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The Coevolution of Communication Networks and Drinking Behaviors

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Abstract

This study examines the co-evolution of mobile-phone communication networks of 196 undergraduate students and their drinking behaviors over four semesters since 2011. We use stochastic actor-based models to explore the network dynamics and social influences simultaneously, net of other socio-demographic and network factors. We find that individuals with similar alcohol use were more likely to form connections and that individuals adjusted their drinking behaviors to those of their peers. Social influence processes turned out to play a more significant role than selection processes in predicting similarity in alcohol use.

Introduction

While the drinking behaviors among adolescents in the United States has declined since the late 1990s, nowadays there are still 70.8% of 9th- to 12th-grade students who have had at least one drink of alcohol (other than a few sips) on at least one day during their life and about one fifth of them began drinking by 13 years old (CDC 2011). Underage drinking is linked to many negative outcomes, such as alcohol-related car crashes and other unintentional injuries, abuse of other drugs, unwanted/unplanned/unprotected sexual activities, higher absence rates from school, and poor or failing grades (see Bonnie and O'Connell 2004; HHS 2007; Miller et al. 2007).

Although the alcohol use of adolescents has long been recognized to be influenced by the drinking behaviors of peers, adolescents also tend to select friends who are similar in alcohol use (see Ellickson and Hays 1991; Urberg, Degirmencioglu, and Pilgram 1997; Kirke 2004; Ennett et al. 2006; Ennett et al. 2008; Leung, Toumbourou, and Hemphill 2012). The emergence of stochastic actor-based (SAB) models (Snijders, van de Bunt, and Steglich 2010; Snijders, 2011) allow us to disentangle selection and influence effects for the first time in a model in which friendship formation and drinking behaviors change simultaneously. Pearson and his collaborators (2006) conducted one such study and found both selection ("bird of a feather" effects) and assimilation (influence) effects on the drinking behaviors of a cohort of 129 pupils over three waves in the West of Scotland. Similar studies were done by using longitudinal data collected in Netherlands (Knecht et al. 2010), Italy (Giletta et al. 2012), Finland (Mercken et al. 2012), and Sweden (Burk et al. 2012), and again both selection and influence processes were found to play significant roles in predicting adolescent drinking behavior similarity. The first study using this modeling strategy to examine drinking behaviors of US adolescents was published by Mundt and his colleagues. They utilized the data from the National Longitudinal Study of Adolescent Health (AddHealth), a longitudinal study of US adolescents from 7th to 12th grades between 1995 and 1996. They only found significant selection effects on alcohol use (Mundt, Mercken, and Zakletskaia 2012). That said, a separate study using data on 450 15-to-17 year-old students attending a public high school in the Northeastern United States between 2004 and 2006 showed only a significant effect of peer influence on alcohol use (Mathys, Burk, and Cillessen 2013). Moreover, another study named PROSPER followed 13,214 6th-to-9th grade adolescents from 50 classrooms in Iowa and Pennsylvania during the fall 2002 and 2003, and both significant influence and selection effects were found to explain drinking behavior similarity (Osgood et al. 2013).

Our paper contributes to this line of research by examining the importance of peer selection and peer influence processes related to alcohol use in adolescent friendship networks. We use data collected from the *NetSense* project (see Striegel et al. 2013) to explore the co-evolution of mobile-phone communication networks of 196 undergraduate students and their drinking behaviors over four semesters since 2011. We hypothesize that students tend to both select friends with similar alcohol use and adjust their alcohol consumption level based on the drinking behavior of their existing friends.

Data and Methods

Data

Our data come from the *NetSense* project. 196 first-year undergraduate students from the University of Notre Dame were randomly selected and provided with free Android-powered smartphones and phone plans for two years (including unlimited voice calls to and from other mobile phones, 200 voice-call minutes per month to and from other landlines, unlimited texting, and unlimited data from August 2011 to May 2013). These mobile phones were programmed to capture the background information on communication events (i.e., text messages, voice calls, emails, and Facebook posts) and the proximity between the devices. Information on the *content* of telephone calls, emails, text messages, Facebook posts or other forms of communication was not collected. Students who were under 18 years old were required to have their parent or guardian read, complete and sign the Parental Consent Form. All students (either under 18 or above 18) were required to read, complete and sign a Student Consent Form. The students were asked to take on-line surveys each semester to answer questions about their status, attitudes, preferences and activities. The data were securely transferred to secure computer servers. For more details of the *NetSense* project, please see Striegel et al. 2013.

