Dynamic Networks and Behavior: Separating Selection from Influence

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Background

- *Homogeneity bias (network autocorrelation)*: People who are closely related to each other tend to be similar on salient individual behavior and attitude dimensions
  - *Influence mechanisms* & *contagion (assimilate):* a perspective largely in line with classical sociological theory on socialization and coercion
  - *selection mechanisms (homophily)*
  - *context*

Background (cont.)

- A recurrent problem in the analysis of behavioral dynamics:
  - *Given a simultaneously evolving social network, the difficulty of separating the effects of partner selection from the effects of social influence.*
  - *Misattribution of selection effects to social influence, or vice versa.*
  - *Approaches are needed to enable researchers to separate the two effects in a statistically adequate manner.*

Overview

- Three major methodological obstacles to analyze *network autocorrelation*
- A review and critique of prior research methods
- The actor-based model family for network and behavior coevolution
- Application: the coevolution of smoking and drinking behavior with friendship networks

Three major obstacles

- Network dependence of the actors :: Statistical techniques that rely on independent observations
- Control for alternative mechanisms of network evolution and behavioral change in order to avoid misinterpretation in terms of homophily and assimilation
- Incomplete observations implied by the use of panel data :: Evolution processes operate in continuous time

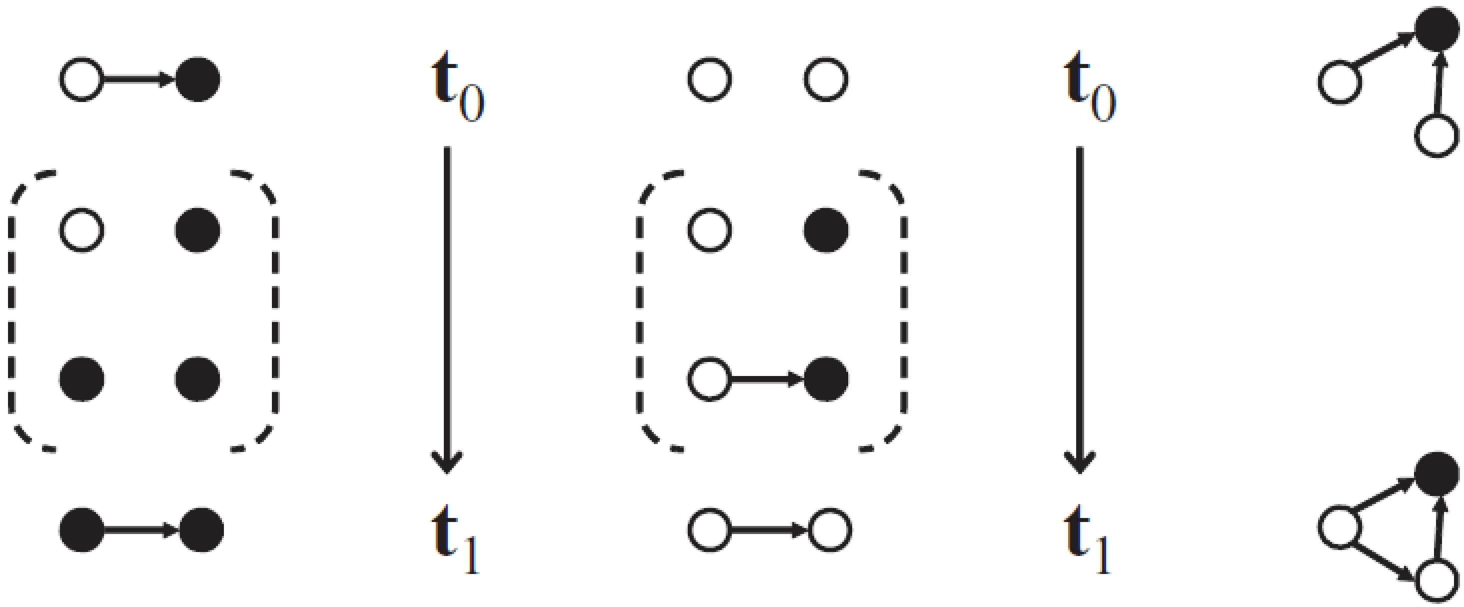


FIGURE 1. Illustrations for two of the three "key issues" mentioned in the text: incomplete observation of changes (left and middle column) and alternative mechanisms (all columns).

Previous Approaches

- Modeling frequencies in a contingency table
  - 1) Network dependence: an acceptable weakness: inadequately assuming dyad independence
  - 2) Control for alternative mechanisms: unaddressed
  - 3) Incomplete observations: unaddressed

Previous Approaches (cont.)

- Analyzing characteristics aggregated from the personal network
  - 1) Network dependence: data are analyzed under independence assumptions
  - 2) Control for alternative mechanisms 3) Incomplete observations: the assumption that all change is observed and sufficiently reflected in the chosen statistics

Previous Approaches (cont.)

- Structural equation models
  - 1) Network dependence: violates independence of observations
  - 2) Control for alternative mechanisms: selection being modeled at an aggregate level precludes expressing alternative mechanisms at the dyadic or triadic level
  - 3) Incomplete observations: estimated path coefficients directly link the observed variables to each other

A new approach: Actor-based models

- Central model components: the actors' behavioral rules (altering either their outgoing network ties or their behavior) determining network and behavioral changes

TABLE 1
Schematic Overview of the Model Components

	Occurrence	Rule of Change
Network changes	Network rate function	Network objective function
Behavioral changes	Behavioral rate function	Behavioral objective function

A new approach: Actor-based models (cont.)

- Major assumptions:
  - At any given moment, not more than one tie variable or one behavior variable can change
  - An instantiation of myopic rationality
- Variables:
  - Outcome (endogenous): the changing network and the changing actor behavior
  - Independent (exogenous): individual or dyadic, changing or unchanging

Notations and terms

- **N** actors
- Network variable: $\mathbf{x}$, $\mathbf{x}_{ij}(\mathbf{t})$
  - e.g., *friendship, advice, share ownership*
- Behavioral variable: $\mathbf{z}$, $\mathbf{z}_{i}(\mathbf{t})$
  - e.g., *smoking behavior, employee performance, activity in a given market segment of a business firm*
- Actor-level exogenous covariates: $\mathbf{v}_{i}(\mathbf{k})$
  - e.g., *sex*, *age, education, # of employees*
- Dyad-level exogenous covariates: $\mathbf{w}_{ij}(\mathbf{k})$
  - *e.g., classmate relation between pupils, organizational hierarchy between employees, geographical distance of business firms*
- Network-behavior panel data: a finite set of time points ($\mathbf{t}1 < \mathbf{t}2 < \cdot \cdot \cdot < \mathbf{tM}$)

Notations and terms (cont.)

- *Micro steps:* each opportunity to change one of outgoing tie variables, or to change behavior
- *Rate functions:* the frequency by which actors have the opportunity to make a change (separate rate functions for the behavioral and the network changes: e.g., more frequent changes in the network than in substance use)

Notations and terms (cont.)

- The waiting time until actor **i** takes a micro step: $\mathbf{T}_i^{net}$ & $\mathbf{T}_i^{beh}$: exponentially distributed with parameters $\boldsymbol{\lambda}_i^{net} > 0$ and $\boldsymbol{\lambda}_i^{beh} > 0$ [$\Pr(\mathbf{T} > \mathbf{t}) = \exp(-\boldsymbol{\lambda}\mathbf{t})$ for all $\mathbf{t} > 0$]
  - expected waiting time: $1/\boldsymbol{\lambda}$
  - expected waiting time until occurrence of the next micro step of either kind by any actor: $1/\lambda_{total}$

$$\boldsymbol{\lambda}_{\text{total}} = \sum_{\mathbf{i}} \left(\boldsymbol{\lambda}_{\mathrm{i}}^{\text{net}} + \boldsymbol{\lambda}_{\mathbf{i}}^{\text{beh}}\right)$$

  - probability that this is a network micro step taken by a particular actor i: $\lambda_i^{net}/\lambda_i^{total}$
  - probability that this is a behavior micro step taken by a particular actor i: $\lambda_i^{beh}/\lambda_i^{total}$

Notations and terms (cont.)

- *objective functions:*
  - **f**net (**f**beh): a measure of the actor's satisfaction with the result of the network (behavioral) decision
  - i chooses that value x' for which $f_i$net (x, x', z) + $\varepsilon_i$net (x, x', z) is maximal
  - i chooses that value z' for which $f_i$beh (x, z, z') + $\varepsilon_i$beh (x, z, z') is maximal
  - *ε* is a random disturbance term
  - choice probabilities:

$$\exp\left(\mathbf{f}_{\mathbf{i}}^{\mathrm{net}}(\mathbf{x}', \mathbf{z})\right) \Big/ \sum_{\mathbf{x}''} \exp\left(\mathbf{f}_{\mathbf{i}}^{\mathrm{net}}(\mathbf{x}'', \mathbf{z})\right)$$

$$\exp\left(\mathbf{f}_{\mathbf{i}}^{\mathrm{beh}}(x, z')\right) \Big/ \sum_{z''} \exp\left(\mathbf{f}_{\mathbf{i}}^{\mathrm{beh}}(\mathbf{x}, \mathbf{z}'')\right)$$

Notations and terms (cont.)

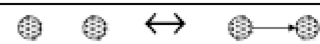
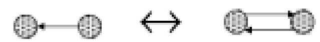
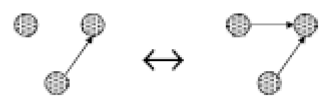
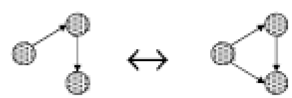
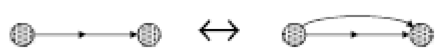
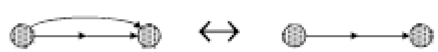
- *objective functions:*

$$\mathbf{f_i^{net}}(\mathbf{x}, \mathbf{x}', \mathbf{z}) = \sum_{\mathbf{h}} \boldsymbol{\beta}_{\mathbf{h}}^{\mathrm{net}} \mathbf{s}_{\mathbf{h}}^{\mathrm{net}}(\mathbf{i}, \mathbf{x}, \mathbf{x}', \mathbf{z})$$

$$\mathbf{f_i^{beh}}(\mathbf{x}, \mathbf{z}, \mathbf{z}') = \sum_{\mathbf{h}} \boldsymbol{\beta}_{\mathbf{h}}^{\mathrm{beh}} \mathbf{s}_{\mathbf{h}}^{\mathrm{beh}}(\mathbf{i}, \mathbf{x}, \mathbf{z}, \mathbf{z}')$$

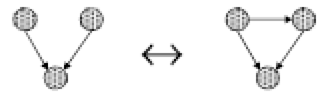
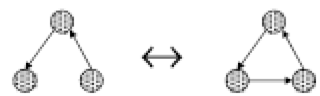
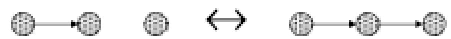
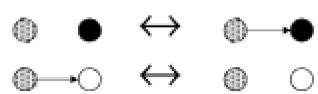
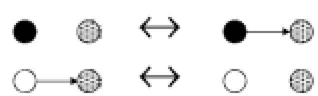
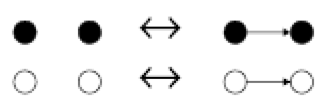
  - Statistics **s** stand for the effects, weighted by parameters ***β*** whose size is determined by fitting the model to the data;
  - ***β*** *: t*he degree to which the actors have a tendency to change into a direction where the network-behavioral state has high values for these effects;
  - Snet : endogenous network effects;
  - Sbeh : endogenous behavioral effects;

