007-2010 Bank entered 43 villages offered loans, not other 32
- 2011-2012 We resurveyed all villages

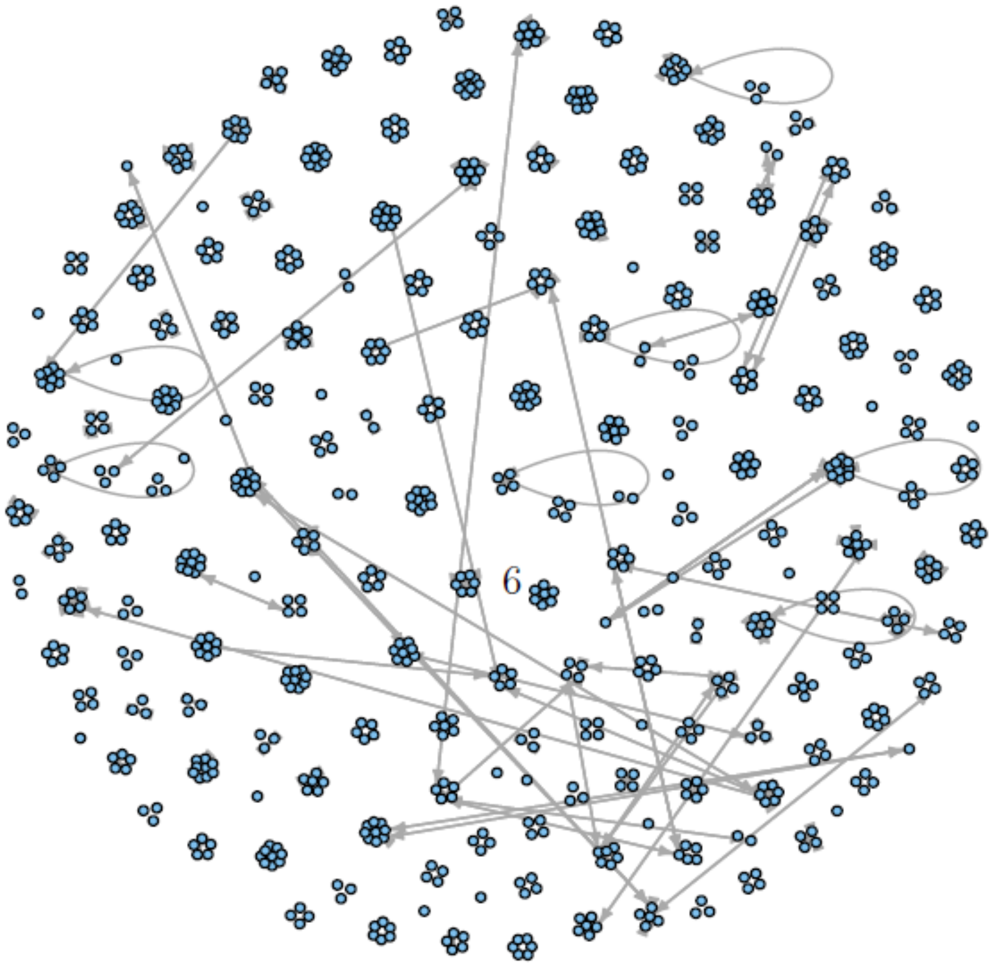

Karnataka

Money Borrow:

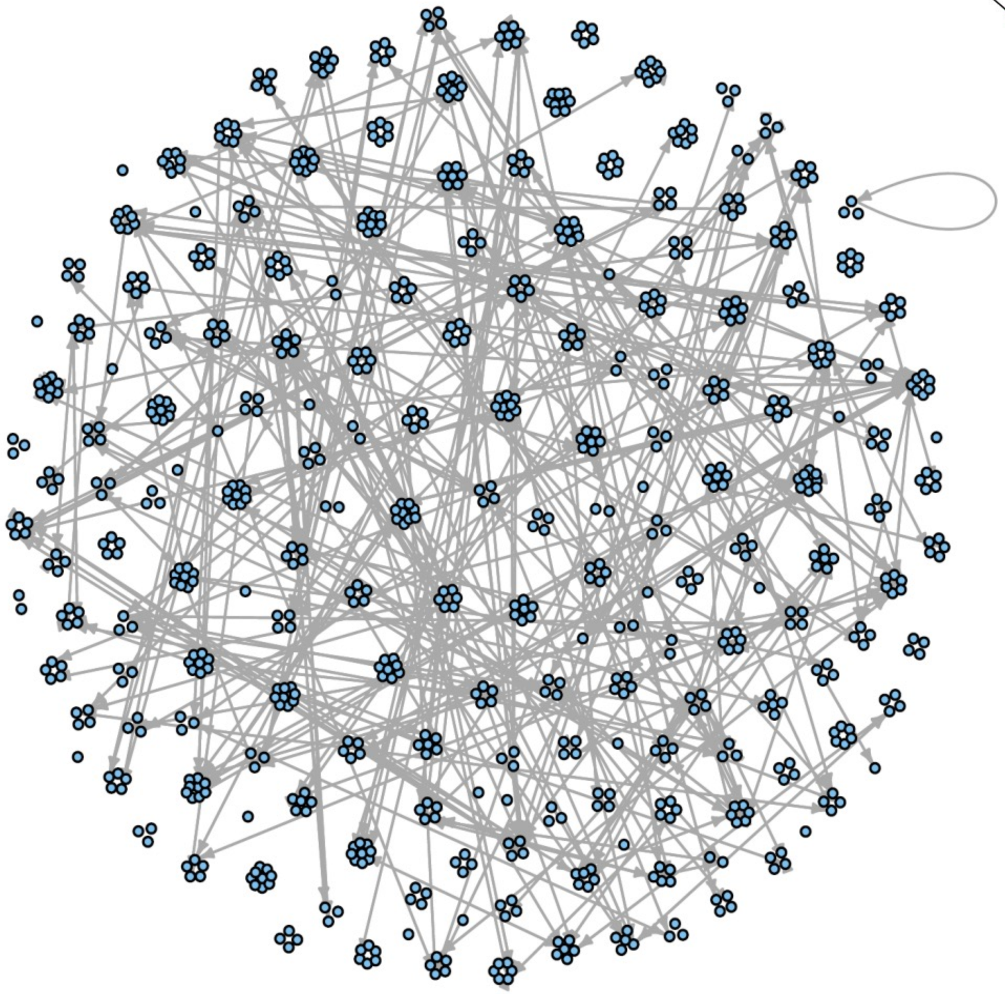


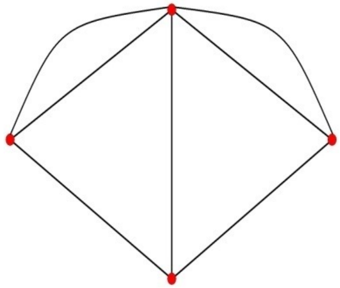


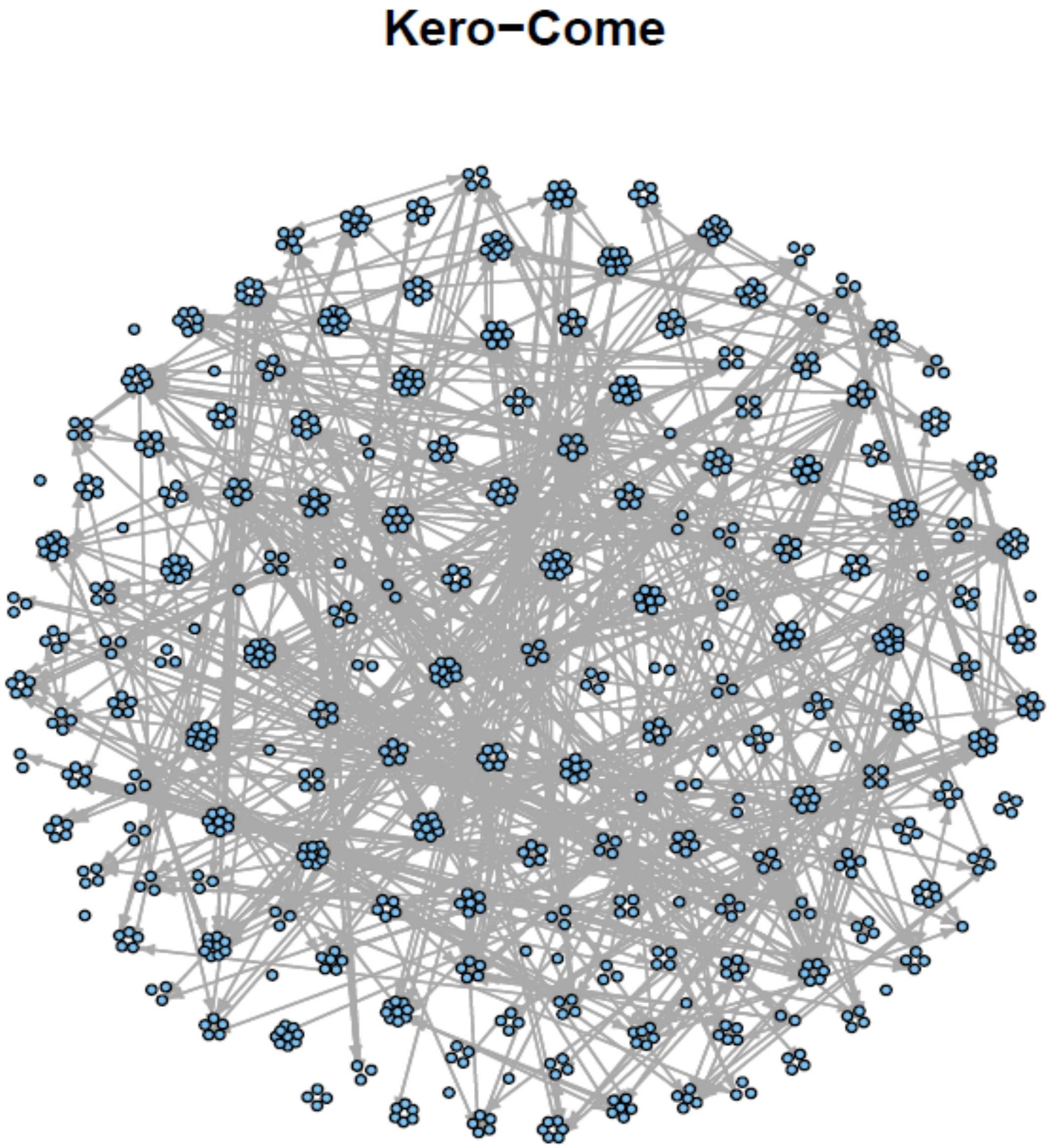
Temple

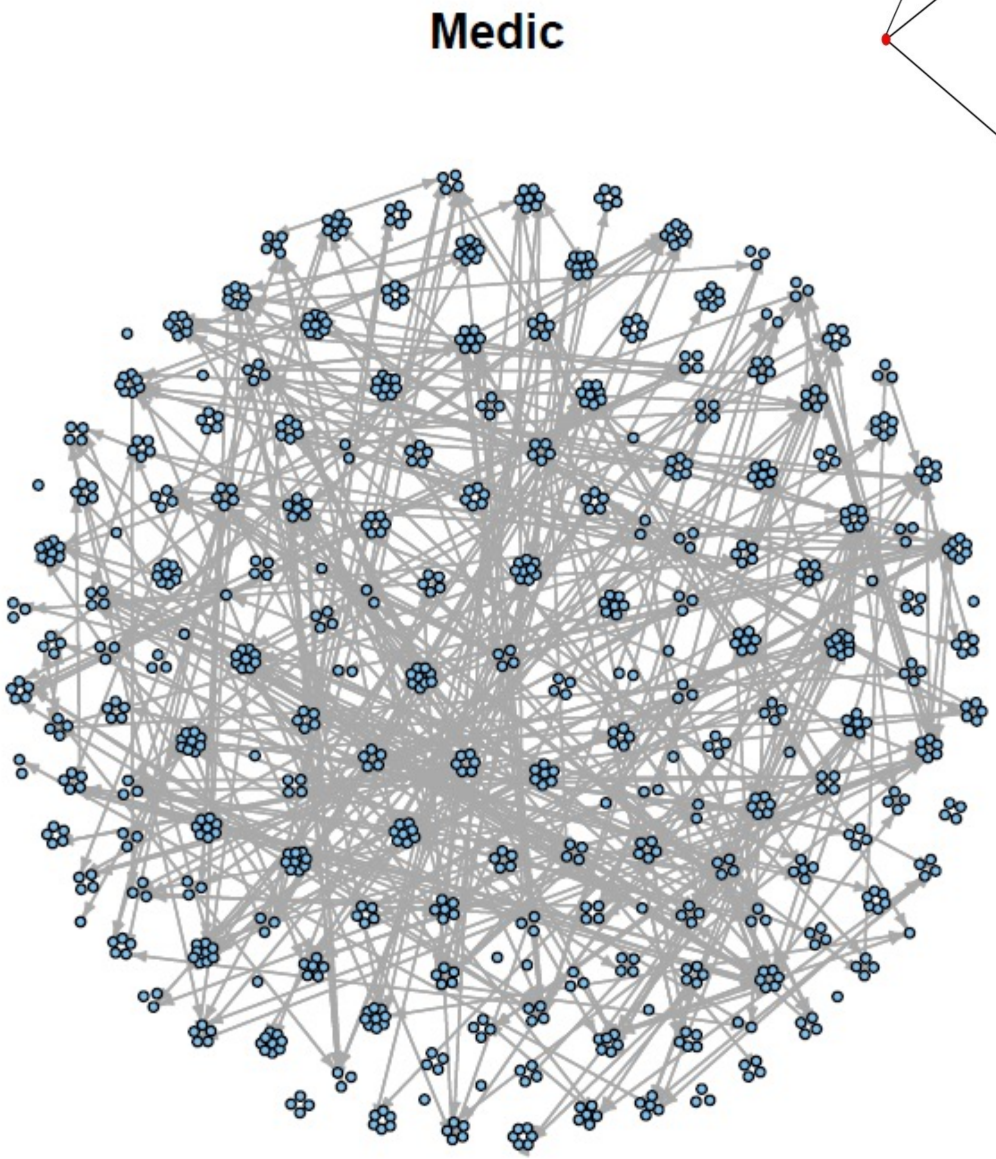


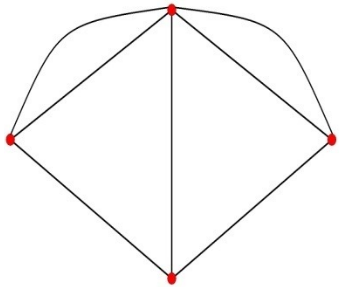
Advice

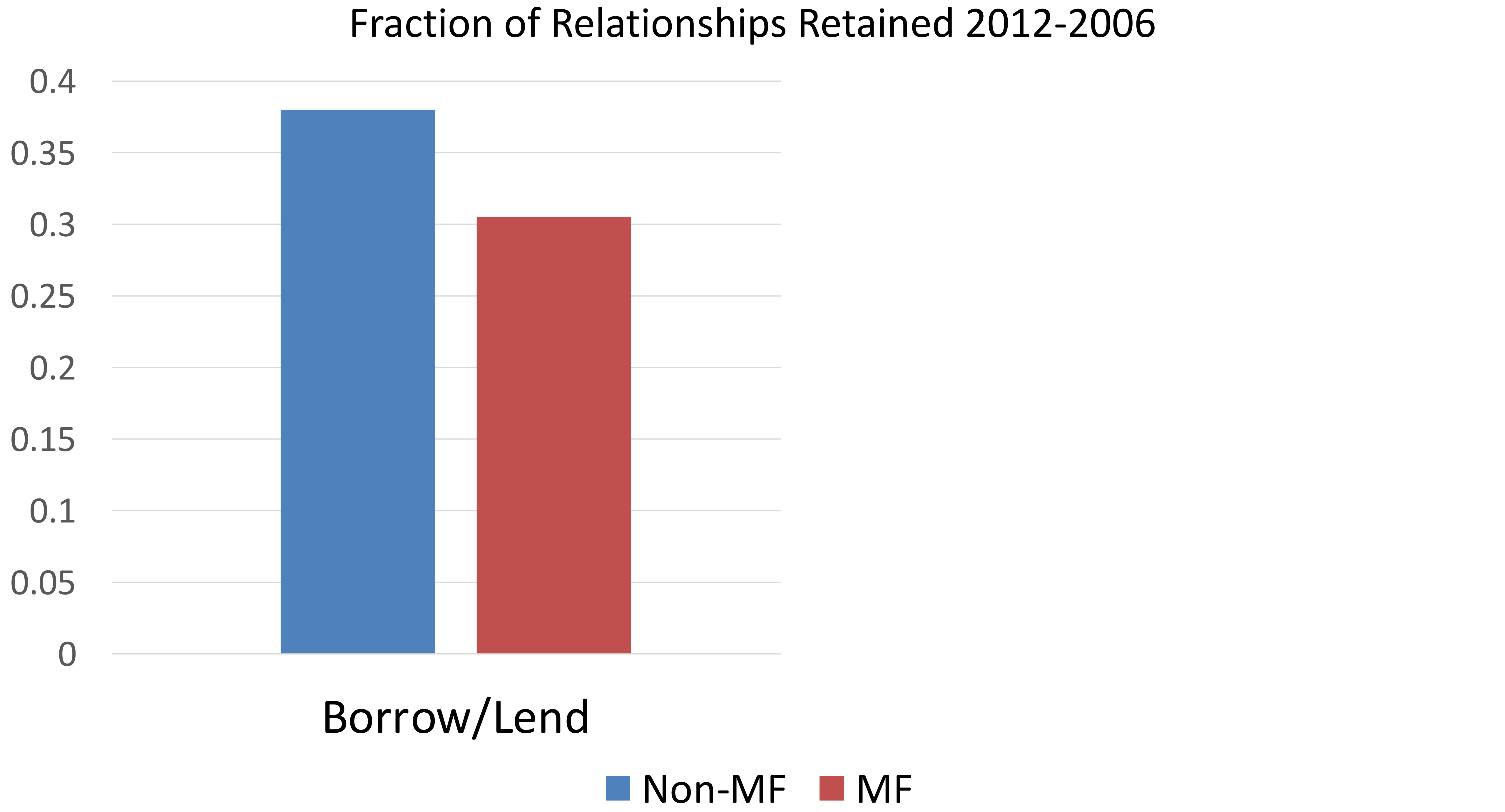


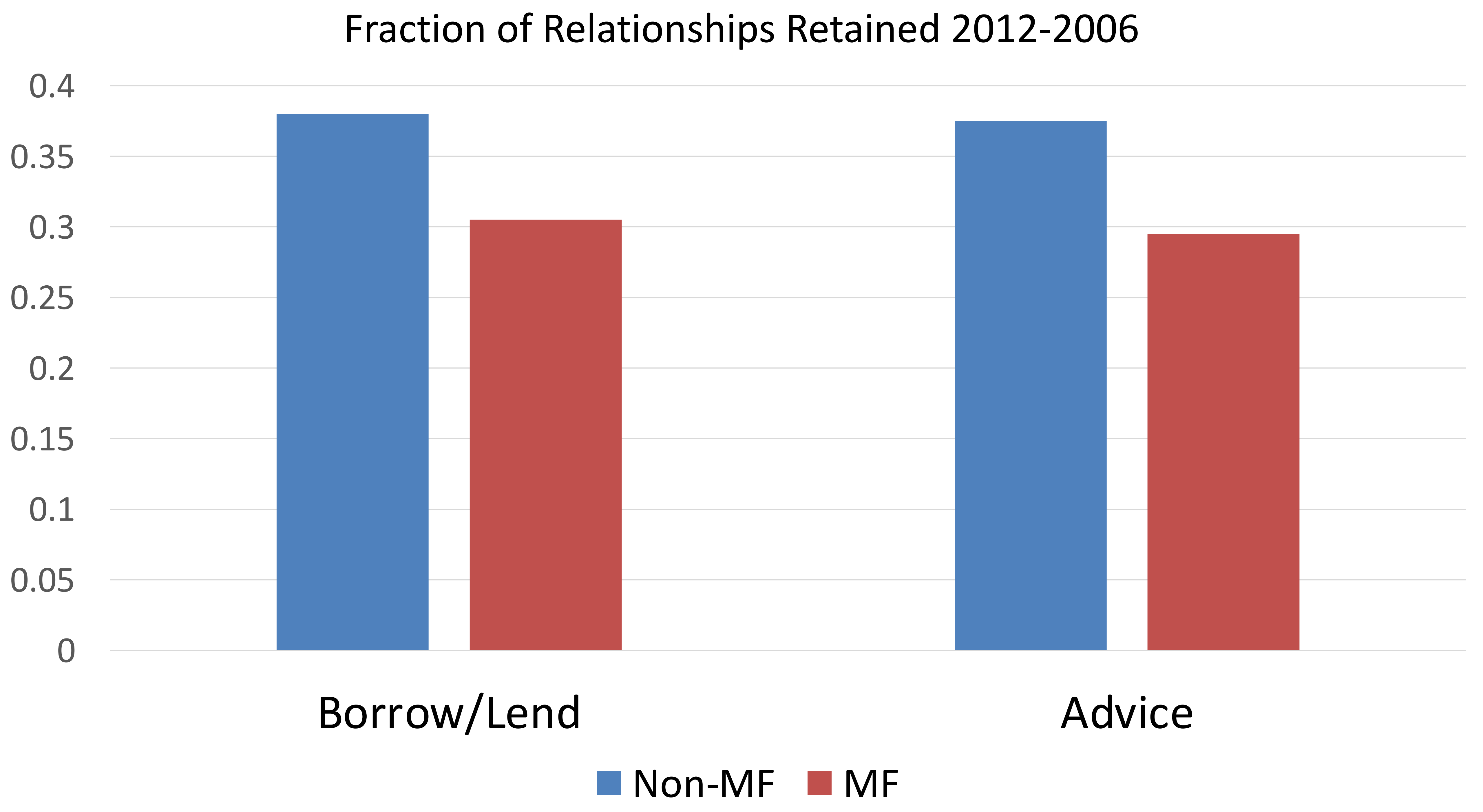



Kero−Come


Medic