Variables

The dependent (behavioral) variable measures the frequency of beer drinking over the semester (0 = not at all, 1 = less than one time a month, 2 = 1-2 times a month, 3 = 1-2 times a week, 4 = every day or almost every day). The control variables include age, gender (0 = male, 1 = female), and race (0 = non-white, 1 = white).

Method

To explore the coevolution of friendship networks and drinking behaviors in continuous Markov time, we apply the SAB model with the R-based Simulation Investigation for Empirical Network Analysis (RSiena) software package (see Ripley, Snijders, and Preciado 2013). The SAB model assumes that an ego will make decisions that optimize her or his network and behavior status in the next time step based on her or his current state of network-behavioral configuration, which is referred to as the objective function. The objective function is defined as $f_i(\beta, y) = \sum_k \beta_k s_{ik}(y)$, where β_k is the estimated parameter for the actor-specific effect $s_{ik}(y)$. Positive values of the objective function indicate the preferred direction of changes in micro-steps, while negative values suggest the avoidance of such changes. In RSiena, the objective function of network changes and behavior changes are estimated simultaneously to generate both a network and a behavioral model. Together these models constitute a set of interdependent equations with the rate functions, which indicate the expected frequency of changes in the networks or behaviors the egos make between observation points.

As shown in Table 1, in the network model predicting tie selection we included several structural network measures, such as out-degree density and reciprocity measures indicating tie preference, transitive triplets, three cycles, transitive ties and geodesic distance-2 effects related to triadic closure, and in-degree popularity (square root) parameter implying inclination of preferential attachment (see Barabási and Albert 1999).

Table 1 Effects for Modeling Network Evolution

Effect	Network statistic	Description
Rate parameter	-	The average number of network change opportunities for each ego
Outdegree (density)	$\sum_j x_{ij}$	General tendency to choose a friend
Reciprocity	$\sum_j x_{ij} x_{ji}$	Tendency to have reciprocal (mutual) friendships
Transitive triplets	$\sum_{j,h} x_{ij} x_{ih} x_{jh}$	Tendency to become the friend of a friend's friend
Three cycles	$\sum_{j,h} x_{ij} x_{jh} x_{hi}$	Tendency to form relationship cycles
Transitive ties	$\sum_j x_{ij} \max_h (x_{ih} x_{hj})$	Tendency toward triadic closure
Number of distance at 2	$\sum_j (1 - x_{ij}) \max_h (x_{ih} x_{hj})$	Tendency to keep others at geodesic distance 2
In-degree popularity	$\sum_j x_{ij} x_{+j}$	Tendency to choose a popular student as a friend
Covariate alter	$\sum_j x_{ij} (v_j - \bar{v})$	Main effect of potential friends' behavior on tie preference (popularity in network)
Covariate ego	$\sum_j x_{ij} (v_i - \bar{v})$	Main effect of ego's behavior on tie preference (activity in network)
Covariate similarity	$\sum_j x_{ij} (sim_{ij}^v - sim^v)$	Tendency to have ties to similar others (homophile selection)

The network model also includes individual covariates (v_i) such as age, gender, and race which may affect network evolution in three ways: as a main effect on alter attractiveness (covariate alter), as a main effect on network activity of ego (covariate ego), and as a similarity (homophily) effect (covariate similarity). Finally, we also constructed a measure of similarity in drinking behaviors.

The effects in the behavior model are given in Table 2. The linear and quadratic shape parameters model the shape of the long-term distribution of drinking behaviors. The average alter effect is the focal parameter capturing the additional tendencies for students to change their drinking behaviors to be reinforced by the average alcohol use of their friends. Additional covariates (v_i) were included as main effects to capture drinking behaviors changes.

