sociological science

Network Evolution and Social Situations

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Abstract: Studying the evolution of friendship networks has a long tradition in sociology. Multiple micromechanisms underlying friendship formation have been discovered, the most pervasive being reciprocity, transitivity, and homophily. Although each mechanism is studied in depth on its own, their relation to one another is rarely analyzed, and a theoretical framework that integrates research on all of them does not exist. This article introduces a friendship evolution model, which proposes that each micromechanism is related to interactions in different social situations. Based on this model, decreasing returns to embedding in multiple mechanisms are hypothesized. Complete social network data of adolescents and statistical network models are used to test these hypotheses. Results show a consistently negative interaction in line with the formulated model. The consequences of this negative relation between the network evolution mechanisms are explored in a simulation study, which suggests that this is a strong determinant of network-level integration and segregation.

Keywords: friendship networks; reciprocity; transitivity; homophily; network theory

HUMANS are inherently social; interpersonal friendships are central in the lives of most people. The content and structure of these friendships are important predictors of diverse individual and group-level outcomes, such as psychological wellbeing, occupational success, physical health, neighbourhood cohesion, and political mobilisation (Mouw 2006; Rivera, Soderstrom, and Uzzi 2010; Dunbar 2018). Given these insights, how friendship networks form and evolve was of interest to sociologists from the beginning of the discipline. Decades of research have found three major determinants of friendship network evolution. These are reciprocity, transitivity, and homophily[1] (Rivera et al. 2010). Although studied in great depth individually, the concurrence and interrelation of these mechanisms is less understood. This is surprising, as friendship networks are unanimously conceptualized as multimechanistic systems, in which the structure of friendship networks is the outcome of multiple processes operating simultaneously. Nevertheless, we lack a comprehensive picture of how networks evolve empirically that can take these intermechanistic relations into account. The lack of empirical work on the link between reciprocity, transitivity, and homophily is mirrored by a lack of theoretical integration. Numerous theories explain the persistence of individual network evolution mechanisms, but no framework exists that can take all of them into account at the same time. A common ground under which all of them can be understood is necessary.

The first part of this article outlines such a framework. I build a simple model of friendship evolution in which the three dominant network evolution mechanisms are connected to interaction in different social circles. This model places interaction and friendship formation opportunities at the heart of friendship evolution and leads to testable hypotheses about the relation between reciprocity, transitivity, and

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homophily, particularly that there is a mitigating relation between them—or in statistical terms, a negative interaction. These hypotheses are tested by using two data sets on adolescent friendship networks (N = 160; N = 1,716) and longitudinal statistical network models (stochastic actor-oriented models [SAOMs] or Siena-models).

In the second part of the article, the implications of these results are extrapolated to network structures by using simulations. The interplay of reciprocity, transitivity, and homophily is likely to impact integration or separation in a community connected by informal relations. Each mechanism is a force of attraction that brings people together; if they reinforce one another, networks should form cohesive and largely separated clusters in which people are homophilous and transitively and reciprocally tied (Sorenson and Stuart 2008). A mitigating relation, on the other hand, would foster integration between different parts of the network. The simulation study illustrates this relation between network structure and the interaction of network structuring processes.

Network Evolution Mechanisms and Background

Homophily, transitivity, and reciprocity not only guide network formation but relate to core sociological issues. (1) Homophily is the main force driving social segregation (McPherson, Smith-Lovin, and Cook 2001). Because people predominantly form ties to similar others, interpersonal contact mainly stays within ethnicities, religions, social classes, and genders. (2) Transitivity is key in the formation of informal groups (Heider 1958). These informal groups satisfy people's needs for safety, approval, affection, and so on but also constrain behaviour and attitudes through group norms and sanctions (Festinger, Schachter, and Back 1950). (3) Reciprocity and the associated giving and taking are crucial for social relations to be durable and stable in the long run (Gould 2002).