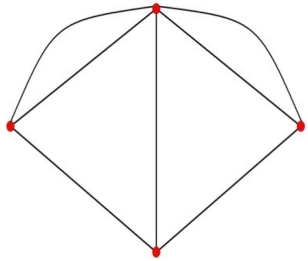



Fraction of Relationships Retained 2012-2006
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Borrow/Lend
Non-MF
MF



Fraction of Relationships Retained 2012-2006
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Borrow/Lend
Advice
Non-MF
MF

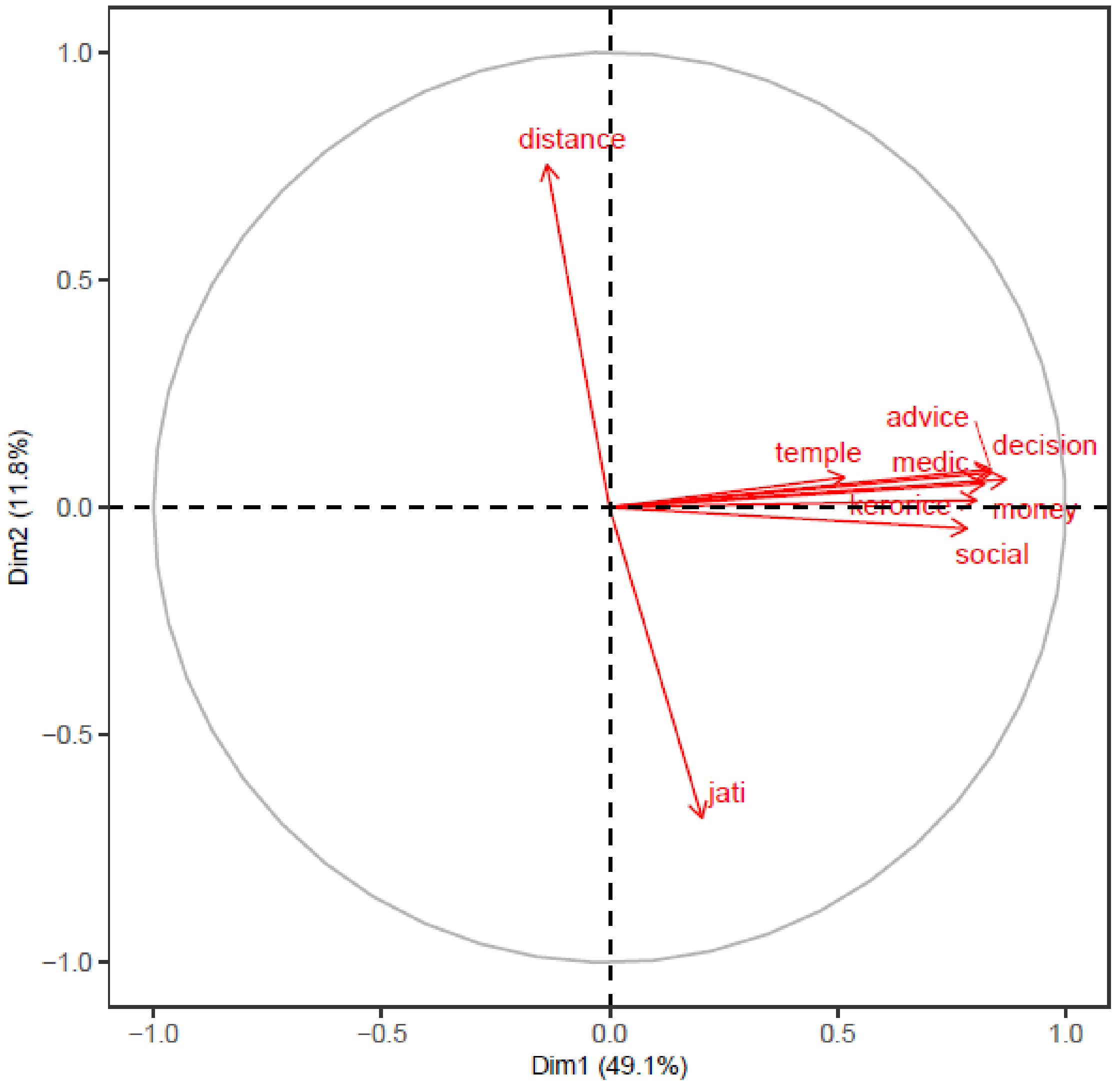
Networks:



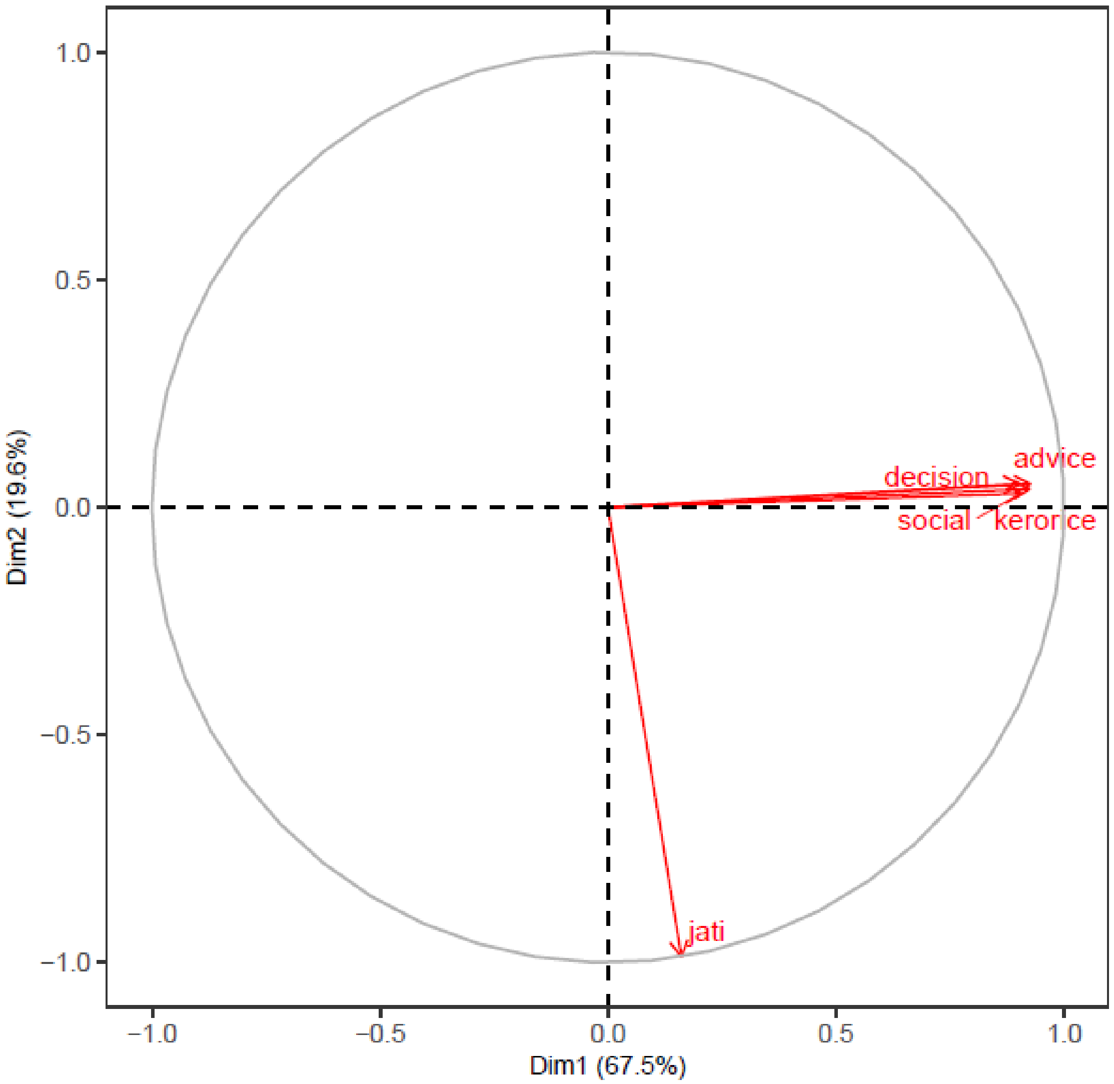
- MF (75 villages) 9 layers:
  - Kero-Rice
  - Money
  - Socialize: relatives, non, visit
  - Medical help
  - Temple
  - Advice
  - Decision Help
  - Jati
  - Geography

- RCT (68 diff villages) 5 layers:
  - Kero-Rice/Money
  - Socialize
  - Advice
  - Decision help
  - Jati

Principal Component Analysis

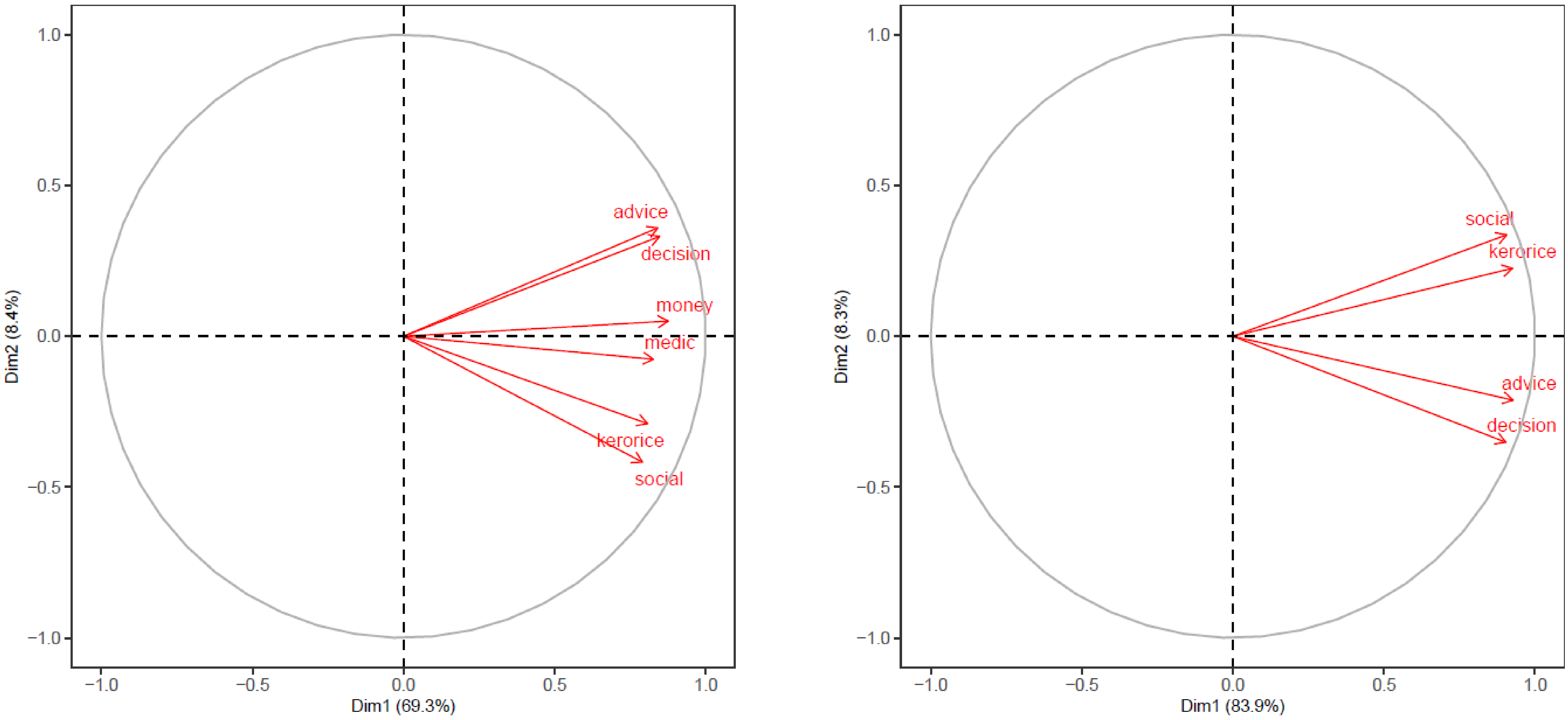


MF villages



RCT villages

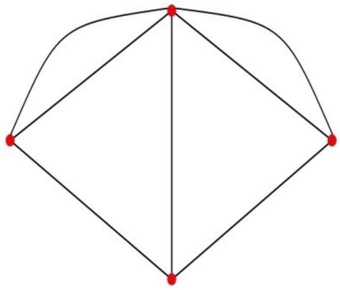
Principal Component Analysis (excluding jati and geography)