Table 2 Effects for Modeling Behavioral Evolution

Effect	Behavior statistic	Description
Rate parameter	-	The average number of behavior change opportunities for each ego
Linear shape	$z_i - \bar{z}$	The basic drive toward high values of behavior
Quadratic shape	$(z_i - \bar{z})^2$	The self-reinforcing function of the behavior
Average alter	$\sum_j (z_i - \bar{z})(z_j - \bar{z})$	Main effect of alters' average behavior
Covariate	$(z_i - \bar{z})v_i$	Main effect of covariate on the behavior

Results

Descriptive Results

Of the 196 students, 46% were females, 68% were whites, and their ages ranged from 17 to 19 with the mean equal to 18.28 (sd = 0.48) during the fall semester 2011.

The behavior and network descriptive statistics are summarized in Table 3. We see that the frequency of drinking behaviors fluctuated over time. At the same time, the communication network among these 196 students appears to shrink. Most of the ties in all the time periods are reciprocal ones. Though the probability of a tie being in a triangle is low, it is much higher than what one would expect if ties were formed at random. There is also a high turnover of friends, as indicated by the Jaccard index.

Table 3 Behavior and Network Descriptive Statistics (*n* = 196)

	Fall 2011	Spring 2012	Summer 2012	Fall 2012
Drinking behavior				
Not at all (%)	44.19	41.42	48.55	36.73
< once a month (%)	12.79	11.24	17.92	13.61
1-2 times a month (%)	19.19	22.49	15.03	16.33
1-2 times a week (%)	23.26	24.26	16.18	31.97
(Almost) everyday (%)	0.58	0.59	2.31	1.36
Network statistics				
Out-going ties	790	670	269	495
Reciprocal index	0.93	0.91	0.93	0.92
Transitive index	0.08	0.07	0.10	0.10
Jaccard index	0.41	0.35	0.41	

Note: The reciprocity index is the proportion of ties that were reciprocated. The transitivity index is the proportion of 2-paths (ties between AB and BC) that were transitive (ties between AB, BC, and AC). The Jaccard index measures the network stability between consecutive waves and values of 0.3 or greater are ideal to fit the micro-step assumption of network changes in SAB modeling (see Snijders, van de Bunt, and Steglich 2010).

Mobile Phone Network Evolution: Selection Processes

As shown in Table 4, the significant negative out-degree density and the significant positive reciprocity parameters suggest that the students were reluctant to form arbitrary ties, unless those were reciprocal ones. The students also preferred to be friends with their friends' friends (triadic closure), as indicated by the positive transitive ties and the negative geodesic distance-2 effects.

Table 4 Network Model: Selection Process

Network model	β	SE (β)
Rates		
Rate (t_1-t_2)	15.95***	1.38
Rate (t_2-t_3)	10.33***	0.84
Rate (t_3-t_4)	13.39***	1.73
Endogenous network processes		
Outdegree (density)	-5.78***	0.35
Reciprocity	7.22***	0.20
Transitive triplets	0.26	1.00
3-cycles	0.18	2.01
Transitive ties	0.51***	0.11
Number of distance at 2	-0.20**	0.08
In-degree popularity (square root)	-0.49	0.29
Individual attributes		
Same residence	0.87***	0.10
Alter age	-0.09	0.16
Ego age	-0.02	0.14
Age similarity	0.13	0.13
Alter female	-0.11	0.13
Ego female	0.15	0.13
Gender similarity	-0.04	0.07
Alter white	0.18	0.19
Ego white	-0.12	0.20
Race similarity	0.24**	0.08
Drinking behavior similarity	0.47*	0.20

* Two-sided p<0.05 ** Two-sided p<0.01 *** Two-sided p<0.001

Turning to the control variables, the students were more likely to send out-going ties to those residing in the same residence hall and who have same race. There were no differences in the tendency to send out-going ties or to receive in-coming ties on the basis of other individual characteristics such as gender and age.