Owing to the importance of reciprocity, transitivity, and homophily, numerous theoretical rationales explain their persistence. For example, friendship reciprocation can be explained by social exchange theory (Emerson 1976). Social relations involve costs and rewards, and only in reciprocated friendships do both parties invest in the relationship so that it is rewarding for each of the two. Transitivity tends to be explained by balance theory (Heider 1958), or that a common friend implies a high probability of meeting in an atmosphere that is conducive to friendship formation (Granovetter 1973). Homophily on ascribed dimensions (such as sex and ethnicity) can be explained by similarity leading to increased meeting opportunities, as similar people engage in similar activities (Feld 1982). Additionally, friendship between similar people might be more rewarding (McPherson and Smith-Lovin 1987; Kossinets and Watts 2009); having something in common can simplify establishing trust and solidarity and facilitate interaction.

Overall, different theoretical explanations exist for each network evolution mechanism. However, each presented theory is concerned with a subset of the three phenomena but has little to say on the others. This diagnosis aligns with Rivera et al, who assert that "these theoretical streams have also tended to progress in relative isolation – favouring their own theoretical foundations and explanatory variables" (2010:108). Thus, although reciprocity, transitivity, and homophily have been examined extensively in a variety of contexts, a theoretical framework that can relate them to one another is missing. Equally, empirical studies that analyze the relation between them are scarce (see the end of the next section). A theoretical framework to achieve this integration is presented in the next section; empirical analyses follow subsequently.

Friendship Evolution Mechanisms and Social Situations

A Minimal Friendship Evolution Model

An initial challenge in formulating a model for friendship evolution is that there is no commonly agreed upon definition of friendship.[2] However, two basic features of a friendship are (1) positive affection and (2) spending time together. It is intuitive that people like their friends. Spending time together is the behavioural dimension of friendship and distinguishes friends from others who are merely liked (also called friendly relations) (Van De Bunt, Duijn, and Snijders 1999) and is a condition of the familiarity that is typical of friendships. For the model proposed below, friendship will be understood as a function of these two dimensions.

Given that liking and familiarity can, in principle, be understood as continuous concepts, we can think of a composite scale that combines these two dimensions (the exact definition of this composite is not relevant for the argument). This concept expresses "the extent to which a relation is like a friendship." The binary category "friendship" can, in this formulation, be understood as an indicator if this continuous, composite measure crosses some threshold. It is important to note that this threshold must not be universal but can vary between people; some might need more familiarity or intimacy before calling somebody else a friend than others (see Adams, Blieszner, and de Vries 2000).

Given this conceptualisation of friendship, how are friendships formed and maintained over time? This is analyzed via changes in the continuous measure underlying a friendship choice. Change in this measure is most likely to happen in interpersonal interactions, in which a person gains appreciation of another and becomes increasingly familiar (or, to the contrary, realises he or she does not like the other). Given a sufficient number of social encounters that increase affection and familiarity, at some point, the nonfriend might become a friend. Such a stylized evolution of how one person (Richard) starts considering two other persons (Anne and Will) as friends is depicted in Figure 1a and 1b. Over a series of meetings in different contexts, Richard's esteem of Anne and Will rises until he considers each one a friend, after which they continue spending time together. To the contrary, Figure 1c shows the evolution of the relationship between Richard and Jeffrey. Even though they meet regularly, no friendship evolves, as they do not get along well. This illustrates that meeting is a necessary but not sufficient condition for friendship. Beyond the depiction in Figure 1, this model can incorporate other factors that influence the perception of another person, including interactions with third parties that change esteem (e.g., gossip) as well as the potential decay of a