MF villages

RCT villages

Outline



- Empirical background multiplexing
- How do multiple layers affect diffusion (in an RCT)?
- Theory on how multiplexing impacts diffusion (simple, complex)

RCT on Diffusion

- Spread information about a chance to win a cell phone

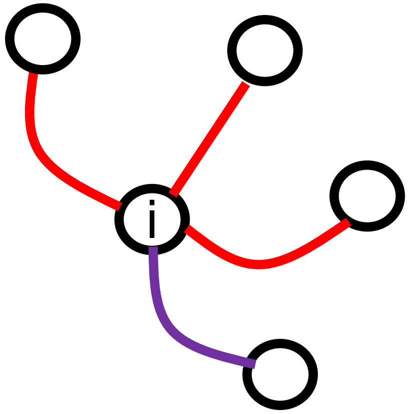
- Randomly tell 3 to 5 people in each village and ask them spread information

- Measure diffusion of information by how many people participate in the cell-phone giveaway

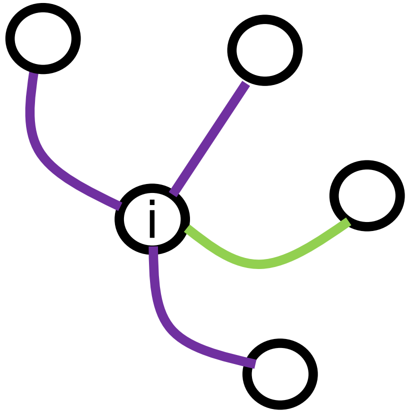
Diffusion

- Which network layer(s) best predict the diffusion?
  - Is it more important to have ``seeds’’ central in advice or in kero/rice or in jati…?

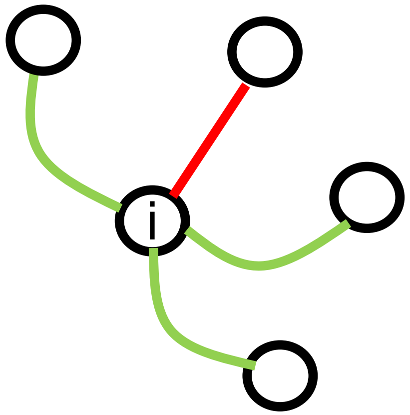
central in
advice network

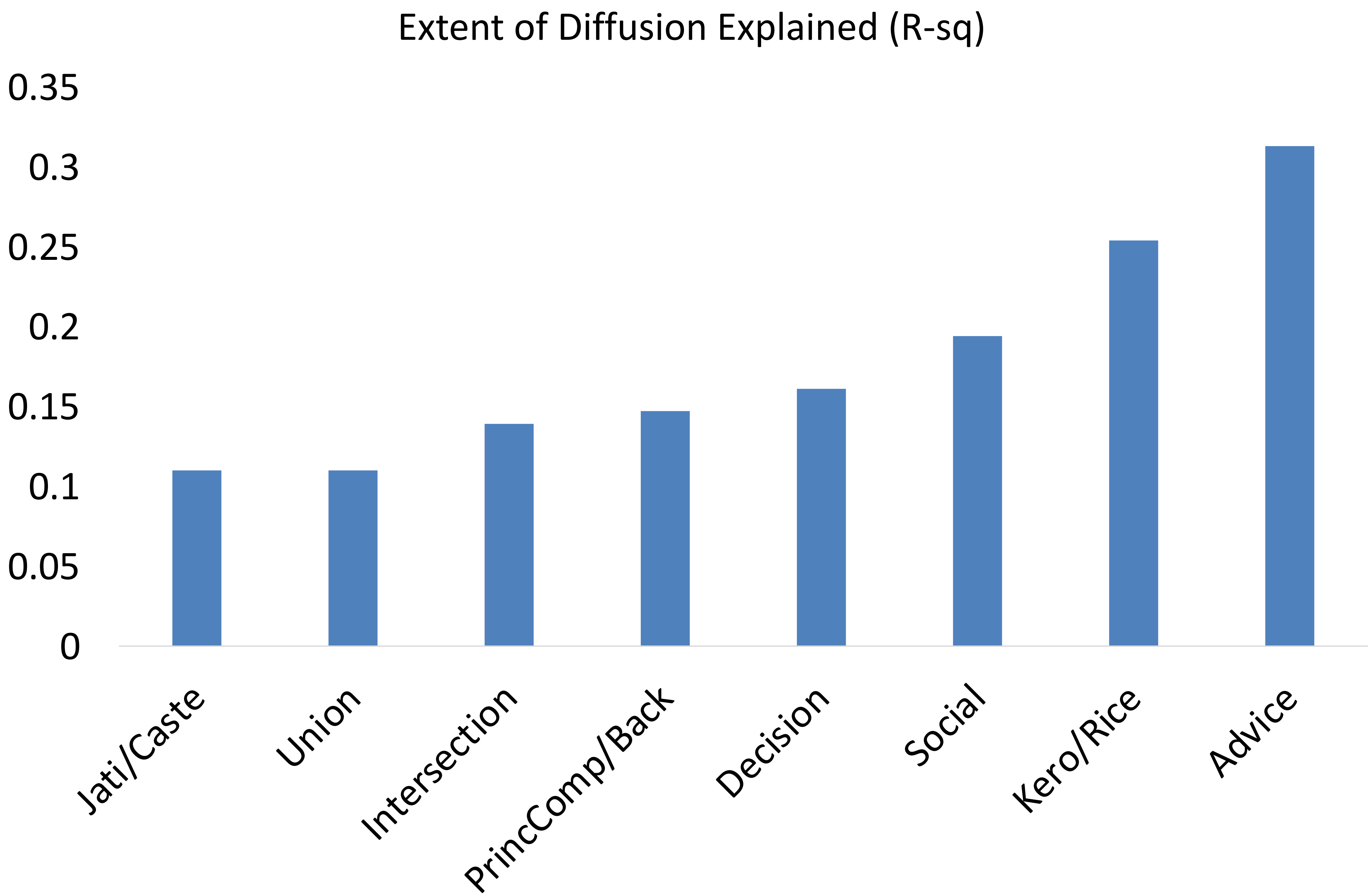


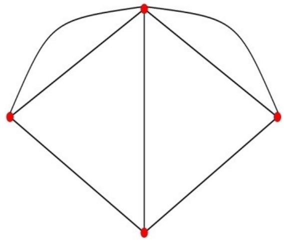
central in
kero/rice network



central in
jati network




Extent of Diffusion Explained (R-sq)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Jati/Caste
Union
Intersection
PrincComp/Back
Decision
Social
Kero/Rice
Advice

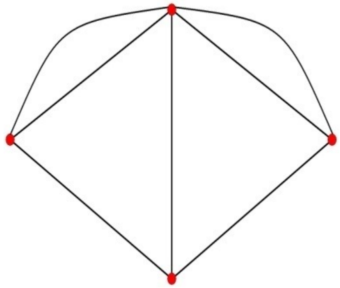


Cumulative Predictive Power:

layer	df	R.sq.	F-stat	p-val
advice	1	0.233	20.057	0.000
intersection	2	0.276	3.888	0.053
kerorice	3	0.281	2.134	0.127
jati	4	0.325	2.844	0.045
backbone	5	0.336	2.415	0.058
union	6	0.340	1.971	0.096
social	7	0.342	1.657	0.147
decision	8	0.344	1.419	0.215

More than just advice matters:
combinations of layers matter in predicting diffusion

Outline



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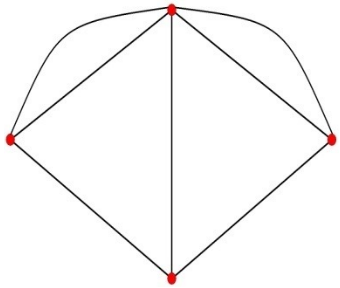
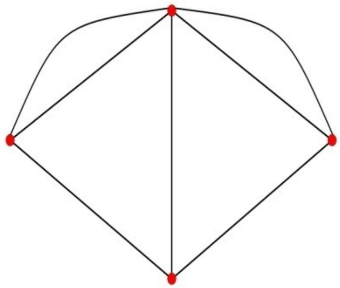
- Theory on how multiplexing impacts diffusion (simple, complex)

Theory: Diffusion



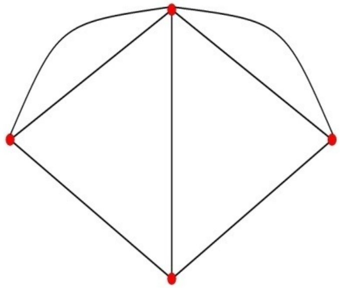
- Agents either infected or susceptible
- If infected recover randomly at some rate δ each period
- If susceptible can be infected by contact with infected neighbors