In terms of how drinking affected tie selection, we observe a significant positive parameter for drinking similarity (*b* = 0.47, *p* < .05). This effect provides evidence that the students were more likely to communicate with others who have similar levels of alcohol use.

Drinking Behavior Evolution: Influence Processes

As shown in Table 5, the average change opportunities in drinking behaviors for each ego increased over time. The significant negative linear shape effect and insignificant quadratic shape function suggest that overall the 196 undergraduate students tended to drink less over time.

In terms of influence processes, the average alter drinking effect in the behavioral model is positive and significant at 0.05 level (*b* = 0.37, *p* < .05), which indicates that students tended to match the drinking behavior of their peers.

Table 5 Behavior Model: Influence Process

Behavior model	β	SE (β)
Rate		
Rate drinking (t_1-t_2)	1.10***	0.18
Rate drinking (t_2-t_3)	2.37***	0.48
Rate drinking (t_3-t_4)	3.01***	0.58
Linear shape	-0.34***	0.07
Quadratic shape	0.01	0.04
Average alter drinking effect	0.37*	0.15
Individual attributes		
Age effect	-0.11	0.13
Gender effect (female)	-0.10	0.12
Race effect (white)	0.30*	0.14

* Two-sided p<0.05 ** Two-sided p<0.01 *** Two-sided p<0.001

The objective function including linear effect, quadratic effect, and average alter effect can be calculated by

$$f_i^{beh}(\beta, y) = -0.34(z_i - \bar{z}) + 0.01(z_i - \bar{z})^2 + 0.37(z_i - \bar{z})(\bar{z}_j - \bar{z}),$$

where the drinking behavior of ego z_i and the mean of alters' drinking behavior $\bar{z}_j$ ranges from 0 to 4, and the mean of drinking behavior of all actors $\bar{z}$ is equal to 1.26 over the four semesters.

As the solid line (with solid circles) shows in Figure 1, if a student was connected mainly to non-drinkers ($\bar{z}_j = 0$), s/he tended to drink less. The dotted line (with solid triangles) indicates that if a student was connected mainly to heavy drinkers ($\bar{z}_j = 4$), s/he tended to drink more.

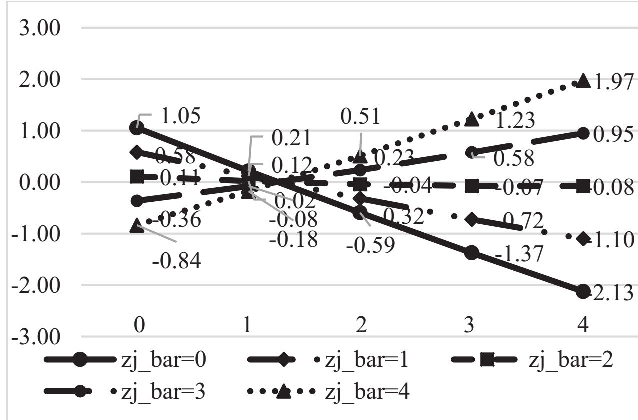

Figure 1 Objective Function Combining Linear, Quadratic, and Average Alter Effects

Table 6 gives us the exact probability of increasing, decreasing, or staying the same in a person's alcohol use level for various combinations of egos' and average alters' drinking behaviors. The table shows that egos who had alters with either lower or higher drinking behaviors would be more likely to be pulled in that direction. For example, a light-drinker ($z_i^t = 1$) had a 61.55% predict probability of turning into a non-drinker ($z_i^{t+1} = 0$) in the next time period if s/he was connected to non-drinkers ($\bar{z}_j = 0$). On the other hand, a frequent-drinker ($z_i^t = 3$) at baseline had a 58.62% predicted probability of turning into a heavy-drinker ($z_i^{t+1} = 4$) if s/he was connected to heavy-drinkers ($\bar{z}_j = 4$).