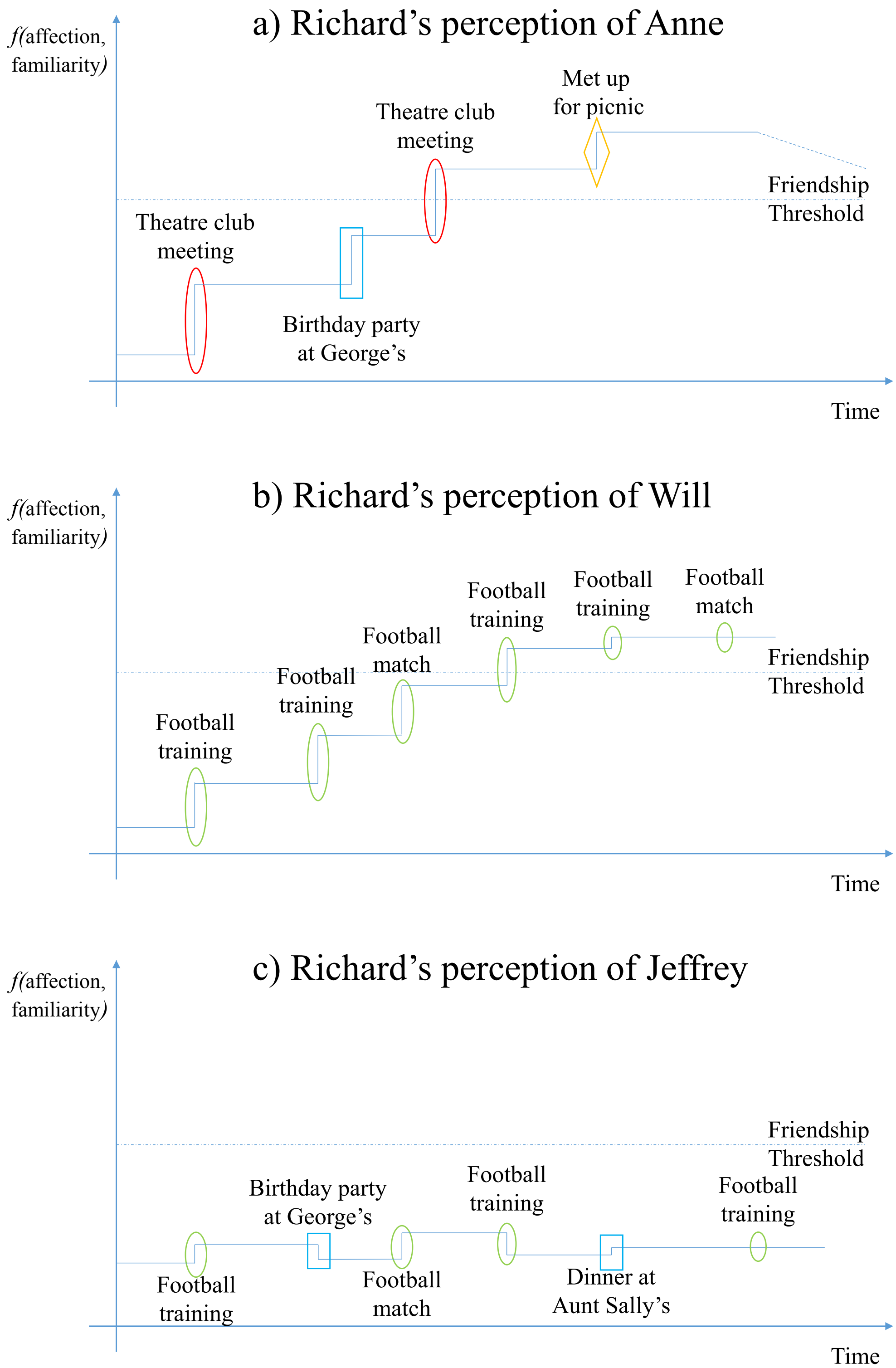

Figure 1: Illustration of a minimal friendship model. Circles refer to exogenous, group-based situations; rectangles denote endogenous, group-based situations; and diamonds indicate endogenous, dyadic situations.

friendship once people stop spending time together (as indicated by the dotted line in Figure 1a).

Whether Richard and Anne (or Will) become friends thus has two nested dimensions. First, what makes Richard and Anne likely to meet? And once they meet, what factors increases the positive perception Richard has of Anne? The latter is likely to be a mix of predictors, including whether they share common interests and a sense of humor, or whether they find something interesting to talk about; these factors can be summarized as "compatibility." Furthermore, idiosyncratic factors, such as mood, potential seating arrangements at a dinner, and so on, will play some role in individual meetings. The former factor—what makes Richard and Anne likely to meet—lies at the core of the argument in this article and will be discussed in the next section. The strong focus on meeting is because it is logically prior to any consideration of what makes two people like each other: you cannot become friends if you never meet.