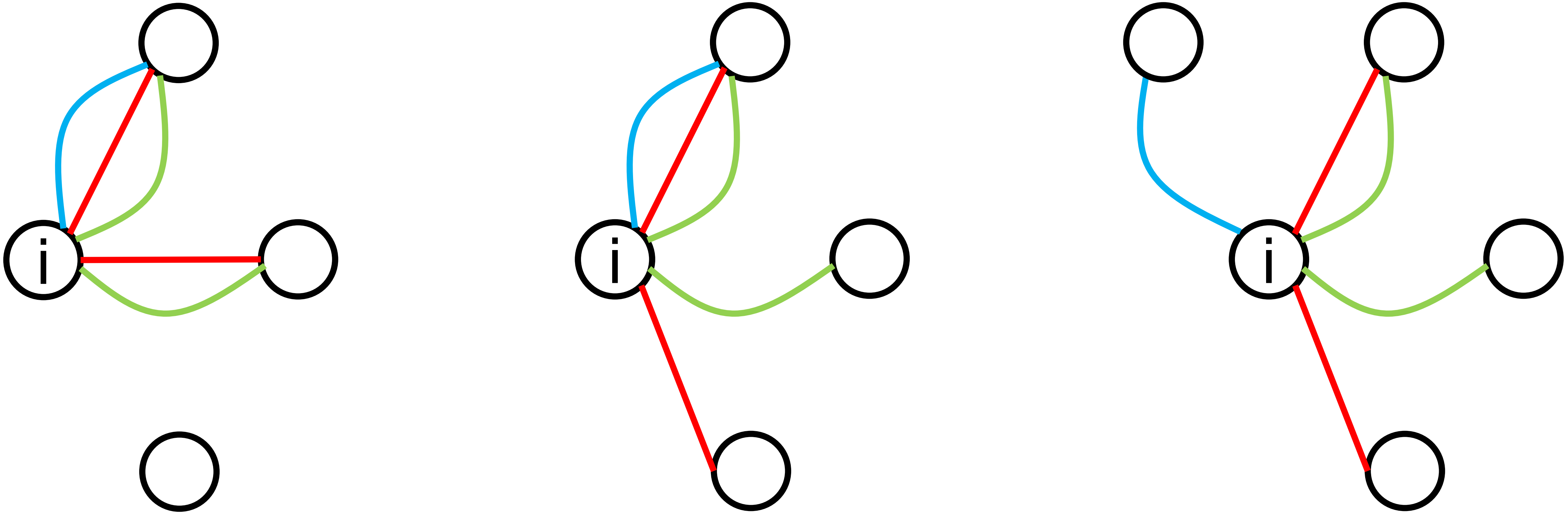
Theory: Diffusion



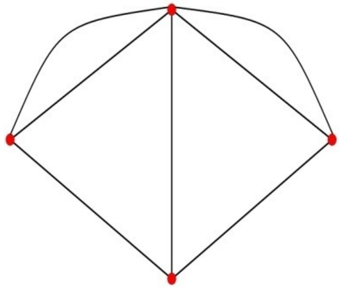
- Probability q_l that infected agent contacts susceptible on layer l
- Agent becomes infected when getting at least τ \`contacts'
  - $\tau = 1$ simple contagion
  - $\tau > 1$ complex contagion
- Contacts independent across layers (not too negatively correlated)

Less Multiplexed





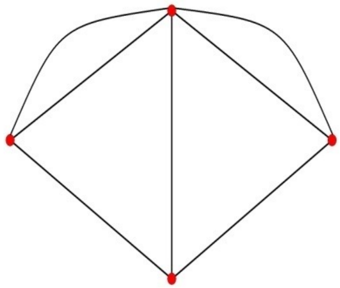
Proposition: Multiplexing Hurts Diffusion under *Simple Diffusion*



Consider agents *i* and *j*, with *i more* multiplexed than *j*.

If *i*'s and *j*'s neighbors are each infected with probability p, then *i* is *less* likely to be infected.

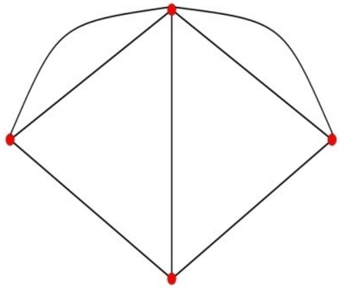
Less multiplexing – more diffusion/contagion



Intuition/Proof Logic:

- *p* chance neighbor is infected
- Infection on one multiplexed relation: $q_A p + q_B p - q_A q_B p$
- Infection on two un-multiplexed relations: $q_A p + q_B p - q_A q_B p^2$

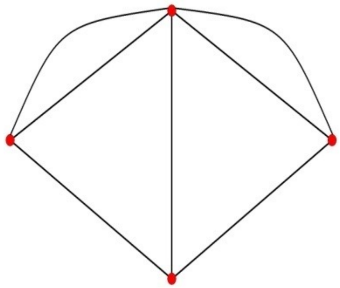
Proposition: Multiplexing Hurts Diffusion under *Simple Contagion*



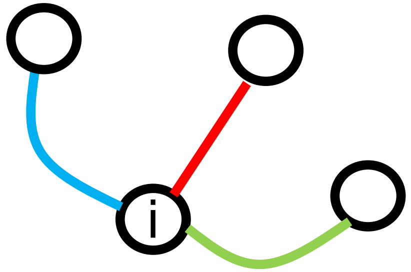
In the SIS (or SIR) model, the mean-field steady-state infection rate is **decreasing** in the multiplexing of the network.

Less multiplexing - more diffusion/contagion

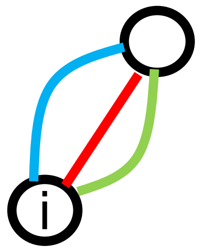
Back to the Data



Theory: more multiplexed networks less simple diffusion/contagion



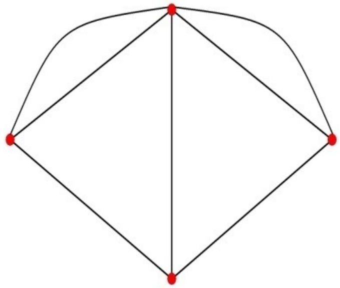
more diffusion



less diffusion

Do we see less diffusion in more multiplexed villages?

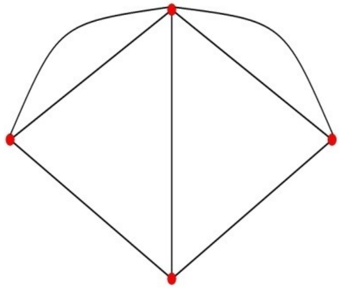
Multiplexing Index



$$m_v := \frac{1}{n} \sum_i \frac{\sum_j \left(\sum_\ell g^\ell_{ij,v} / L \right)}{\sum_j \mathbf{1}\{\sum_\ell g^\ell_{ij,v} > 0\}}$$

	Participation
High Multiplexing x Seed Set Centrality	-.039**
	(.017)
Seed Set Centrality	.052***
	(.016)
High Multiplexing	-.023
	(.016)
Observations	68