TABLE 2
Selection of Possible Effects for Modeling Network Evolution

Effect	Network Statistic	Effective Transitions in Network[a]	Verbal Description
1. Outdegree	$\sum_j x_{ij}$		Overall tendency to have ties
2. Reciprocity	$\sum_j x_{ij}x_{ji}$		Tendency to have reciprocated ties
3. Preferential attachment	$\sum_j x_{ij}\sqrt{\sum_h x_{hj}}$		Tendency to attach to popular others (with decreasing marginal sensitivity to alter's popularity)
4. Transitive triplets	$\sum_j x_{ij} \sum_h x_{ih}x_{hj}$		Tendency toward triadic closure of the neighborhood (linear effect of the number of indirect ties)
5. Transitive ties	$\sum_j x_{ij} \max_h(x_{ih}x_{hj})$	 (*number* of intermediaries is irrelevant)	Tendency toward triadic closure of the neighborhood (binary effect of indirect ties)
6. Actors at distance 2	$\sum_j (1 - x_{ij}) \max_h(x_{ih}x_{hj})$	 (*number* of intermediaries is irrelevant)	Tendency to keep others at social distance 2 (negative measure of triadic closure)

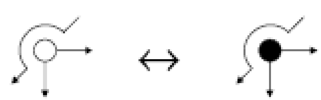
(Continued)

TABLE 2
(Continued)

Effect	Network Statistic	Effective Transitions in Network[a]	Verbal Description
7. Balance	$\sum_j x_{ij}\mathrm{strsim}_{ij}$		Tendency to have ties to structurally similar others (structural balance)
8. 3-cycles	$\sum_j x_{ij} \sum_h x_{jh} x_{hi}$		Tendency to form relationship cycles (negative measure of hierarchy)
9. Betweenness	$\sum_j x_{ij} \sum_h x_{hi}(1 - x_{hj})$	 (*no direct link* from left to right actor)	Tendency to occupy an intermediary position between unrelated others (broker position)
10. Covariate alter	$\sum_j x_{ij}(z_j - \bar{z})$		Main effect of alter's behavior (covariate determines popularity in network)
11. Covariate ego	$\sum_j x_{ij}(z_i - \bar{z})$		Main effect of ego's behavior on tie preference (covariate determines activity in network)
12. Covariate similarity	$\sum_j x_{ij}\mathrm{sim}_{ij}$		Tendency to have ties to similar others (homophile selection on covariate, linear in score differences)

[a]In the *effective transitions* illustrations, it is assumed that the covariate is dichotomous and centered at zero; the coding is ○ = low score (negative), ● = high score (positive), ◍ = arbitrary score. The tie x_{ij} from actor **i** to actor **j** is the one that changes in the transition indicated by the double arrow. Illustrations are not exhaustive.

TABLE 3
Selection of Possible Network Effects for Modeling Behavioral Evolution

Effect	Network Statistic	Effective Transitions in Behavior[a]	Verbal Description
1. Shape: linear and quadratic	$(z_i - \bar{z})$ and $(z_i - \bar{z})^2$	○ ↔ ●	*The two parameters together define a parabola shape of the objective function, allowing it to capture the basic shape of the observed distribution of the behavioral variable.*
2. Average similarity	$(\sum_j x_{ij}\mathrm{sim}_{ij})/(\sum_j x_{ij})$	○→● ↔ ●→● ●→○ ↔ ○→○	Assimilation to neighbors' average behavior (small neighborhoods pull as much as big ones)
3. Sum of similarity	$\sum_j x_{ij}\mathrm{sim}_{ij}$	○→● ↔ ●→● ●→○ ↔ ○→○	Assimilation to neighbors' average behavior (size of neighborhood determines size of effect)
4. Average alters	$(\sum_j x_{ij}(z_j - \bar{z}))/(\sum_j x_{ij})$	○→● ↔ ●→● ●→○ ↔ ○→○	Main effect of neighbors' average behavior (contagion/influence, but not necessarily assimilation)
5. Indegree × behavior	$(z_i - \bar{z})\sum_j x_{ji}$	○←◍ ↔ ●←◍	Effect of own popularity in the network on behavior
6. Outdegree × behavior	$(z_i - \bar{z})\sum_j x_{ij}$	○→◍ ↔ ●→◍	Effect of own activity in the network on behavior
7. Isolation × behavior	$(z_i - \bar{z})(1 - \max_j(x_{ij}))$		Effect of being isolated in the network on behavior

[a]In the *effective transitions* illustrations, it is assumed that the behavioral dependent variable is dichotomous and centered at zero; the color coding is ○ = low score (negative), ● = high score (positive), ◍ = arbitrary score. Actor **i** is the actor who changes color z_i in the transition indicated by the double arrows. Illustrations are not exhaustive.

Simulation algorithm

The model is a Markov chain, the simulation algorithm is defined by giving the step of a single change in the process.

- A waiting time is drawn from the exponential distribution with parameter **(1)**, and the time parameter **t** is incremented by this waiting time. The process stops when time exceeds the end time of the period.
- If it continues, using probabilities **(2)** and **(3)**, it is determined whether the next event is a network change or a behavior change, and who is the actor making the change.
- The change to be made is chosen according to probabilities **(4)** or **(5)**, respectively. The process repeats itself until the end of the period is reached.
- The resulting simulated network-behavior configuration can be evaluated.

$$\boldsymbol{\lambda}_{\text{total}} = \sum_{\mathrm{i}} \left(\boldsymbol{\lambda}_{\mathrm{i}}^{\text{net}} + \boldsymbol{\lambda}_{\mathrm{i}}^{\text{beh}} \right) \quad (1)$$

$$\boldsymbol{\lambda}_{\mathbf{i}}^{\text{net}} \Big/ \lambda_{\text{total}} \quad (2)$$

$$\boldsymbol{\lambda}_{\mathrm{i}}^{\text{beh}} \Big/ \lambda_{\text{total}} \quad (3)$$

$$\exp\left(\mathbf{f}_{\mathrm{i}}^{\text{net}}(\mathbf{x}', \mathbf{z}) \right) \Big/ \sum_{\mathbf{x}''} \exp\left(\mathbf{f}_{\mathrm{i}}^{\text{net}}(\mathbf{x}'', \mathbf{z}) \right) \quad (4)$$

$$\exp\left(\mathbf{f}_{\mathrm{i}}^{\text{beh}}(x, z') \right) \Big/ \sum_{z''} \exp\left(\mathbf{f}_{\mathrm{i}}^{\text{beh}}(\mathbf{x}, \mathbf{z}'') \right) \quad (5)$$

TABLE 1
Schematic Overview of the Model Components

	Occurrence	Rule of Change
Network changes	Network rate function	Network objective function
Behavioral changes	Behavioral rate function	Behavioral objective function

λ^{net} λ^{beh}

$$\mathbf{f}_{\mathbf{i}}^{\text{net}}(\mathbf{x}, \mathbf{x}', \mathbf{z}) = \sum_{\mathbf{h}} \boldsymbol{\beta}_{\mathbf{h}}^{\text{net}} \mathbf{s}_{\mathbf{h}}^{\text{net}}(\mathbf{i}, \mathbf{x}, \mathbf{x}', \mathbf{z})$$

$$\mathbf{f}_{\mathbf{i}}^{\text{beh}}(\mathbf{x}, \mathbf{z}, \mathbf{z}') = \sum_{\mathbf{h}} \boldsymbol{\beta}_{\mathbf{h}}^{\text{beh}} \mathbf{s}_{\mathbf{h}}^{\text{beh}}(\mathbf{i}, \mathbf{x}, \mathbf{z}, \mathbf{z}')$$

Evaluation

- Moments estimation routine:
  - Each model parameter ***ϑ.*** must be matched with a statistic **S.**
  - e.g., four types of statistics for the four types of model parameters:

Network rate, period $\boldsymbol{m}$ $\quad \boldsymbol{\theta}_{\cdot} = \lambda_{\mathbf{m}}^{\mathrm{net}} \quad \mathbf{S}_{\cdot} = \sum_{\mathbf{ij}} |\mathbf{X_{ij}(t_{m+1}) - x_{ij}(t_m)}|$

Behavior rate, period $\boldsymbol{m}$ $\quad \boldsymbol{\theta}_{\cdot} = \lambda_{\mathbf{m}}^{\mathrm{beh}} \quad \mathbf{S}_{\cdot} = \sum_{\mathbf{i}} |\mathbf{Z_i(t_{m+1}) - z_i(t_m)}|$

Network objective function effects $\quad \boldsymbol{\theta}_{\cdot} = \boldsymbol{\beta}_{\mathbf{h}}^{\mathrm{net}} \quad \mathbf{S}_{\cdot} = \sum_{\mathbf{m}} \sum_{\mathbf{i}} \mathbf{s_h^{net}(i, X(t_{m+1}), z(t_m))}$

Behavior objective function effects $\quad \boldsymbol{\theta}_{\cdot} = \boldsymbol{\beta}_{\mathbf{h}}^{\mathrm{beh}} \quad \mathbf{S}_{\cdot} = \sum_{\mathbf{m}} \sum_{\mathbf{i}} \mathbf{s_h^{beh}(i, x(t_m), Z(t_{m+1}))}$

Application

The co-evolution of friendship and substance use

Questions Addressed

- To what degree can influence and selection mechanisms account for the observed coevolution of substance use and friendship ties?
- Does the answer to this question differ between the use of tobacco and the use of alcohol?
- Which amount of network autocorrelation on the substance use dimensions can be accounted for by selection mechanisms, by influence mechanisms, or by other 'control' mechanisms?

Data

- A year cohort at a secondary school in Glasgow, Scotland
- Friendship networks, smoking behavior, alcohol consumption, and other lifestyle variables
- Three time points in successive academic years, February 1995 (12–13 years old) to January 1997 (150 in the first wave, 146 in the second, and 137 in the third)

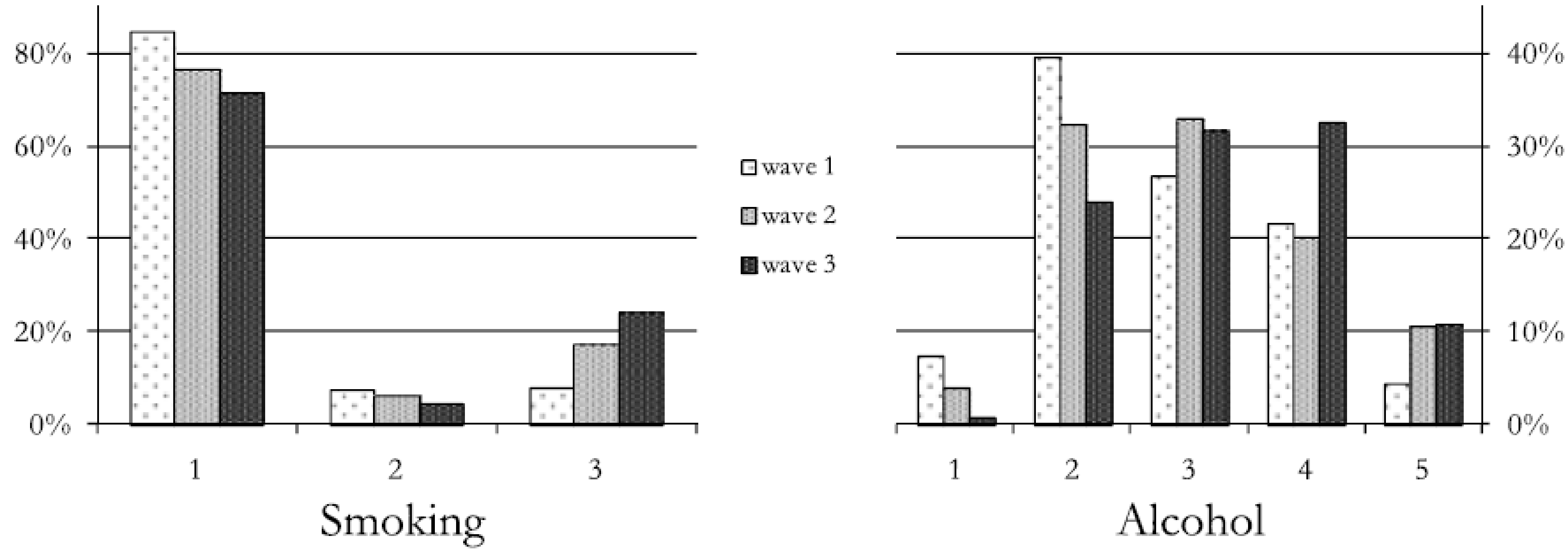


FIGURE 2. Observed distribution of substance use in the three waves.