This nested model of "meeting and mating" (Verbrugge 1977) has direct implications for how increasing the number of encounters between two people influences the probability to become friends. Meeting more regularly should increase the chances to become friends when interactions are sparse; for example, meeting weekly rather than monthly should make forming a friendship more likely when two people are compatible. However, there are decreasing returns to meeting more often; if two people are not compatible, they will not become friends, independent of how often they meet. This is depicted in Figure 1c: Richard and Jeffrey would not become friends if they met more often. Thus, there is a ceiling effect to the extent that meeting more regularly predicts friendship formation. This is illustrated in Figure 2.

A Typology of Social Circles

The focal question underlying friendship formation here is: what makes individuals meet for social interaction? People seek social meetings to fulfil social and emotional needs, such as validation of the self, emotional support, and to engage in social, group-based activities, for example, playing football or going dancing (Fischer 1982; Baumeister and Leary 1995). These varying social and emotional needs are typically satisfied at different times and in different places; sometimes individuals meet to talk about emotional problems, and at other times, they meet to play ping-pong. The different times when and contexts in which people meet for social interaction have appeared repeatedly within the sociological literature, for example, as "social circles" (Simmel 1950), "social foci" (Feld 1981), or "social settings" (Pattison and Robins 2002), often examining how they structure contact between individuals. I refrain from discussing the subtle differences between these concepts and call them "social circles," which are defined as the times and contexts that allow for social interaction in which a set of people regularly meet. A "social situation" is an instantiation of a social circle, or a specific meeting of people who make up a social circle. In these social situations, existing friendships are maintained and new ones are formed. In the example of Richard and Anne, the social situations in which they meet are at their theatre club, a birthday party, and a picnic. Richard and Will

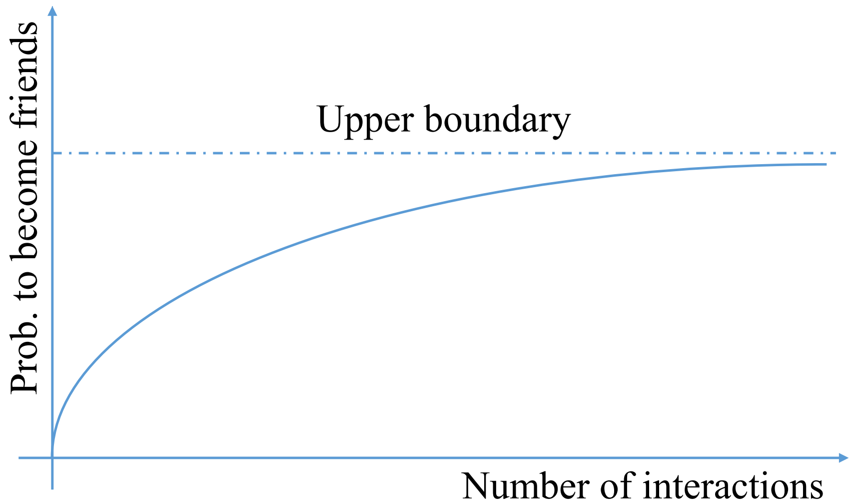

Figure 2: Decreasing returns to multiple meeting opportunities. Prob, probability.

repeatedly meet in the social circle of their football club. People recruit their friends from social circles, and within these constraints, they can find out who would be a compatible friend.

Social circles take place in all types of qualitatively different settings with compositions of people who are related to the reason for getting together. However, a typology of social circles is missing to date. Here, I argue that a systematic treatment and distinctions of types of social circles and their relation to different network evolution mechanisms would allow for new insights into the evolution of networks. I propose two dimensions according to which social circles can be differentiated.

The first dimension distinguishes dyadic and group-based situations. Dyadic situations are, by definition, when only two people meet and spend time together, whereas in group-based circles, more people meet. The content of dyadic situations is likely to be more intimate, such as self-disclosure, emotional problems, and advice, interaction content that requires a high level of trust, which is established easier between a pair of people. Group-based interactions, on the contrary, are more likely to have social activities as their content, for example, doing a sport, playing a game, or going to a concert or nightclub.