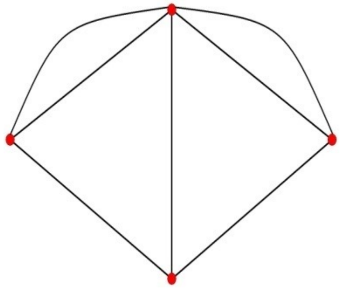
Complex Diffusion is more Complex

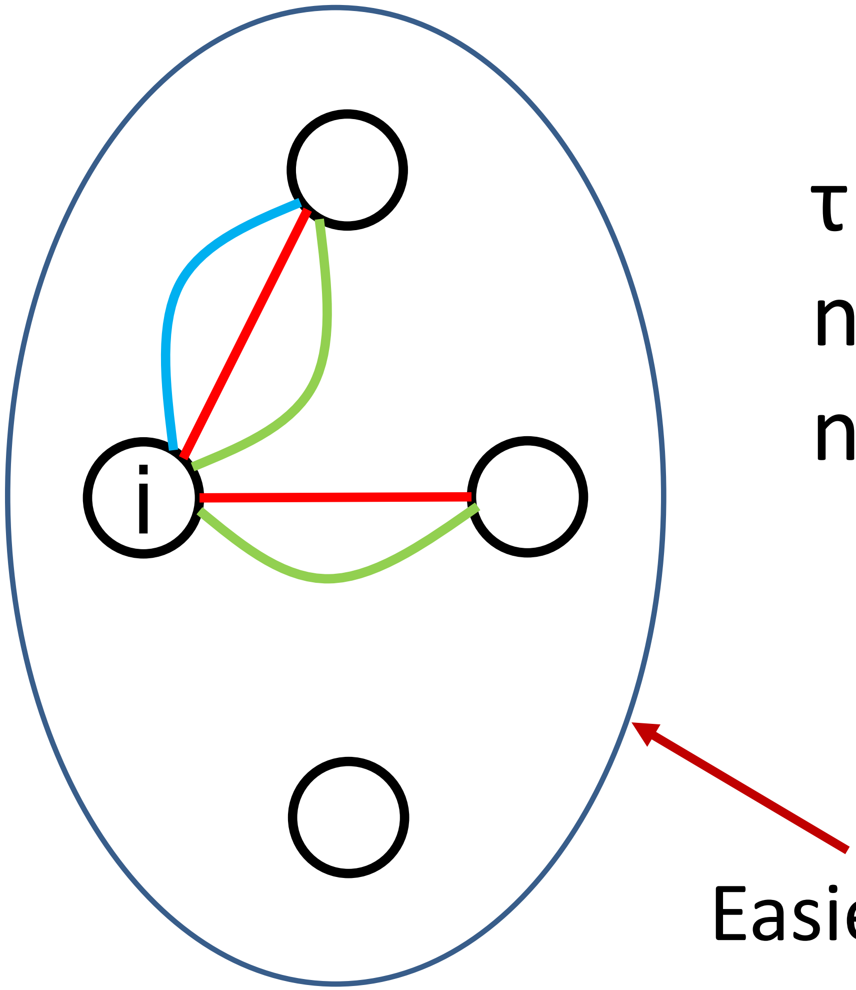


No longer can order based on multiplexing

Interaction with threshold

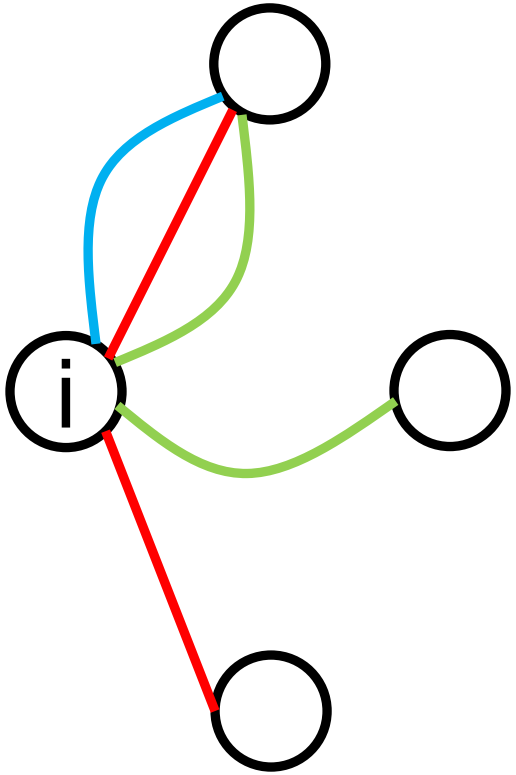
Complex Contagion



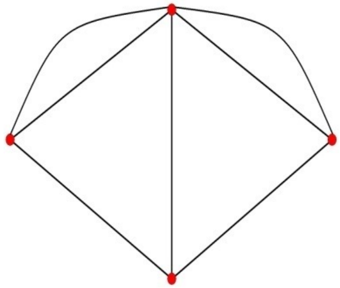


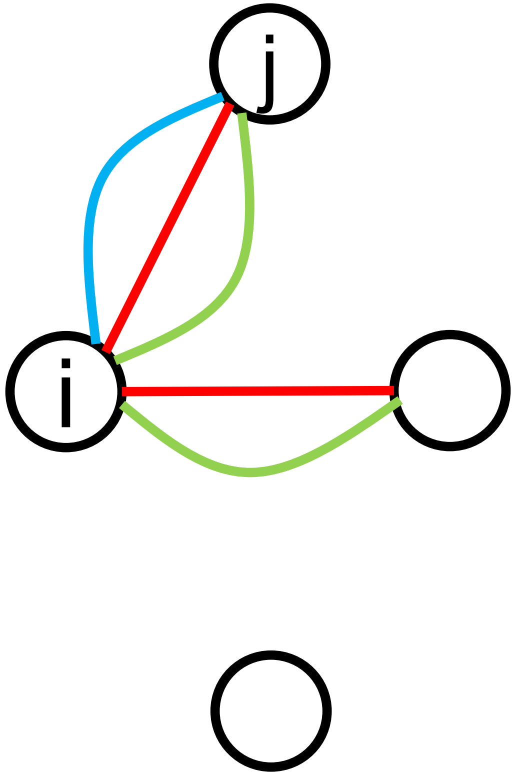
τ = 5
need all
neighbors

Easier to infect



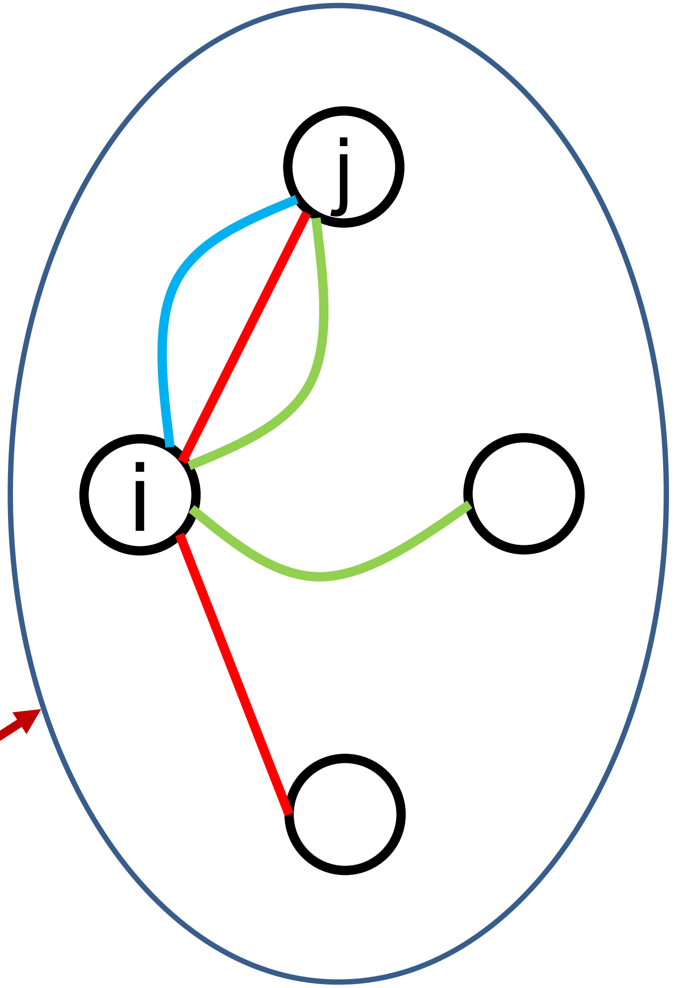
Complex Contagion





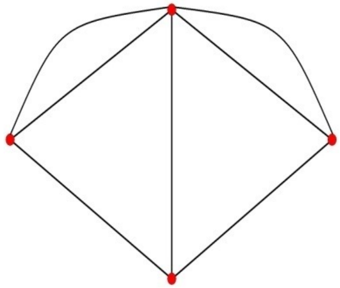
$\tau = 4$

need j and one other



Easier to infect

Proposition: Complex Contagion

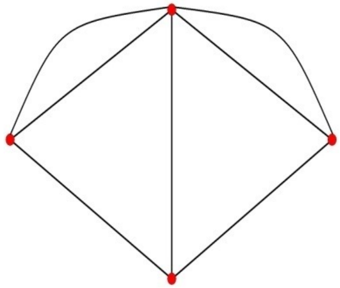


With **complex** contagion (threshold >1), total degree summed across layers is at least $\tau + 1$:

There exist $p' < p''$ (increasing in threshold) such that

- for $p < p'$ infection probability is **increasing** in multiplexing;
- for $p > p''$ infection probability is **decreasing** in multiplexing.

Complex Contagion

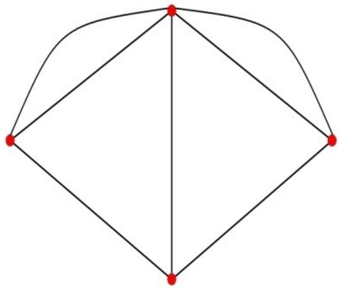


When the infection rate is low,

- Two neighbors being infected is unlikely.
- A multiplexed neighbor infected gives twice contact.