Smoking: 1 (nonsmokers) to 3 (regular smokers-more than one cigarette per week)
Alcohol consumption: 1 (not at all) to 5 (more than once a week)

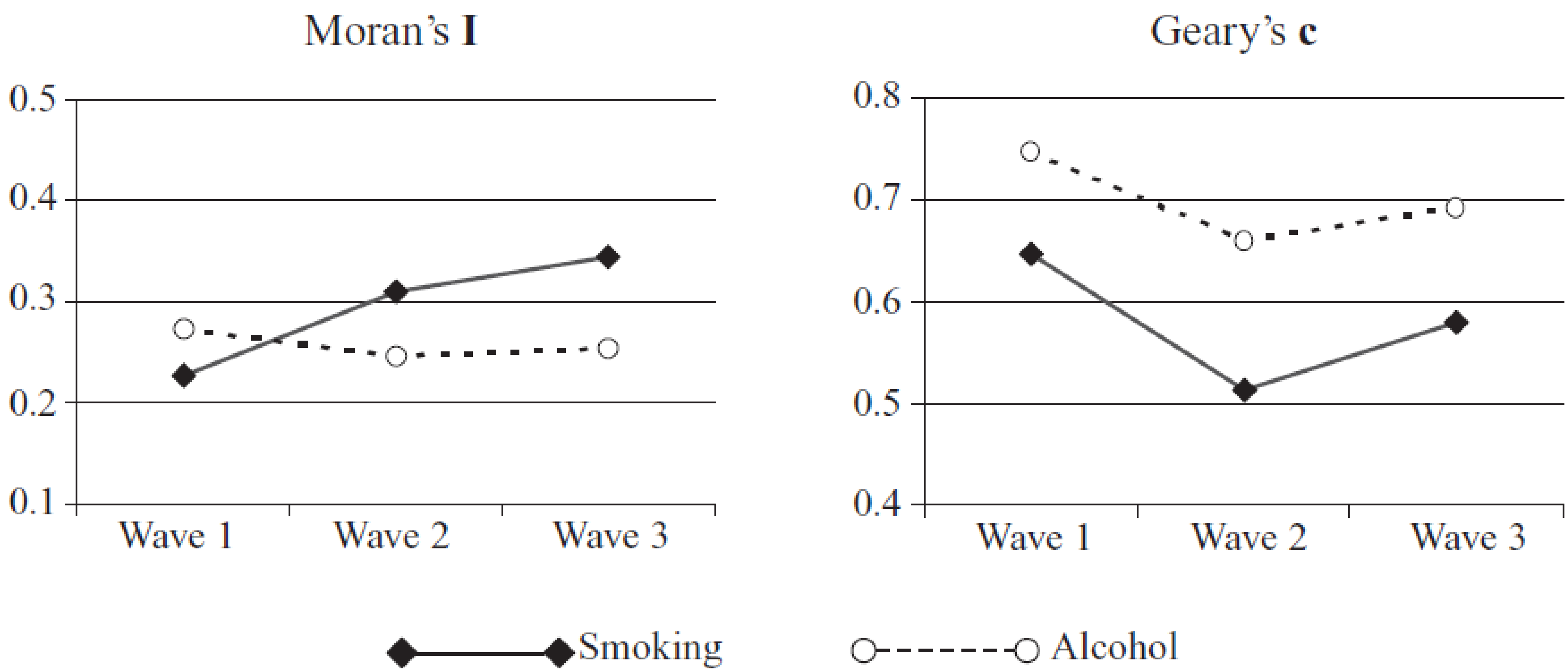


FIGURE 3. Observed network autocorrelation.

I-coefficient (Moran, 1948): based on cross-products of behavioral Scores of relational partners (close to zero: a weak network autocorrelation; close to one: a very strong network autocorrelation)

c-coefficient (Geary, 1954): based on squared differences on the behavioral variable between relational partners (close to zero: strong behavioral homogeneity; close to one: random pairing)

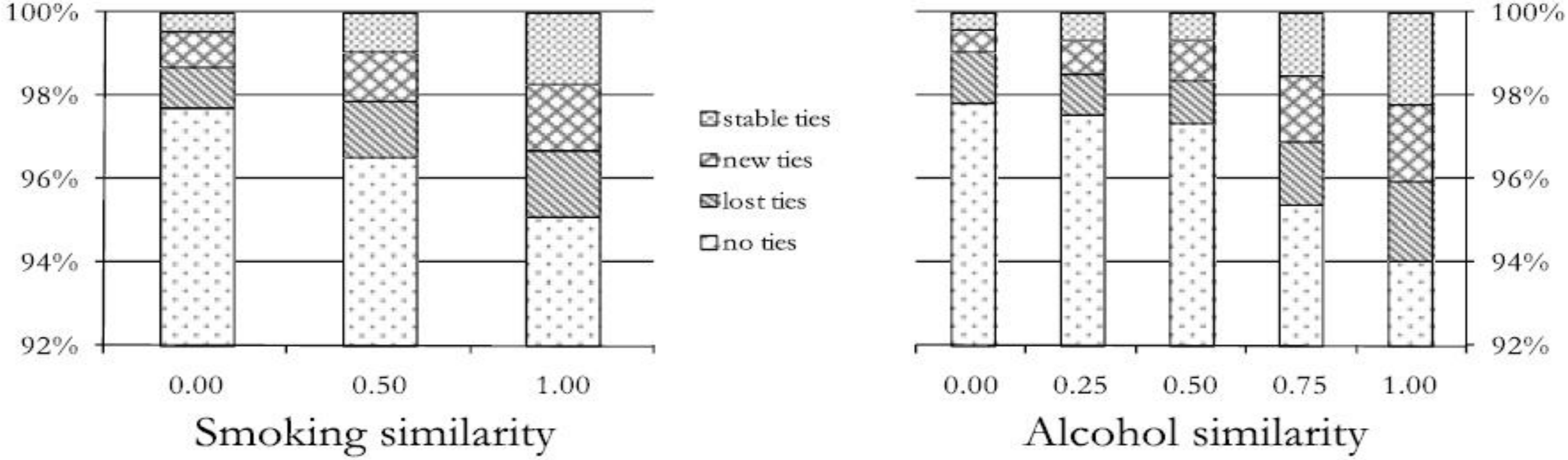


FIGURE 4. Tie change patterns by initial behavior.

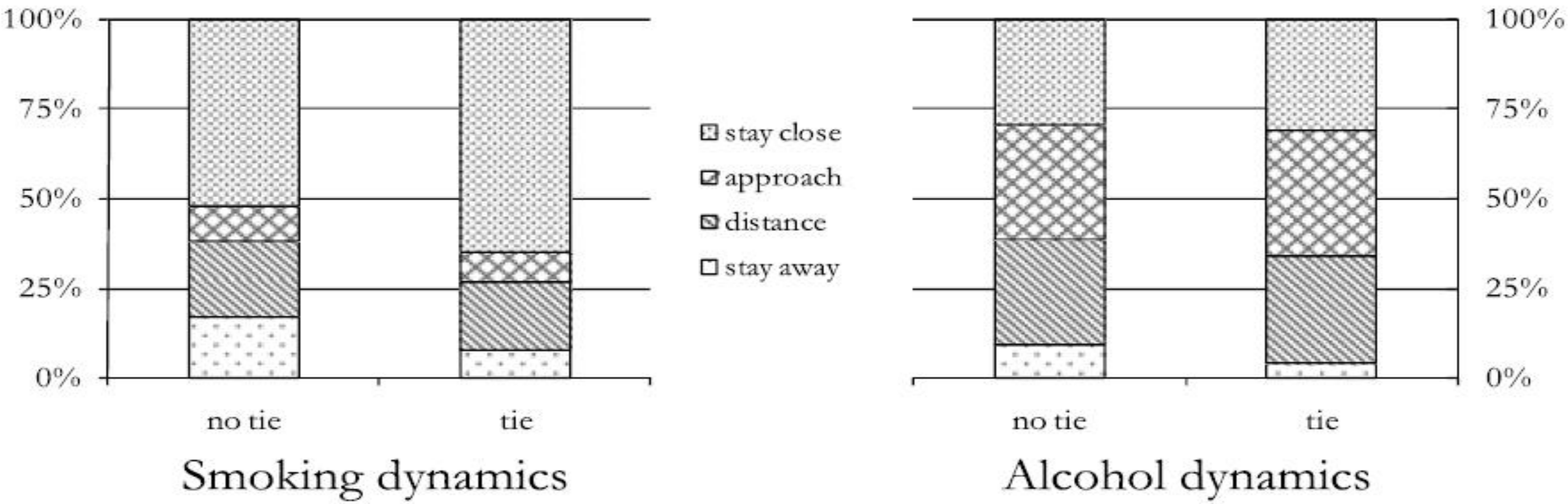


FIGURE 5. Behavior change patterns by initial tie status.