The second dimension differentiating social circles is whether the reason for meeting is primarily social, meaning endogenous to the network, or primarily instrumental, meaning exogenous to the network. In socially motivated circles, the primary reason to get together is to see friends and spend time together. They are endogenous to the network because their composition is defined by the friendship ties between people. A prime example is a dinner party or romantic date. The actual content (eating or watching a movie) is only secondary but provides a frame for socializing. Instrumental social circles are primarily defined through a joint activity. They are exogenous to the network insofar as participation is not primarily based on social relations but on a joint enterprise of some sort that cannot be done alone.

Examples of exogenous social circles are sports teams, book clubs, or voluntary organizations.

Starting from this categorization, I discuss three types of situations in which people interact distinguished by the two dimensions of endogenous or exogenous and dyadic or group based[3]. Interaction in these typical situations can be related to specific network configurations and network mechanisms in which friendships between people are embedded.

In endogenous, dyadic situations, two people meet to interact on a one-to-one basis because they enjoy each other's company and want to spend time together in a dyad. A meeting of this kind is likely to involve two individuals who are in a *reciprocated* friendship, as there is no reason to engage in this meeting otherwise: two people do not meet socially in a dyad unless they consider each other a friend. In the example in Figure 1a, the picnic of Richard and Anne is such a situation, highlighted by a yellow diamond.

In endogenous, group-based situations, a set of people interacts with the explicit purpose to socialize. Often one or a few individuals make an organizing effort for one situation to bring people together (e.g., for a dinner, a birthday party, etc.). All participants in this situation are likely to be, if not directly, indirectly connected to present others with a friendship tie, having at least the organizer as an intermediary. Thus, endogenous, group-based situations are characterized by high levels of *transitivity* between the participants. In Figure 1a, the birthday party thrown by George constitutes such a situation, highlighted by the light blue rectangle.

In exogenous, group-based situations, people meet for a specific activity or goal. Participation is generally open to people who fulfill certain objective criteria (e.g., sex for sport teams). These situations are characterized by participants sharing interests and attitudes (e.g., they enjoy playing football). Thus, people coming together here are characterized by *homophily* on the dimension that brings them together as well as on dimensions that limit participation. Additionally, participants are likely to be homophilous on demographic dimensions, as interest in many types of activities is stratified by demographic characteristics (Feld 1982). However, most exogenous, group-based social circles are characterized by members being similar along few dimensions, whereas similarity or dissimilarity on other dimensions is not relevant for this circle (Turner 1987; Block and Grund 2014). For example, membership in political organizations (such as unions or parties) is often related to social class or status but less so to age; church membership is stratified more by ethnicity than by sex; and sports teams are separated by sex and age but not by religion or party affiliation. Thus, exogenous social circles are related to different dimensions of homophily, and people who are homophilous on relevant dimensions tend to interact in specific social circles. In Figure 1, these situations are indicated by green and red circles.

Summarizing this discussion in relation to the friendship model, I propose that different types of social situations and different characteristics of network ties are associated with one another (see Figure 3). In the example in Figure 1, Richard and Will meet in the context of the football club (a group-based, exogenous situation), which is indicative of at least their same sex and similar age. Richard and Anne

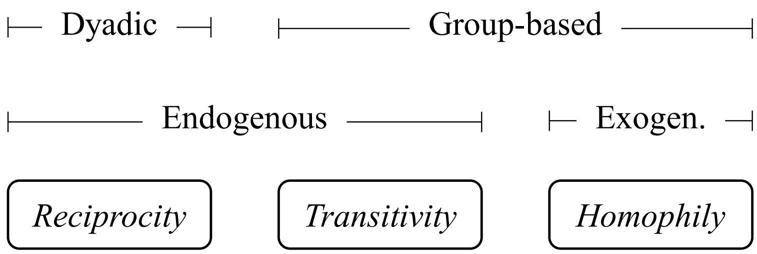

Figure 3: Social circles and their related network embedding. Exogen, exogenous.

meet (1) in the theatre club, which indicates a similar socioeconomic background; (2) at the birthday party of George—a group-based, endogenous situation—showing that they are transitively tied, as they have George as a common friend; and (3) for a picnic that only includes the two of them (dyadic, endogenous), indicating their mutual relationship.