Table 6 Probability of Changing Ego's Alcohol Use in the Next Time Step, Based on Ego's and Average Alters' Current Drinking Behaviors

Ego's current drinking behavior	Change	Average alters' drinking behaviors				
		0	1	2	3	4
0	-1	NA	NA	NA	NA	NA
	same	69.82%	61.41%	52.25%	42.95%	34.11%
	+1	30.18%	38.59%	47.75%	57.05%	65.89%
1	-1	61.55%	49.13%	36.06%	24.12%	14.77%
	same	26.61%	30.88%	32.95%	32.05%	28.52%
	+1	11.84%	19.98%	31.00%	43.83%	56.71%
2	-1	60.64%	48.11%	35.06%	23.29%	14.16%
	same	26.99%	31.14%	32.99%	31.85%	28.17%
	+1	12.37%	20.75%	31.95%	44.86%	57.67%
3	-1	59.72%	47.09%	34.07%	22.47%	13.58%
	same	27.37%	31.38%	33.01%	31.64%	27.80%
	+1	12.92%	21.53%	32.92%	45.89%	58.62%
4	-1	67.94%	59.31%	50.06%	40.81%	32.17%
	same	32.06%	40.69%	49.94%	59.19%	67.83%
	+1	NA	NA	NA	NA	NA

Of the individual attributes, the remaining parameters in the behavior model show that whites seemed to drink more than minorities, while the students' gender and age did not significantly associate with the drinking behaviors.

Network Autocorrelation

To evaluate the relative contribution of selection and influence based on alcohol use status, we apply Moran's I to measure the percentage of network autocorrelation allocated by several fitted models following the different mechanisms (see Steglich, Snijders, and Pearson 2010). A value of Moran's I close to zero indicates that relational partners are not more similar than one would expect under random pairing, while values closer to one indicate a very strong network autocorrelation.

$$I = \frac{n\sum_{ij} x_{ij}(z_i - \bar{z})(z_j - \bar{z})}{\left(\sum_{ij} x_{ij}\right)\left(\sum_{i}(z_i - \bar{z})^2\right)}$$

Six model specifications are used to determine the contribution of various mechanisms generating the similarities in drinking behavior among the 196 undergraduate students in the study. These include: (1) the null model, which serves as a baseline and by default the value of Moran's I is set to be -1/(*n*-1); (2) the trend model, the control model, and the full model, which are estimated directly through RSiena; and (3) two hybrid models – the selection/no influence model and the influence/no selection model, which are elicited from the full model to determine the contribution of various mechanisms generating observed similarities in drinking behavior among students.

More specifically, the trend model expresses only the effects of the time trends in number of friends and in drinking. The control model includes all the selection and influence mechanisms except the drinking-based network selection and influence between actors. The full model covers all the afore-mentioned effects. The selection/no influence model can be derived from the full model by excluding influence from the drinking behavior of alters, while the influence/no selection model differs from the full model by the exclusion of drinking-based selection effects. Starting from the very first wave (Fall semester 2011) of network and behaviors, we run 1,000 independent simulations to generate both networks and behaviors at wave 2 (Spring semester 2012), wave 3 (Summer semester 2012), and wave 4 (Fall semester 2012). We calculate network autocorrelation measures (expressed in Morn's Is) based on the estimates of each of the five SAB models averaged over wave 2 through 4.

Figure 2 shows the mean percentage of similarity in drinking behavior between actors generated by each of the postulated mechanisms. The trend and control effects account for nearly 38 percent of the observed network autocorrelation. About 17 percent of the network autocorrelation results from selection processes based on alcohol use status. The proportion of network autocorrelation attributed to the influence of alters on ego is higher than the proportion attributed to peer selection processes. Finally, we find that other determinants (beyond selection and influence processes) of changes in network compositions and drinking behaviors played only a small role in explaining drinking behavior similarity, less than 3 percent.