Hypotheses

TABLE 4
Summary of Expectations About Model Parameters

Verbal Description	*Model Parameter*	*Sign*
(a) Rules of Network Change (Friendship)		
1. The density of friendship networks is low.	outdegree	–
2. Friendship nominations tend to be reciprocated.	reciprocity	+
3. Popular pupils attract friendship nominations.	preferential attachment	+
4. Friendship networks tend to display triadic closure.	transitive ties	+
	distance-2	–
5. Friends tend to be structurally equivalent.	balance	+
6. Friendship is more likely between classmates.	classmate	+
7. There is homophily according to sex.	sex similarity	+
8. Older students are less invested in school networks.	birth year ego/alter	+
9. Money attracts friends.	money alter	+
10. There is homophily according to money.	money similarity	+
11. Romantic relations reduce investment in the network.	romantic ego/alter	–
12. There is homophily according to romantic relations.	romantic similarity	+
13. There is homophily according to substance use.	behavior similarity	+

TABLE 4

Summary of Expectations About Model Parameters

Verbal Description	*Model Parameter*	*Sign*
(b) Rules of Behavioral Change (Substance Use)		
14. Own substance use is assimilated to friends' use.	average similarity	+
15. Older pupils use more substance.	birth year	–
16. Pupils whose parents/siblings smoke use more substance.	parent/sibling smoking	+
17. Pupils who use one substance also use the other.	other substance use	+
18. Pupils with more money use more substance.	money	+
19. Pupils involved in romantic relations use less substance.	romantic	–

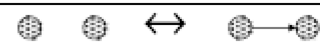
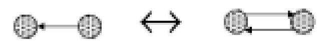
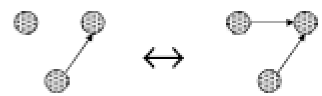
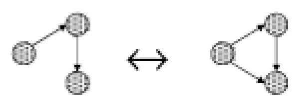
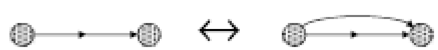
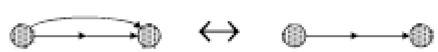
Model and Results

TABLE 5

Estimates and Standard Errors for Friendship Evolution

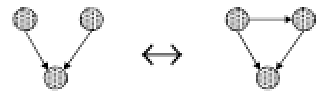
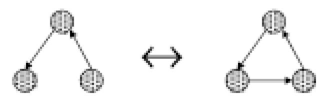
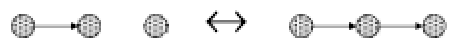
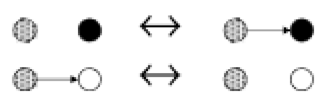
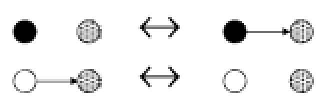
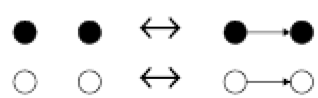
	Full Model			Control Model			Straw Man Model			Trend Model		
Network Dynamics	*Estimate*	*Standard Error*	*p-Value*	*Estimate*	*Standard Error*	*p-Value*	*Estimate*	*Standard Error*	*p-Value*	*Estimate*	*Standard Error*	*p-Value*
Rate period 1	14.16	(1.63)		14.05	(1.43)		10.14	(0.70)		6.27	(0.33)	
Rate period 2	11.57	(1.30)		11.48	(1.06)		9.06	(0.69)		5.63	(0.31)	
Outdegree (density)	−2.53	(0.22)	<0.001	−2.64	(0.17)	<0.001	−2.68	(0.06)	<0.001	−1.88	(0.03)	<0.001
Reciprocity	1.55	(0.10)	<0.001	1.63	(0.10)	<0.001	2.44	(0.08)	<0.001	—		
Preferential attachment	0.17	(0.09)	0.041	0.23	(0.08)	0.003	—			—		
Transitive ties	0.55	(0.12)	<0.001	0.57	(0.12)	<0.001	—			—		
Number of actors at distance 2	−0.35	(0.09)	<0.001	−0.37	(0.09)	<0.001	—			—		
Balance	0.13	(0.02)	<0.001	0.13	(0.02)	<0.001	—			—		
Classmate	0.01	(0.07)	0.905	−0.01	(0.07)	0.934	—			—		
Sex alter	−0.11	(0.09)	0.189	−0.14	0.08	0.069	—			—		
Sex ego	0.10	(0.10)	0.327	0.09	0.09	0.304	—			—		
Sex similarity	0.62	(0.08)	<0.001	0.64	(0.07)	<0.001	0.97	(0.08)	<0.001	—		
Birth year alter	0.10	(0.08)	0.220	0.12	(0.08)	0.144	—			—		
Birth year ego	0.27	(0.10)	0.009	0.30	(0.10)	0.002	—			—		
Birth year similarity	0.19	(0.16)	0.226	0.22	(0.18)	0.217	—			—		
Money alter	0.10	(0.05)	0.050	0.09	(0.05)	0.048	—			—		
Money ego	−0.05	(0.07)	0.474	−0.02	(0.06)	0.717	—			—		
Money similarity	0.96	(0.28)	<0.001	0.98	(0.30)	0.001	—			—		
Romantic alter	−0.04	(0.08)	0.613	−0.06	(0.08)	0.425	—			—		
Romantic ego	−0.10	(0.10)	0.337	−0.12	(0.10)	0.241	—			—		
Romantic similarity	0.13	(0.08)	0.107	0.15	(0.07)	0.033	—			—		
Alcohol alter	0.03	(0.07)	0.688	—			—			—		
Alcohol ego	0.14	(0.09)	0.136	—			—			—		
Alcohol similarity	0.73	(0.39)	0.061	—			1.05	(0.43)	0.014	—		
Smoking alter	−0.05	(0.08)	0.501	—			—			—		
Smoking ego	−0.10	(0.11)	0.394	—			—			—		
Smoking similarity	0.27	(0.16)	0.086	—			0.28	(0.13)	0.024	—		

TABLE 2
Selection of Possible Effects for Modeling Network Evolution

Effect	Network Statistic	Effective Transitions in Network[a]	Verbal Description
1. Outdegree	$\sum_j x_{ij}$		Overall tendency to have ties
2. Reciprocity	$\sum_j x_{ij} x_{ji}$		Tendency to have reciprocated ties
3. Preferential attachment	$\sum_j x_{ij} \sqrt{\sum_h x_{hj}}$		Tendency to attach to popular others (with decreasing marginal sensitivity to alter's popularity)
4. Transitive triplets	$\sum_j x_{ij} \sum_h x_{ih} x_{hj}$		Tendency toward triadic closure of the neighborhood (linear effect of the number of indirect ties)
5. Transitive ties	$\sum_j x_{ij} \max_h (x_{ih} x_{hj})$	 (*number* of intermediaries is irrelevant)	Tendency toward triadic closure of the neighborhood (binary effect of indirect ties)
6. Actors at distance 2	$\sum_j (1 - x_{ij}) \max_h (x_{ih} x_{hj})$	 (*number* of intermediaries is irrelevant)	Tendency to keep others at social distance 2 (negative measure of triadic closure)

(Continued)

TABLE 2
(Continued)

Effect	Network Statistic	Effective Transitions in Network[a]	Verbal Description
7. Balance	$\sum_j x_{ij}\mathrm{strsim}_{ij}$		Tendency to have ties to structurally similar others (structural balance)
8. 3-cycles	$\sum_j x_{ij} \sum_h x_{jh} x_{hi}$		Tendency to form relationship cycles (negative measure of hierarchy)
9. Betweenness	$\sum_j x_{ij} \sum_h x_{hi}(1 - x_{hj})$	 (*no direct link* from left to right actor)	Tendency to occupy an intermediary position between unrelated others (broker position)
10. Covariate alter	$\sum_j x_{ij}(z_j - \bar{z})$		Main effect of alter's behavior (covariate determines popularity in network)
11. Covariate ego	$\sum_j x_{ij}(z_i - \bar{z})$		Main effect of ego's behavior on tie preference (covariate determines activity in network)
12. Covariate similarity	$\sum_j x_{ij}\mathrm{sim}_{ij}$		Tendency to have ties to similar others (homophile selection on covariate, linear in score differences)

[a]In the *effective transitions* illustrations, it is assumed that the covariate is dichotomous and centered at zero; the coding is ○ = low score (negative), ● = high score (positive), ◍ = arbitrary score. The tie x_{ij} from actor **i** to actor **j** is the one that changes in the transition indicated by the double arrow. Illustrations are not exhaustive.

TABLE 6
Estimates and Standard Errors for the Evolution of Substance Use

	Full Model			Control Model			Straw Man Model			Trend Model		
Alcohol Dynamics	*Estimate*	*Standard Error*	*p-Value*	*Estimate*	*Standard Error*	*p-Value*	*Estimate*	*Standard Error*	*p-Value*	*Estimate*	*Standard Error*	*p-Value*
Rate period 1	1.70	(0.40)		1.39	(0.26)		1.70	(0.35)		1.32	(0.22)	
Rate period 2	2.64	(0.53)		2.52	(0.45)		2.69	(0.53)		2.40	(0.44)	
Shape: linear	0.41	(0.14)	0.004	0.37	(0.11)	0.001	0.45	(0.14)	0.001	0.42	(0.11)	<0.001
Shape: quadratic	0.01	(0.11)	0.926	−0.33	(0.08)	<0.001	0.07	(0.11)	0.511	−0.28	(0.07)	<0.001
Average similarity	6.70	(2.18)	0.002	—			7.32	(2.26)	0.001	—		
Smoking	0.05	(0.20)	0.821	0.17	(0.16)	0.285	—			—		
Sex	0.06	(0.23)	0.801	0.13	(0.19)	0.498	−0.07	(0.20)	0.731	—		
Birth year	0.29	(0.30)	0.342	0.15	(0.24)	0.539	—			—		
Money	0.23	(0.15)	0.134	0.24	(0.12)	0.049	—			—		
Romantic	−0.45	(0.32)	0.151	−0.25	(0.26)	0.344	—			—		

	Full Model			Control Model			Straw Man Model			Trend Model		
Smoking Dynamics	*Estimate*	*Standard Error*	*p-Value*	*Estimate*	*Standard Error*	*p-Value*	*Estimate*	*Standard Error*	*p-Value*	*Estimate*	*Standard Error*	*p-Value*
Rate period 1	5.09	(2.90)		4.53	(2.66)		5.11	(1.74)		3.82	(0.99)	
Rate period 2	4.26	(1.31)		4.59	(1.81)		4.00	(1.25)		4.08	(1.26)	
Shape: linear	−2.61	(0.42)	<0.001	−3.41	(0.45)	<0.001	−2.57	(0.42)	<0.001	−3.42	(0.37)	<0.001
Shape: quadratic	2.62	(0.31)	<0.001	2.71	(0.33)	<0.001	2.67	(0.29)	<0.001	2.80	(0.32)	<0.001
Average similarity	2.63	(1.06)	0.014	—			2.82	(1.06)	0.008	—		
Alcohol	−0.03	(0.18)	0.868	0.05	(0.16)	0.750	—			—		
Sex	−0.01	(0.28)	0.981	0.24	(0.20)	0.227	−0.03	(0.25)	0.897	—		
Birth year	0.02	(0.29)	0.954	−0.11	(0.23)	0.653	—			—		
Parent smoking	−0.25	(0.26)	0.345	−0.17	(0.21)	0.420	—			—		
Sibling smoking	0.24	(0.37)	0.515	0.15	(0.32)	0.637	—			—		
Money	0.08	(0.17)	0.649	0.11	(0.15)	0.455	—			—		
Romantic	0.23	(0.27)	0.389	0.25	(0.23)	0.274	—			—		