This outlines the core assumptions of this study that will be corroborated in the first part of the empirical analysis (within the limits of available data). Giving a compatible interpretation of the different network evolution mechanisms, these propositions allow conclusions about the relation between these mechanisms to be drawn.

Assumption 1: Reciprocated friendships are connected to spending time together in dyads.

Assumption 2: Transitively embedded friendships are related to meeting in socially defined groups.

Assumption 3: Homophilous friendships are associated with interacting in groups that are characterized by (demographic) similarity.

Hypotheses Development

These assumptions, jointly with the earlier assertion that there are decreasing returns to meeting more often, imply a set of testable hypotheses that relate the three mechanisms of reciprocity, transitivity, and homophily to one another. The crucial question is do people befriend those they meet in multiple different social circles that are related to different network evolution mechanisms rather than those they meet only in one?

If two people are, for example, homophilous and transitively tied, they will be likely to meet in endogenous group–based situations (related to transitivity) as well as in exogenous group–based situations (related to homophily). Thus, being homophilous and transitively tied probabilistically leads to meeting more often than if only one of the two conditions is fulfilled. This leads to more opportunities and situations in which interaction can take place that allow for an evaluation of whether two people want to become friends. However, as outlined in the section on the minimal friendship model, there are decreasing returns to meeting more often. Thus, the impact of being both homophilous and transitively tied on the probability to become friends will be less than the additive effect of each embedding on its own. More abstractly, meeting in an additional social circle is less important compared to the first. Once two people meet in one social circle, they have the chance to see whether they are compatible for a friendship. Consequently, multiple embedding in different network evolution mechanisms does not necessarily make choosing the other as a friend much more likely, as a contact opportunity is already provided by the first embedding.

Applied to the examples from Figure 1, if Richard would not like Anne when they meet in setting A (the theatre club, related to *homophily*), he would also not like her when they meet in setting B (somebody's birthday party, related to *transitivity*). If Richard likes Anne at the theatre club, they become friends regardless of whether they also meet at a birthday party. The homophily that brings them together in the theatre club facilitates the formation of a tie. The additional joint friend who invites both to a birthday party is less relevant in bringing them together as opposed to if they would not have already met at the theatre club. Thus, the importance of transitivity is decreased, as they already meet related to their homophily (implying a negative interaction). At the time they are reciprocally tied and meet for a picnic, the importance of transitive and homophilous embedding diminishes, as they form their own situations for interacting, indicating a negative interaction between reciprocity and transitivity as well as between reciprocity and homophily.

The friendship between Richard and Will (Figure 1b) forms solely in the context of their football club. If they additionally were to meet in a context of transitivity (through a joint friend), this might speed up the process of friendship formation, but the meeting in the football club already provides the forum in which they can get to know each other to form a friendship. Thus, additional embedding would be less important. Finally, the relation between Richard and Jeffrey (Figure 1c) will not turn into a friendship regardless of how often they meet. Thus, the probabilistic increase in friendship formation that results from being homophilous and meeting in the football club is not increased by the additional meeting at the birthday party.

In summary, the decreasing returns to meeting more often, in combination with the assumption that embedding in transitive, reciprocated, and homophilous structures are related to meeting opportunities, lead to the hypotheses that the three network evolution mechanisms interact negatively. In particular, I propose the following:

Hypothesis 1: Multiple transitive embedding has decreasing returns.

Hypothesis 2: The interaction between reciprocity and transitivity is negative.

Hypothesis 3: The interaction between reciprocity and homophily is negative.

Hypothesis 4: The interaction between homophily and transitivity is negative.

Hypothesis 5: Multiple dimensions of homophily interact negatively.

The set of interactions outlined in the hypotheses is presented again in Figure 4. They will be tested in the empirical part of the article.