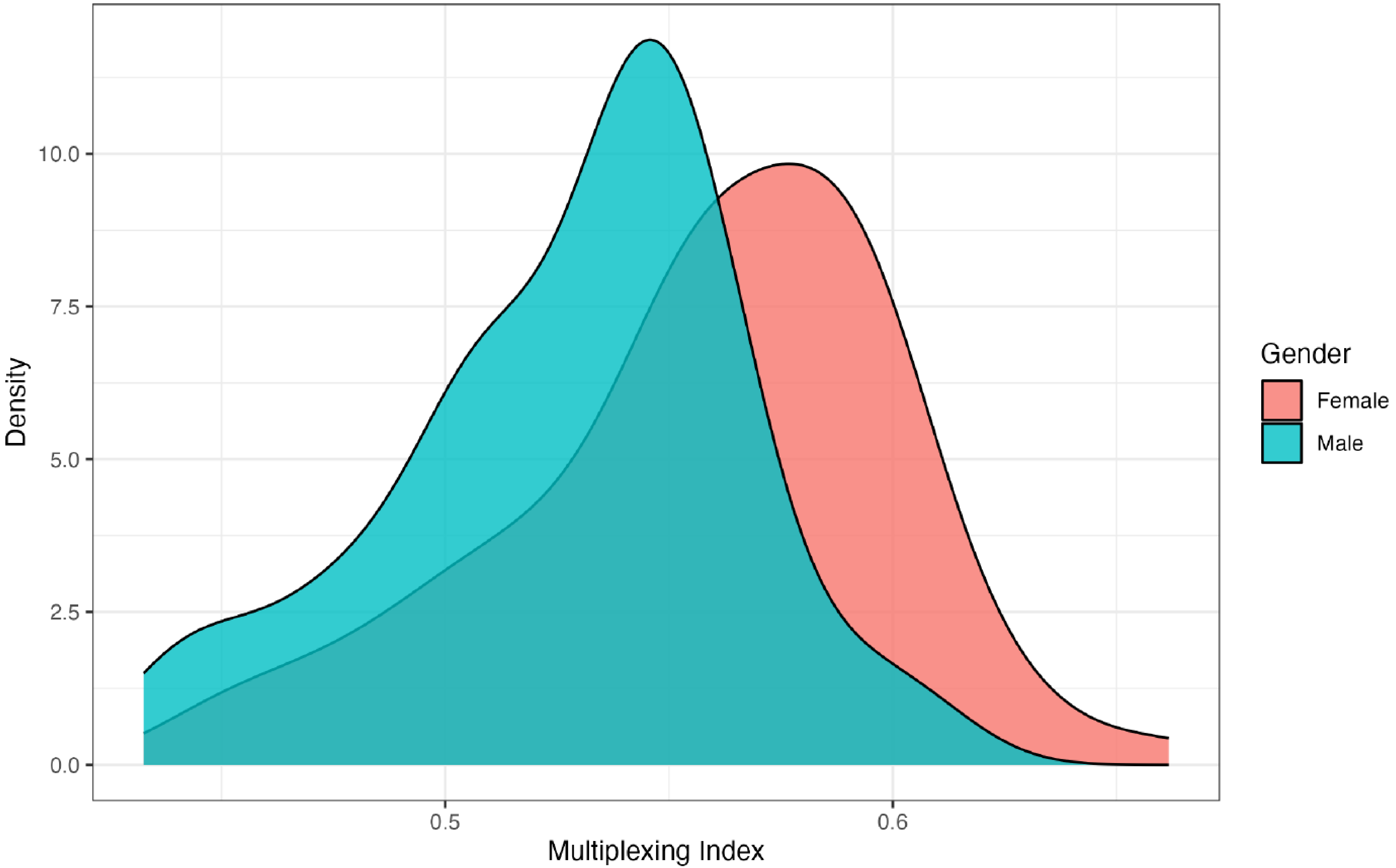
When the infection rate is higher,

- More likely that only need one contact from these two links
- Non-multiplexed more likely to get at least one contact.

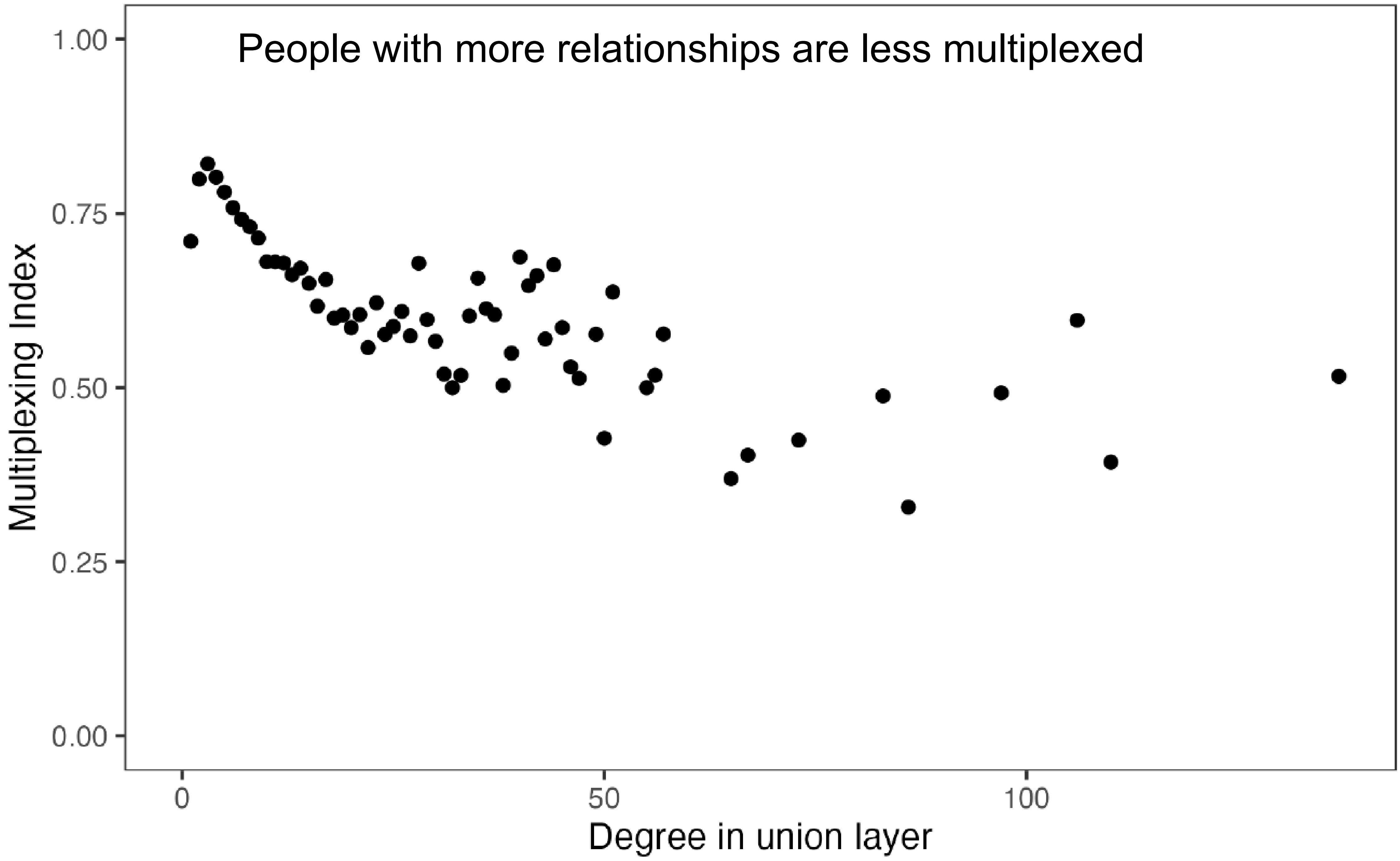


Further Observations

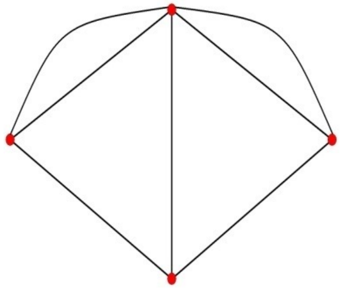
- Who is more multiplexed?


10.0
7.5
5.0
2.5
0.0
Density
0.5
0.6
Multiplexing Index
Gender
Female
Male

	High Multiplexing
Poverty Index	.017**
	(.007)
Observations	12732


People with more relationships are less multiplexed
Multiplexing Index
1.00
0.75
0.50
0.25
0.00
0
50
100
Degree in union layer

Closing Thoughts



- Multiplexing matters in many contexts
  - Networks between nations (trade, migration, war)
  - Networks between companies (partnerships, lending, competition)
  - Networks among workers (communication, direction, collaboration)
  - Networks among students (friends, study partners, roommates)
  - ….
- Need for more theory/empirics of multiplexing and behaviors, network formation, methods…