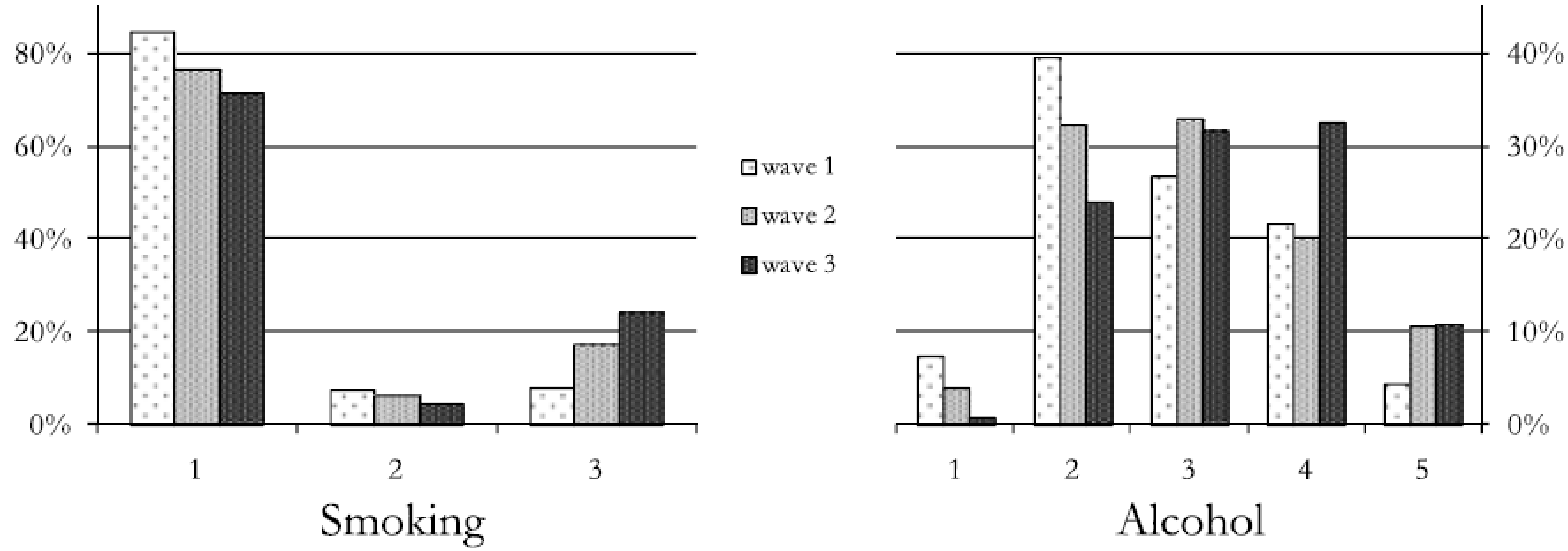
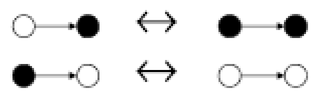
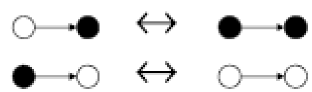
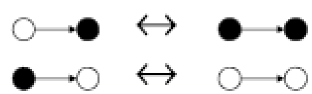
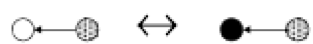
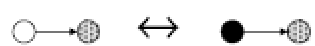
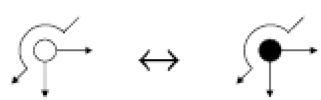


FIGURE 2. Observed distribution of substance use in the three waves.

Smoking: 1 (nonsmokers) to 3 (regular smokers-more than one cigarette per week)
Alcohol consumption: 1 (not at all) to 5 (more than once a week)

TABLE 3

Selection of Possible Network Effects for Modeling Behavioral Evolution

Effect	Network Statistic	Effective Transitions in Behavior[a]	Verbal Description
1. Shape: linear and quadratic	$(z_i - \bar{z})$ and $(z_i - \bar{z})^2$		*The two parameters together define a parabola shape of the objective function, allowing it to capture the basic shape of the observed distribution of the behavioral variable.*
2. Average similarity	$(\sum_j x_{ij}\mathrm{sim}_{ij})/(\sum_j x_{ij})$		Assimilation to neighbors' average behavior (small neighborhoods pull as much as big ones)
3. Sum of similarity	$\sum_j x_{ij}\mathrm{sim}_{ij}$		Assimilation to neighbors' average behavior (size of neighborhood determines size of effect)
4. Average alters	$(\sum_j x_{ij}(z_j - \bar{z}))/(\sum_j x_{ij})$		Main effect of neighbors' average behavior (contagion/influence, but not necessarily assimilation)
5. Indegree × behavior	$(z_i - \bar{z})\sum_j x_{ji}$		Effect of own popularity in the network on behavior
6. Outdegree × behavior	$(z_i - \bar{z})\sum_j x_{ij}$		Effect of own activity in the network on behavior
7. Isolation × behavior	$(z_i - \bar{z})(1 - \max_j(x_{ij}))$		Effect of being isolated in the network on behavior

[a]In the *effective transitions* illustrations, it is assumed that the behavioral dependent variable is dichotomous and centered at zero; the color coding is ○ = low score (negative), ● = high score (positive), ◍ = arbitrary score. Actor **i** is the actor who changes color $\mathbf{z}_i$ in the transition indicated by the double arrows. Illustrations are not exhaustive.

Conclusions

- A confirmation of social influence theories: for both substances, the parameters (Average Similarity) for homophilous selection and for assimilation are significant;
- The addictive nature of smoking may override social influence: the quadratic shape parameter for smoking remains significant and is positive in the full model;
- Similarity resulting from context effects rather than occurring independently from those: marginal significant Alcohol and Smoking Similarities.

A Quantitative Assessment of the Determinants of Network Autocorrelation

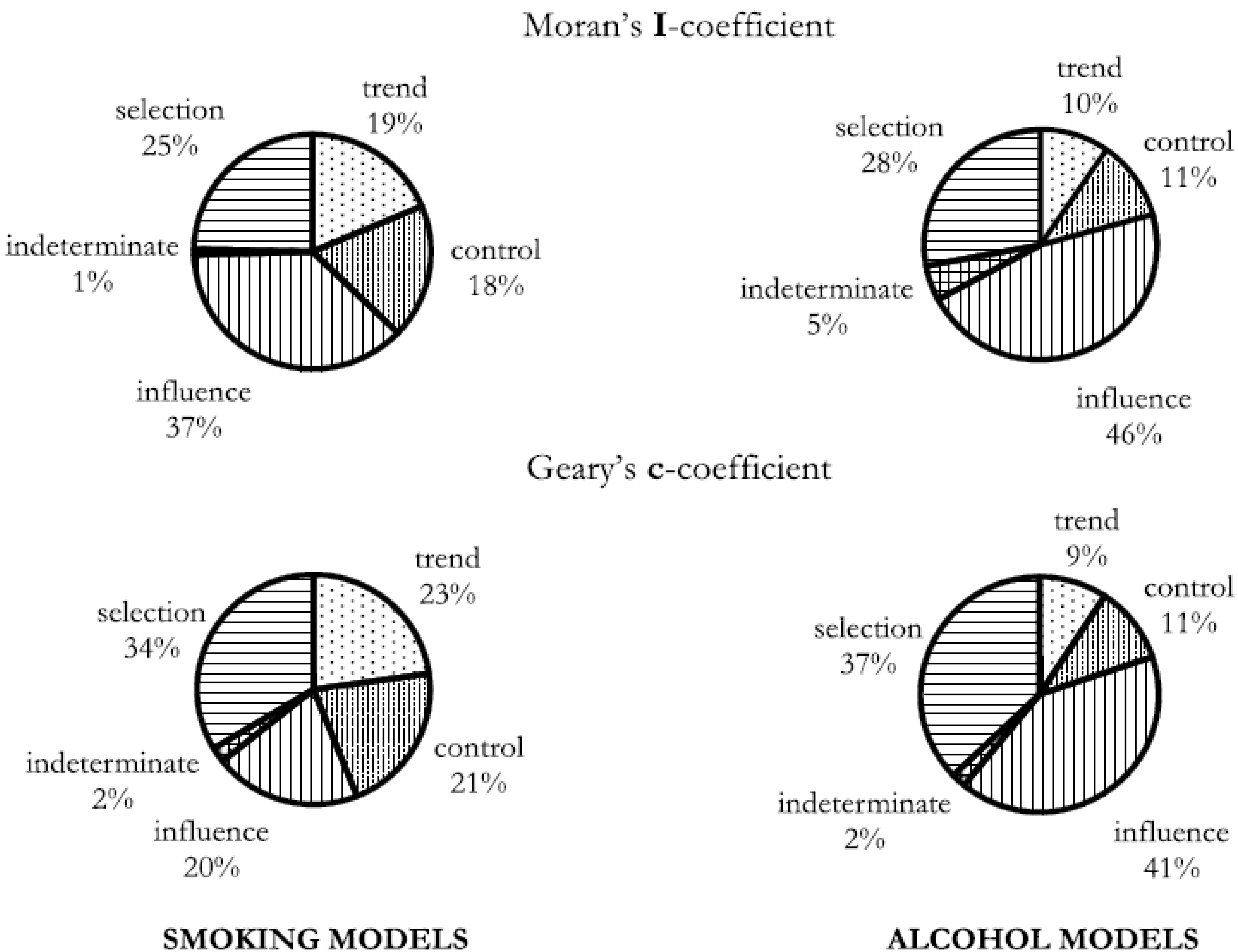


FIGURE 6. Model-based decomposition of network autocorrelation. Slice sizes correspond to percentages of the coefficient size difference between average predictions of null and full models that through simulations could be allocated to different coevolution mechanisms.

TABLE 7
Model-Based Simulated Network Autocorrelation

	Smoking					Alcohol			
Model	Moran		Geary		Model	Moran		Geary	
Null	−0.007		1.000		Null	−0.007		1.000	
Trend	0.046	(0.049)	0.908	(0.067)	Trend	0.024	(0.055)	0.968	(0.071)
Control	0.097	(0.064)	0.823	(0.084)	Control	0.057	(0.066)	0.930	(0.082)
No influence	0.166	(0.064)	0.680	(0.082)	No influence	0.143	(0.067)	0.799	(0.077)
No selection	0.201	(0.075)	0.733	(0.082)	No selection	0.200	(0.079)	0.785	(0.083)
Full	0.272	(0.076)	0.598	(0.083)	Full	0.301	(0.082)	0.648	(0.077)
Observed	0.310		0.542		Observed	0.247		0.696	

While there is significant evidence for assimilation to friends on both substance use dimensions, this influence effect seems to occur more strongly in the behaviorally extreme groups, because Moran's coefficient (which is more sensitive to the contribution of these groups) identifies an overall stronger role of influence. For smoking, these extreme groups are the majority of students (U-shape of the distribution), which explains why the discrepancy of decomposition results between autocorrelation coefficients is particularly strong. For alcohol use, the extreme groups constitute a minority (inverse U-shape), hence the discrepancy of results is smaller.

Dynamics of adolescent friendship networks and smoking behavior

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Purpose of this study

1. Study the mutual effects of smoking behavior and friendships on adolescence.
   - Similarity in smoking behavior among friends could be caused by selection of similar others as friends as well as by influence processes where friends adjust their smoking behavior to each other, or by a combination of these.
2. Disentangle influence and selection processes in reciprocal and non-reciprocal friendships
   - Study the impact of friendship reciprocity on selection and influence processes.

- Actor-based model:
  - Considers alternative selection and influence mechanism
  - Models continuous-time changes

Shortcomings of previous studies

- Most previous studies did not control adequately for alternative explanatory influence and/or selection mechanisms
- Researchers did not consider the continuous changes of network structure and smoking behavior over time: incomplete data collection
- *Independence* assumptions that underlie the employed statistical methods are violated.