Past Empirical Work on the Relation between Network Mechanisms

Past studies that model friendship networks have analyzed a subset of the relations between reciprocity, transitivity, and homophily. Multiple transitivity is treated in the literature on the statistical modeling of social networks (Snijders et al. 2006). However, the motivation for these studies is mainly technical: so-called alternating triangle or geometrically weighted edgewise shared partner (GWESP) terms are needed in many applications to realistically model transitive closure. These imply decreasing returns to embedding in multiple triangles. Studies on multiple homophily were conducted by Block and Grund (2014) and Leszczensky and Pink (2015); both find equally decreasing returns to multiple similarity. The interaction between transitivity and reciprocity was modeled by Igarashi (2013) and Block (2015). Across all analyses described above, authors consistently find a negative estimate for the respectively modeled interaction, indicating initial support for the outlined hypotheses. However, motivations behind these studies are manifold and use diverse theoretical reasoning and methods for analysis. This article provides a comprehensive analysis of the relation between all these network evolution mechanisms.

Macro-Level Consequences

Analyzing how reciprocity, transitivity, and homophily work in unison to guide individual tie choices not only promises to improve understanding of network evolution, it has important consequences for macro-level network structure, in particular, network-level integration and segregation. Analyzing the extent of contact between different demographic and informal groups is crucial for understanding individual outcomes that are related to network ties. These outcomes depend on personal network diversity (Granovetter 1973; Burt 1992) as well as being tied to others who possess the information, resources, or (more broadly) social capital relevant to the outcome (Cross and Lin 2008). Network-level segregation, therefore, perpetuates the disadvantages of isolated groups by restricting social access to those who are better off.

The interplay between reciprocity, transitivity, and homophily strongly impacts the integration of a community that spans a friendship network. Each mechanism increases the chances of tie formation and brings people together. If mechanisms were additive or even superadditive, people would preferentially form ties that are homophilous on many dimensions as well as transitively embedded and reciprocally tied. In the long run, this would lead to networks made of cohesive and largely separated clusters.

For example, a positive interaction between homophily and transitivity, meaning superadditivity, implies that individuals prefer ties to others who are *at the same time* similar to themselves and share common friends. This would result in sharper segregation and less chance of integration between people who belong to different

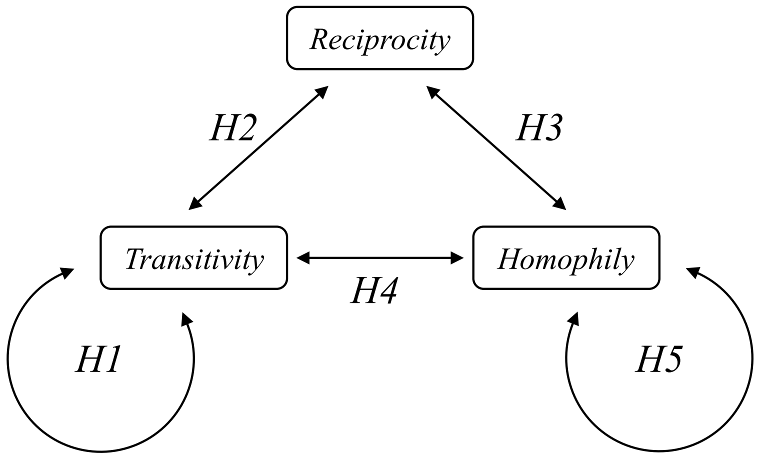

Figure 4: Interactions between the three main friendship network evolution mechanisms numbered according to the hypotheses. H1, hypothesis 1; H2, hypothesis 2; H3, hypothesis 3; H4, hypothesis 4; H5, hypothesis 5.

groups, as the tendencies fostering group formation on social (transitive) and demographic levels amplify one another. In contrast, a negative relation suggests that transitive embedding and homophily can substitute for one another. Homophily would allow for the forming of ties outside of informal groups, as the positive effect of transitive embedding would be offset by the negative interaction. Equally, transitivity could compensate for dissimilarity on demographic dimensions and foster heterophilous friendships.

As a second example, a positive relation between homophily and reciprocity would cause mainly homophilous ties to be reciprocated. Reciprocity would manifest friendships that are homophilous. On the contrary, a negative relation entails that reciprocity mitigates homophily and facilitates crossing informal group boundaries. As such, in case of a negative relation, reciprocity would foster contact between different demographic groups, in which members otherwise prefer friends who are similar to themselves. Similar arguments can be made for all five interactions.