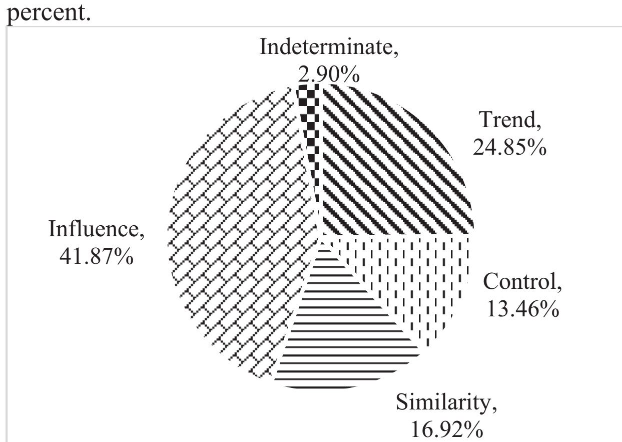

Figure 2 The Relative Contribution of Selection and Influence Processes to Drinking Behavior Similarities

Conclusion and Discussion

This study aims to disentangle influence and selection processes by examining the co-evolution of communication networks and drinking behaviors of 196 undergraduate students, using SAB modeling with RSiena. This modeling strategy is useful because it can explicitly account for alternative mechanisms driving peer selection, as well as non-dyadic dependencies caused by dynamic change in local network configurations. In addition, this technique is capable of modeling continuous-time changes in both individual behaviors and personal networks.

Our findings clearly demonstrate that, contrary to the idea that "social contagion" is everything, selection processes play a significant role in creating drinking behavior similarity in the students' communication networks. Students preferred to connect with others who matched their pre-existing alcohol-use status. The results support previous findings regarding the importance of selection processes in accounting for behavioral similarities among dyads in networks (i.e., Mundt, Mercken, and Zakletskaia 2012; Osgood et al. 2013).

We included a host of control variables that could provide alternative explanations in order to guard against possible overestimation of peer selection based on similar drinking behavior. As expected, students were more likely to prefer reciprocal ties and ties embedded in triangles. Race and residential similarity were two other important factors driving relational choices. These effects underline the need to adjust for these factors when exploring selection and influence processes.

In line with the findings of Mathys, Burk, and Cillessen (2013) and Osgood et al. (2013), we also confirm the importance of peer influence in communication networks. What's more, the peer influence during four successive semesters explained a much large proportion of drinking behavior similarity in the communication networks than the drinking-based selection effect.

Our study contributes to existing literature in several aspects. First, our network data set comes from real-time communication records and as a result it is more accurate and reliable than those collected through ego-centric survey which often suffers from memory bias and weak-tie absence problems. Second, our study is not constrained by limited nomination of alters (i.e., the adolescents could only nominate up to five female and five male friends in AddHealth and seven for each gender in the PROSPER study). Third, we have four waves of data with little attrition while most previous studies worked on two waves of data with missing network ties due to absent respondents. Fourth, we use the network autocorrelation to tease apart how selection and influence processes simultaneously contribute to the drinking behavior similarity among adolescents.

Our study has several limitations. First, drinking behavior could be under-reported. We do not have a physiological indicator of alcohol use with which we could assess the validity of our self-reported measure. However, during the 2012 fall semester the percentage of non-drinkers was 36.73 percent which is only about 6 percent above the correspondent index in the CDC 2011 report. Second, we focused on the relationships within the communication networks of 196 students but these relationships do not represent the entire social networks of our subjects. The data from the *NetSense* project did collect information on the communication behaviors to and from persons outside the *NetSense* study, but we do not have information on communication networks and drinking behaviors of people not enrolled in the study. Future studies should aim to include all friends outside and inside the communication network. Third, the *NetSense* project collected data only from one setting and thus the representativeness of the sample might be questioned. Our findings mirror that of Osgood et al. (2013) but are partially different from that of Mundt, Mercken, and Zakletskaia (2012) and Mathys, Burk, and Cillessen (2013) who also studied US adolescents. More longitudinal social network studies, especially those pertaining to US adolescents, are needed in order to assess the relative contributions of selection and influence processes in generating dyadic similarity in drinking (and other) behaviors.

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