Actor based model

- Assumption
  - At two or more observation moments, a directed (dichotomous) network and one or more behavioral variables (dichotomous or discrete) are observed for a finite set of social actors.
  - Actors are fully informed about the state of the network, covariates and smoking behavior of all other actors in the network.
  - Actors are only allowed to change their own outgoing ties and their own smoking behavior, but not to change others’

Actor based model

- Assumption
  - Each adolescent is assumed to make decisions to change friendship ties or smoking behavior depends on the current configuration of network and behavior
    - Two probabilistic objective functions, one for network change and one for behavior change.
    - Current configuration of network and behavior represent both preferences and constraints of decision making.
  - Actors consider and execute network and behavioral changes independently.
  - Actors may change only one friendship tie or one level of smoking behavior at any moment in time.

Actor based model

- Two models are created, one for friendship network change (modeling selection processes) and one for smoking behavior change (modeling influence processes).
- The network evolution and behavior evolution models are integrated as one internally dependent process

Research Questions

1. Do adolescents select friends based on similar smoking behavior?
2. Are adolescents influenced by friends to adjust to their smoking behavior?
3. Does the strength of these selection and influence processes differ for non-reciprocated and reciprocated friendships?
4. What is the relative contribution of selection and influence processes over time?

Methods

- Participants:
  - 11 schools with in total 1326 adolescents
- Procedure
  - Self-administered questionnaires were distributed in schools among seventh graders
    - Also distributed 12, 24, and 30 months later

Methods

- Questionnaire
  - Friendship: name up to five best friends inside school.
  - Smoking behavior: How many cigarettes do you smoke during a week?
    (0:0 ~ 4: more than 30).
  - Parental smoking behavior: 0: neither smokes, 1: at least one smoke
  - Sibling smoking behavior
  - Alcohol consumption per week: 1:1 ~ 3: more than 5 glasses
  - Age, gender, self-reported school achievement (1: lower third ~ 3: highest third)

Considered Effects

Table 1
Mathematical formula and descriptions of the included effects, as components of objective functions, for modeling selection and influence processes simultaneously.

	SIENA formula	Description
Network decision: selection processes		
Smoking behavior adolescent	$\sum_j x_{ij}z_i$	Main effect of own smoking behavior on own number of friends
Smoking behavior potential friend	$\sum_j x_{ij}z_j$	Main effect of potential friend's smoking behavior on selection
Smoking behavior adolescent × potential friend	$\sum_j x_{ij}z_iz_j$	Tendency to select based on similar smoking behavior
Smoking behavior squared potential friend	$\sum_j x_{ij}z_j^2$	Effect of potential friend's squared smoking behavior on selection
Outgoing friendship ties	$\sum_j x_{ij}$	General tendency to choose friends
Reciprocal outgoing friendship ties	$\sum_j x_{ij}x_{ji}$	Tendency to reciprocate friendships
Transitivity	$\sum_{j,h} x_{ij}x_{jh}x_{ih}$	Tendency to being a friend of a friend's friend
Alcohol consumption adolescent	$\sum_j x_{ij}v_{1i}$	Main effect of own alcohol consumption on own number of friends
Alcohol consumption potential friend	$\sum_j x_{ij}v_{1j}$	Main effect of potential friend's alcohol consumption on selection
Alcohol consumption adolescent × potential friend	$\sum_j x_{ij}v_{1i}v_{1j}$	Tendency to choose a friend based on similar alcohol consumption
Alcohol consumption squared potential friend	$\sum_j x_{ij}v_{1j}^2$	Effect of potential friend's squared alcohol consumption on selection
Age adolescent	$\sum_j x_{ij}v_{2i}$	Main effect of own age on own number of friends
Age potential friend	$\sum_j x_{ij}v_{2j}$	Main effect of potential friend's age on selection of friends
Age adolescent × potential friend	$\sum_j x_{ij}v_{2i}v_{2j}$	Tendency to choose a friend based on similar age
Gender adolescent	$\sum_j x_{ij}v_{3i}$	Main effect of own gender on own number of friends
Gender potential friend	$\sum_j x_{ij}v_{3j}$	Main effect of potential friend's gender on selection
Gender adolescent × potential friend	$\sum_j x_{ij}v_{3i}v_{3j}$	Tendency to choose a friend based on similar gender
School achievement adolescent	$\sum_j x_{ij}v_{4i}$	Main effect of own school achievement on own number of friends
School achievement potential friend	$\sum_j x_{ij}v_{4j}$	Main effect of potential friend's school achievement on selection
School achievement adolescent × potential friend	$\sum_j x_{ij}v_{4i}v_{4j}$	Tendency to choose a friend based on similar school achievement
Smoking behavior similarity × reciprocity[a]	$\sum_j x_{ij}x_{ji}z_iz_j$	Interaction between reciprocity of friendship and tendency to choose a

Behavior decision: influence processes		
Average smoking behavior friends	$\left(\sum_j x_{ij}z_j\right) / \left(\sum_j x_{ij}\right)$	Main effect of friend's smoking behavior on his own smoking behavior
Tendency to smoke	z_i	Linear component in basic preference function for smoking
Tendency to smoke: squared component	z_i^2	Squared component in basic preference function for smoking, representing feedback effect of own smoking behavior
Smoking behavior parents	$z_i v_{5i}$	Main effect of parental smoking behavior on his own smoking behavior
Smoking behavior siblings	$z_i v_{6i}$	Main effect of siblings' smoking behavior on own smoking behavior
Alcohol consumption adolescent	$z_i v_{1i}$	Main effect of own alcohol consumption on own smoking behavior
Age adolescent	$z_i v_{2i}$	Main effect of own age on own smoking behavior
Gender adolescent	$z_i v_{3i}$	Main effect of own gender on his own smoking behavior
School achievement adolescent	$z_i v_{4i}$	Main effect of own school achievement on his own smoking behavior
Number of outgoing friendships[a]	$z_i \sum_j x_{ij}$	Main effect of own number of nominated friends on own smoking behavior
Number of incoming friendship nominations[a]	$z_i \sum_j x_{ji}$	Main effect of number nomination by others on own smoking behavior
Smoking behavior of friends × reciprocity[a]	$\left(\sum_j x_{ij}x_{ji}z_j\right) / \left(\sum_j x_{ij}x_{ji}\right)$	Effect expressing influence from reciprocal friends on smoking behavior, additional to influence from all friends.

[a] Denotes effects tested by means of a score test. Formulae: i = adolescent; j, h = peers; x_{ij} indicates presence of a friendship from i to j; x_{ji}, indicates presence of a friendship tie from j to i. Description: "own" refers to the adolescent him/herself; "selection" refers to selection as a friend. All variables are grand mean centred; z_i = smoking behavior of i, v_{2i} = alcohol consumption, v_{3i} = age, etc.

Results

Table 2
Descriptive statistics of school network structure and individual characteristics.

	Wave 1	Wave 2	Wave3	Wave 4
Average number of outgoing ties	1.67	2.02	1.75	1.77
Average smoking behavior adolescent	0.46	0.90	1.36	1.38
Average observed network autocorrelation (Moran's I)	0.42	0.42	0.41	0.39
	Period 1	Period 2	Period 3	
Average number of adolescents joining a school network	8	9	2	
Average number of adolescents leaving a school network	8	10	20	
				Mean
Number of adolescents in school				121
Alcohol consumption adolescent				0.3
Percentage at least one smoking parent				49.9
Percentage at least one smoking sibling				23.0
Age (in years) at baseline				13.4
Percentage females				47.0
School achievement				2.0

Smoking behavior is coded: 0 – 0 cigarettes each week; 1 – between 0 and 1; 2 – 2–10; 3 – 11–30; 4 – >30; alcohol consumption is coded: 0 – 0 glasses alcohol each week; 1 – 1–2; 2 – 3–5; 3 – >5; school achievement is coded: 1 – among the lower third of the class; 2 – middle third; 3 – best third.

Table 3
Results meta analysis Finland.

	Snijders–Baerveldt method		Fisher's combination test			
			Left one-sided		Right one-sided	
	b	S.E.	Chi-square	*p*-Value	Chi-square	*p*-Value
Network decision: selection processes						
Smoking behavior adolescent	−0.035	0.029	30.8	0.10	13.2	0.93
Smoking behavior potential friend	−0.106	0.197	18.6	0.67	16.0	0.82
Smoking behavior adolescent × potential friend	**0.093*****	**0.016**	**3.7**	**1.00**	**70.8**	**<0.001**
Smoking behavior adolescent × potential friend × reciprocity	**−0.126****	**0.040**	**40.3**	**0.002**	**5.4**	**1.00**
Smoking behavior squared potential friend	0.049	0.102	16.6	0.79	18.2	0.70
Outgoing friendship ties	**−3.356*****	**0.224**	**276.2**	**<0.001**	**0.6**	**1.00**
Reciprocal outgoing friendship ties	**1.763*****,[a]	**0.088**	**0.9**	**1.00**	**3031.9**	**<0.001**
Transitivity	**1.175*****	**0.052**	0.1	**1.00**	**3104.0**	**<0.001**
Alcohol consumption adolescent	−0.023	0.047	24.1	0.34	14.5	0.88
Alcohol consumption potential friend	**0.189***	**0.081**	**10.5**	**0.98**	**40.0**	**0.01**
Alcohol consumption adolescent × potential friend	**0.092***	**0.048**	9.4	0.99	34.6	0.04
Alcohol consumption squared potential friend	**−0.100***	**0.040**	**38.3**	**0.02**	**9.4**	**0.99**
Age adolescent	−0.148	0.080	30.5	0.11	10.8	0.98
Age potential friend	−0.037	0.052	30.4	0.11	12.7	0.94
Age adolescent × potential friend	0.063	0.133	14.0	0.83	19.5	0.49
Gender adolescent	0.019	0.130	21.2	0.51	26.9	0.22
Gender potential friend	−0.117	0.088	31.1	0.09	13.0	0.94
Gender adolescent × potential friend	**3.188*****,[a]	**0.231**	0.0	1.00	**382.9**	**<0.001**
School achievement adolescent	0.018	0.033	14.8	0.87	22.5	0.43
School achievement potential friend	−0.034	0.031	31.4	0.09	19.0	0.64
School achievement adolescent × potential friend	0.023	0.036	17.0	0.77	23.4	0.38
Behavior decision: influence processes						
Average smoking behavior friend	**0.221****	**0.069**	**7.6**	**1.00**	**42.7**	**0.005**
Tendency to smoke	**−0.922*****,[a]	**0.081**	**8477.3**	**<0.001**	**0.0**	**1.00**
Tendency to smoke: squared component	**0.484*****	**0.022**	**0.1**	**1.00**	**3112.4**	**<0.001**
Smoking behavior parents	**0.232*****	**0.047**	**2.2**	**1.00**	**67.2**	**<0.001**
Smoking behavior siblings	0.125*	**0.054**	11.4	0.97	34.4	0.04
Alcohol consumption adolescent	0.009	0.053	24.0	0.35	22.0	0.46
Age adolescent	0.029	0.064	21.9	0.47	21.8	0.47
Gender adolescent	0.056	0.049	15.9	0.82	28.4	0.16
School achievement adolescent	−0.023	0.041	28.6	0.16	19.9	0.59

b – unstandardized coefficients according to the Snijders–Baerveldt method (2003); S.E. – standard error; bold values represent significant results. All chi-squared values have 22 df except for alcohol consumption adolescent × potential friend (df – 18) and age adolescent × potential friend (df – 20).

[a] Significant differences found between schools according to the Snijders–Baerveldt method (2003).
* Two-sided $p < 0.05$.
** Two-sided $p < 0.01$.
*** Two-sided $p < 0.001$.

Table 4
The attractiveness of smoking behavior.

	Adolescent		Friend				
			0	1	2	3	4
Selection	0	(0 cigarette)	**0.288**	0.038	−0.114	−0.169	−0.125
	1	(0-1)	**0.159**	0.002	−0.058	−0.019	0.118
	2	(2-10)	0.030	−0.034	−0.001	0.131	**0.361**
	3	(11-30)	−0.099	−0.070	0.056	0.281	**0.604**
	4	(more than 30)	−0.228	−0.107	0.113	0.431	**0.847**
Influence	0		**1.654**	1.430	1.207	0.983	0.760
	1		0.013	0.011	0.008	0.006	0.003
	2		−0.659	−0.441	−0.222	−0.004	0.214
	3		−0.364	0.075	0.515	0.954	1.394
	4		0.899	**1.560**	**2.220**	**2.881**	**3.541**

Contributions of smoking behavior of adolescent and potential friend to the objective function for friendship (top panel) and for smoking (bottom panel). Smoking behavior is coded: 0 = 0 cigarettes each week; 1 = between 0 and 1; 2 = 2–10; 3 = 11–30; 4 = >30. Bold values represent the most attractive potential friend for adolescents in each smoking behavior category (top panel), and the most attractive smoking behavior for adolescents with friends in each smoking behavior category (bottom panel).

Table 3
Results meta analysis Finland.

	Snijders–Baerveldt method		Fisher's combination test			
			Left one-sided		Right one-sided	
	b	S.E.	Chi-square	*p*-Value	Chi-square	*p*-Value
Network decision: selection processes						
Smoking behavior adolescent	−0.035	0.029	30.8	0.10	13.2	0.93
Smoking behavior potential friend	−0.106	0.197	18.6	0.67	16.0	0.82
Smoking behavior adolescent × potential friend	**0.093*****	**0.016**	**3.7**	**1.00**	**70.8**	**<0.001**
Smoking behavior adolescent × potential friend × reciprocity	**−0.126****	**0.040**	**40.3**	**0.002**	**5.4**	**1.00**
Smoking behavior squared potential friend	0.049	0.102	16.6	0.79	18.2	0.70
Outgoing friendship ties	**−3.356*****	**0.224**	**276.2**	**<0.001**	**0.6**	**1.00**
Reciprocal outgoing friendship ties	**1.763***,a**	**0.088**	**0.9**	**1.00**	**3031.9**	**<0.001**
Transitivity	**1.175*****	**0.052**	0.1	**1.00**	**3104.0**	**<0.001**
Alcohol consumption adolescent	−0.023	0.047	24.1	0.34	14.5	0.88
Alcohol consumption potential friend	**0.189***	**0.081**	**10.5**	**0.98**	**40.0**	**0.01**
Alcohol consumption adolescent × potential friend	**0.092***	**0.048**	9.4	0.99	34.6	0.04
Alcohol consumption squared potential friend	**−0.100***	**0.040**	**38.3**	**0.02**	**9.4**	**0.99**
Age adolescent	−0.148	0.080	30.5	0.11	10.8	0.98
Age potential friend	−0.037	0.052	30.4	0.11	12.7	0.94
Age adolescent × potential friend	0.063	0.133	14.0	0.83	19.5	0.49
Gender adolescent	0.019	0.130	21.2	0.51	26.9	0.22
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Measuring the relative contribution of different effects

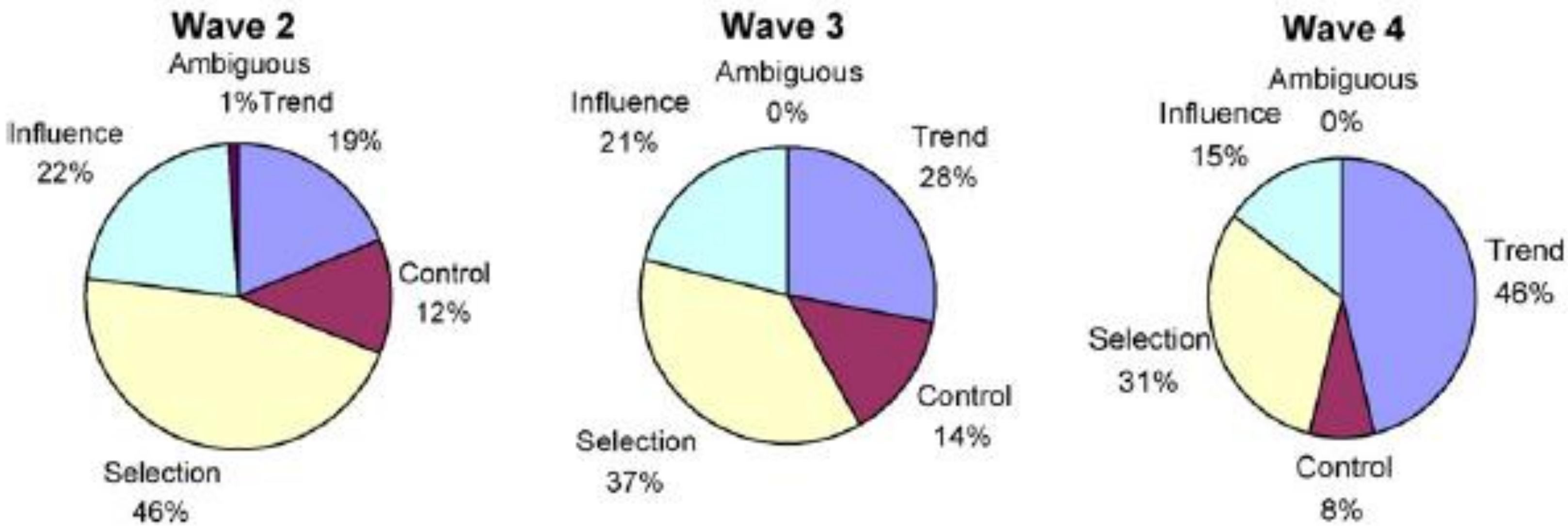


Fig. 2. The relative contribution of selection and influence processes to smoking behavior similarities.

Findings

- Selection and influence processes both played an important role in creating and maintaining smoking behavior similarity within friendships.
- The strength of influence processes did not differ between non-reciprocated and reciprocated friendships.
- Similarity of smoking behavior played a role in friendship selection mainly for the selection of non-reciprocated friends.
- Selection effect had a relatively stronger role than influence effect.

The co-evolution of gossip and friendship in workplace social networks

Lea Ellwardt
Christian Steglich
Rafael Wittek

Friendship vs. Gossip social relations

- Elementary building blocks of informal relations in organizations
  - “the real work in most companies is done informally, through personal contacts”
- Friendship
  - Directly served as a way to assess each other’s trustworthiness.
- Gossip:
  - “informal and evaluative talk in an organization about another member of that organization who is not present”
  - Indirectly determine somebody’s reputation for being a trustworthy partner
- How exactly they influence each other is less clear

Why is this study important?

- Gaining insight into how gossip and friendship ties mutually affect each other contributes to the growing literature on the link between informal networks and cooperation in organizations.
  – Strong informal relations in organizations have long been identified as important conditions that may either reinforce or hamper organizational processes

Social Capital perspective

- Affective friendship relations stimulate the flow of gossip between employees of an organization.
  - “Gossip flourishes in close-knit, highly connected social networks
  - Sender must first trust the receiver in order to share the gossip

Social Capital perspective

- In creating friendship, one's friendship nomination may not immediately lead to reciprocation with a friendship choice by alter.
  - Alter may first need to assess if the ego is trustworthy
  - Alter may first reciprocate with gossip: will the gossip receiver feel the same way as I think, and will the gossip receiver treat the sensitive information confidentially?
- **H1a: If ego nominates alter as a friend, alter will reciprocate this with gossip behavior over time.**

Social Capital perspective

- Employees who receive many friendship nominations (popular employees) → How to reciprocate?
  - One has limited time and ability to reciprocate and maintain all these relations
  - Reciprocating with gossip – a less committed and more sporadic activity – can be a means of nurturing interpersonal relationships.
- **H1b: The higher the number of friendship choices received by ego, the more likely ego's gossip activity will increase over time.**

Evolutionary Perspective

- This perspective suggests that friendship is a product, not a precondition, of gossip.
- Gossip has evolved as a **mechanism** for bonding large social groups
  - It helps an examination into the trustworthiness of one's existing contacts as well as potential new ones.
- It works as a **signal** of trust and interest in a durable relationship

Evolutionary Perspective

- Gossiping signals that the senders is closer to the receiver than to the object of gossip
  - Individuals are likely to interpret a sender's repeated gossip behavior as a signal of intimacy and a shared mindset
- Before entering a friendship, it is saver to first share a gossip to see if the receiver respond positively or negatively
- **H2a: If ego gossips to alter, alter will reciprocate with friendship over time.**

Evolutionary Perspective

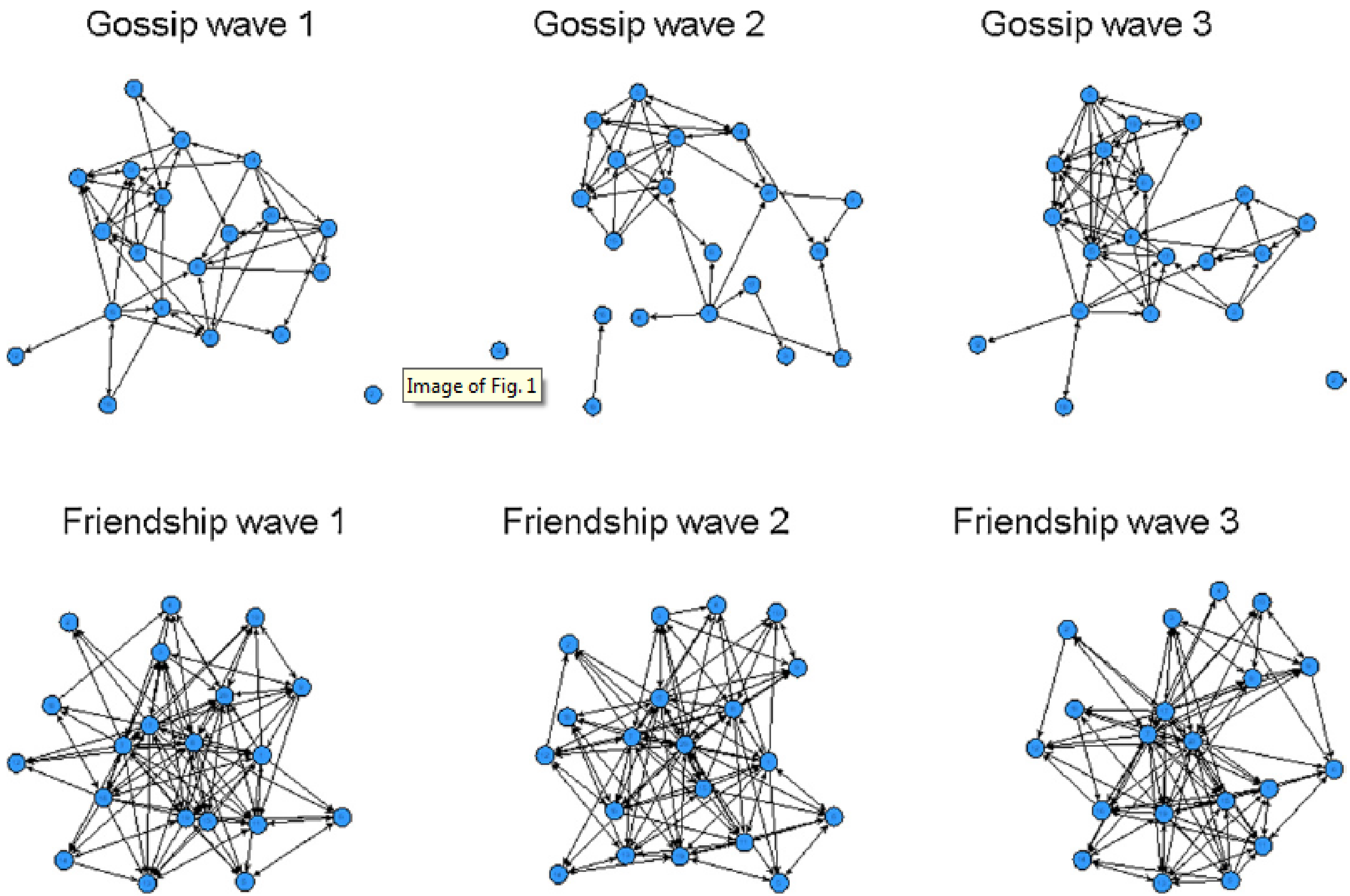
- Employees who frequently share gossip possess high information status in the groups
  - Which makes them attractive as friends, allowing other to treat the gossipers as an efficient instrument to access to exclusive information.
  - Alters also interpret generous sharing of gossip relevant to other members as a signal of commitment to the group.
- **H2b: High gossip activity by ego causes an increase in ego’s popularity in the friendship network over time**

Research Design and Setting

- Data
  - Source: medium-sized Dutch non-profit organization.
  - Data is collected at three time points: Spring 2008, Autumn 2008, and Spring 2009.
  - Around 45 employees, which was split into seven teams of two to eight employees. (employees may join or leave across the three waves).
  - Average age: 36.11; average years of working in the organization: 7.62.

Research Design and Setting

- Measures
  - For each wave, gossip and friendship relations are assessed
    - The two types of social relation are served as co-dependent variables in the analysis.
  - Gossip relations:
    - Asked from whom respondents had received gossip during the last three months (0: absent relation, 1: present relation)
  - Friendship relations:
    - Asked about their relationship with every other employee (1: very difficult ~ 5: good friend)
    - Dichotomization: 0~3→0, and 4, 5→1



Note. Network pictures were created with the visualization program Visone 2.5.1. Only actors are represented who had worked in the organization site at all three time points of data collection.

Fig. 1. Gossip and friendship networks at three measurement waves.

Research Design and Setting

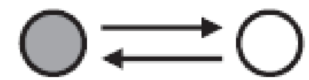
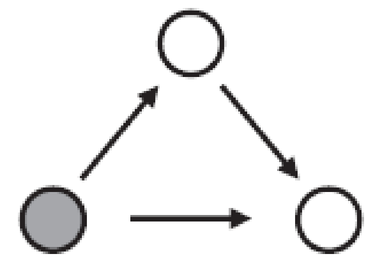
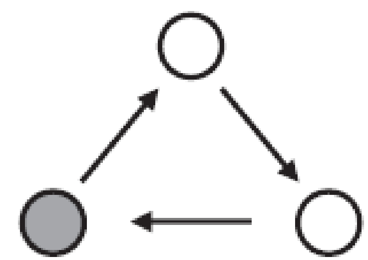
- Measures
  - Control variables:
    - **Formal team membership** (constant dyadic covariate) (1: same team, 0: different teams)
    - **Contact frequency** (changing dyadic covariate) *How often respondents had formal or informal communication with each colleague during the previous three months.* (1: never ~ 6: eight or more times a week)

RSIENA

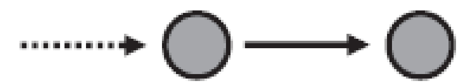
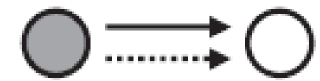
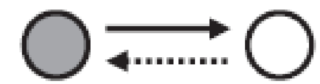
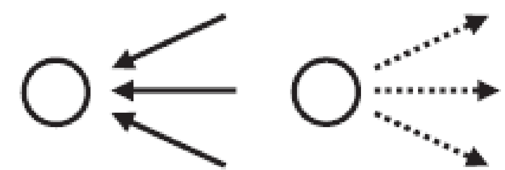
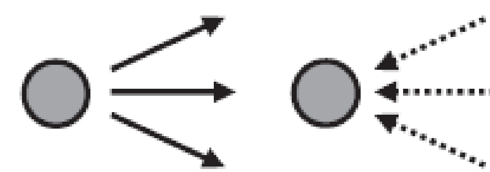
- In this paper the authors used a variant of the SIENA model that allows the study of multiplex networks – co-dependent friendship and gossip networks.
- Two models
  - Model 1: Control variables only, including network configurations, contact frequency, and team membership
  - Model 2: Including the two networks

Model 1 Effects

Table 2
Effects in multiple SIENA.

Effect	Explanation	Graphical Presentation
Endogenous network effects		
Out-degree	Ego's tendency to create ties in a certain network	
Reciprocity	Preference for mutual ties between ego and alter in a certain network	
Transitivity	Ego's preference for creating ties with ego's friends' friends; measure for network closure	
3-Cycles	Negative values denote preference for hierarchical ties in the networks. Positive values indicate generalized reciprocity.	

Model 2: Effects Added

Exogenous network effects (multiplex)		
Dyadic covariate	Ego's tendency to create ties in network A depending on ego's ties in network B	
Out-degree multiplex	Ego's tendency to create ties in network A together with ties in network B	
Reciprocity multiplex	Creating ties in network A by ego (out-degree) is reciprocated with nominations in network B by alter (in-degree)	
Popularity × activity multiplex	Ego's general number of received nominations in network A (in-degree) affects ego's general number of created ties in network B (out-degree)	
Activity × popularity multiplex	Ego's general number of created ties in network A (out-degree) affects ego's general number of received nominations in network B (in-degree)	

Note. Ego is represented with a dark circle, alter is represented with a bright circle. Parts of this table were taken from Sijtsema et al. (2010). Statistical representations for each effect can be found in Ripley et al. (2012: 70).

RSIENA

- Estimation method: method of moments
- First observation is used as a starting point for estimating the network evolution process
- Number of 3^{rd} phase iterations: 8000

Results

- Descriptive statistics

Table 3
Ties, density, means (M) and standard deviations (SD) of the networks.

Variable	Wave 1 (*N* = 29)				Wave 2 (*N* = 32)				Wave 3 (*N* = 33)			
	Ties	Density	*M*	*SD*	Ties	Density	*M*	*SD*	Ties	Density	*M*	*SD*
Gossip[a]	137	0.14	4.72	3.55	115	0.10	3.56	3.26	217	0.18	6.76	4.92
Friendship[a]	300	0.31	10.34	9.62	348	0.30	11.57	8.83	348	0.29	10.91	9.51
Contact frequency[a,b]	n/a	n/a	3.16	0.64	n/a	n/a	2.93	0.60	–	–	–	–
Team membership	146	0.26	4.29	1.85	–	–	–	–	–	–	–	–

[a] Statistics calculated based on out-degree. Density was calculated by dividing the number of ties by the number of possible ties. Possible ties are the product of the number of invited people minus missing and the number of invited people minus one.
[b] Because contact frequency was measured with an ordinal scale, number of ties and density is not provided for this network. Means of the ordinal scale were first calculated per actor and then used to calculate mean and standard deviation for the whole network.

Table 4
Dyad counts and percentages across periods.

	End of period: ego's nominations of alter				
	No tie	Gossip tie only	Friendship tie only	Gossip and friendship tie	Total %
Beginning of period: ego's nominations of alter					
No tie	694	37	103	19	853
	81.36	4.34	12.08	2.23	100.00
Gossip tie only	23	9	5	15	52
	44.23	17.31	9.62	28.85	100.00
Friendship tie only	97	19	175	48	339
	28.61	5.60	51.62	14.16	100.00
Gossip and friendship tie	17	6	28	62	113
	15.04	5.31	24.78	54.87	100.00

	End of period: alter's nominations of ego				
	No tie	Gossip tie only	Friendship tie only	Gossip and friendship tie	Total %
Beginning of period: ego's nominations of alter					
No tie	588	44	151	35	818
	71.88	5.38	18.46	4.28	100.00
Gossip tie only	25	2	11	10	48
	52.08	4.17	22.92	20.83	100.00
Friendship tie only	136	8	117	58	319
	42.63	2.51	36.68	18.18	100.00
Gossip and friendship tie	13	8	37	47	105
	12.38	7.62	35.24	44.76	100.00

Reading example: A gossip tie by ego at the beginning of a period was associated with a friendship tie by alter at the end of a period in 11 out of 48 dyad cases (22.92%). Missing responses are not included in the dyad counts. Ego is represented with a dark circle, alter is represented with a bright circle.

Table 5
Results from R-SIENA on the co-evolution of gossip and friendship.

Parameter	Model 1			Model 2		
	Est.	*SE*	*t*-Value[a]	*Est.*	*SE*	*t*-Value[a]
Outcome: gossip network						
Out-degree (density)	−1.94	0.14	−14.27***	−2.34	0.22	−10.64***
Reciprocity	0.78	0.26	3.02**	0.47	0.30	1.58
Transitive triplets	0.50	0.07	7.63***	0.49	0.07	7.40***
3-Cycles	−0.44	0.12	−3.50***	−0.40	0.13	−3.09**
Period	0.59	0.15	4.04***	0.58	0.15	3.80***
Same team membership	0.82	0.18	4.57***	0.64	0.18	3.60***
Contact frequency	0.27	0.06	4.36***	0.17	0.07	2.52*
Friendship (ego)				1.14	0.39	2.95**
Reciprocity friendship (alter)				0.03	0.32	0.10
Friendship popularity on gossip activity				−0.29	0.19	−1.58
Outcome: friendship network						
Out-degree (density)	−1.36	0.10	−13.84***	−1.73	0.16	−10.52***
Reciprocity	1.11	0.19	5.86***	0.78	0.23	3.32***
Transitive triplets	0.15	0.01	11.42***	0.16	0.02	9.46***
3-Cycles	−0.19	0.03	−5.84***	−0.17	0.04	−4.42***
Period	−0.33	0.10	−3.38***	−0.35	0.11	−3.19**
Same team membership	0.57	0.14	3.98***	0.42	0.16	2.60**
Contact frequency	0.28	0.05	5.54***	0.22	0.06	3.65***
Gossip (ego)				0.47	0.39	1.19
Reciprocity gossip (alter)				1.64	0.50	3.30***
Gossip activity on friendship popularity				−0.25	0.11	−2.40*
Network dynamics (changes)						
Gossip rate period 1	11.01	1.79		11.64	1.93	
Gossip rate period 2	11.67	1.99		12.00	2.12	
Friendship rate period 1	15.49	2.31		16.56	3.06	
Friendship rate period 2	14.54	1.97		15.09	2.23	

[a] The *t*-values are calculated by dividing the parameter estimate by its standard error. They are not calculated for rate functions because a *t*-test would imply the null hypothesis that no change occurred. Change, however, was evidently measured in our data.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

Findings

- Gossip favors the creation of friendship relations, rather than vice versa: evolutionary arguments are supported
- Friendship and gossip relations do not co-evolve.
- Disproportionately active gossipmongers became less, rather than more attractive as friends through time