Altogether, a positive interaction between the three main network evolution mechanisms would lead to Balkanized structures of dense and mostly disconnected clusters. Although these have been used as stylized network models ("connected cavemen networks"; Watts 1999), they neither accord with empirically observed friendship networks nor are in line with fundamental sociological theories about the sorting of people into groups. These trace back to Simmel (1950) and suggest that individuals are part of various, nonoverlapping social circles. At the intersection of these cross-cutting social circles, identity is constructed, such as a mother or father who works as a lawyer, is on a basketball team, and volunteers in an animal rights group. In this article, I apply the logic of compartmentalization of social life into different spheres to the analysis of informal networks. I argue that people within networked communities (e.g., universities or schools) are not members of one homogeneous social group but rather of a number of different social circles. The consequences of the interaction between the mechanisms on overall network structures is analyzed by using a simulation study in the empirical part of this article, showing how it leads to more integrated networks that accord more to empirically observed networks.

Analytical Strategy

The hypotheses are tested on two data sets of complete adolescent school cohort networks. Testing the theory on adolescent networks engages with a vast literature that spans from Coleman (1961) to large-scale data collections of complete adolescent networks in the recent past (e.g., the National Longitudinal Study of Adolescent to Adult Health [AddHealth study] in the United States and the Children of Immigrants Longitudinal Survey in Four European Countries [CILS4EU study] in Europe). Adolescent friendship networks are widely researched, partly because analyzing friendship choices requires knowing the pool of potential applicants; thus, a complete network design is necessary (Marsden 1990). School cohorts that constitute a large part of the social life of members provide an ideal setting. An additional reason to analyze young people's networks is the special role friendships have in the lives of adolescents. Adolescence is a period of reorientation from family to same-age peers, when friendships play an increasingly important part in their lives compared to earlier childhood and adult life, when ties to family members tend to be more important (Steinberg and Morris 2001; Smetana, Campione-Barr, and Metzger 2006). The large amounts of time adolescents spend socializing with friends and the frequent turnover of friendships make the analysis of adolescent friendship networks especially fruitful.

Data

The Glasgow data. The Glasgow data were collected within the context of the Teenage Friends and Lifestyle Study[4] (Pearson and Michell 2000) in the 1990s. A school cohort of 160 adolescents (aged 13 in wave one) was followed over three years. Data on demographic characteristics, lifestyle, and substance use patterns were gathered at the beginning of each calendar year. Demographic characteristics used in this study are sex and the amount of pocket money received, which is a proxy for parents' economic status. Furthermore, participants could nominate up to six persons as friends at each time point, resulting in three waves of complete, directed friendships networks. Previous studies employing these data found strong homophily effects on sex and pocket money (e.g., Steglich, Snijders, and Pearson 2010).

Participants were additionally asked to indicate what they do with each of their friends, choosing from four options with the possibility to give multiple answers. The three activities that are used in this study are "we do activities together"; "we don't do much, we just hang about"; and "we are close, talk a lot, share secrets." For each of these activities, directed networks were created that indicate what the respondents do with their friends at three time points. This allows for analyzing the evolution of joint activities to assess the outlined assumptions. Further description of the data can be found in Steglich et al. (2010). The data are publicly available.[5]

The ASSIST data. Data for Wales and England come from the A Stop Smoking in Schools Trial (ASSIST) study[6] (Campbell et al. 2008; Steglich et al. 2012). Between 2002 and 2004, cohorts of multiple schools were surveyed annually. In the first wave, adolescents were aged 12 to 13. Data from 10 schools are used, for which complete network data are available. Cohort sizes range from 80 to 236 pupils, amounting to a total of 1,716 adolescents. As in the Glasgow data, friendship networks were constructed by using a name generator that allowed for the nomination of up to six friends at each time point. The measured demographic variable used is the respondents' sex; additionally, the form (similar to grade) the pupils were in was recorded. Previous studies consistently found homophily along the lines of sex in the schools (Steglich et al. 2012) as well as form. Descriptive statistics of the analyzed network are available in Block (2015) and Steglich et al. (2012).

Method

Stochastic actor-oriented models. The data are analyzed by using stochastic actor-oriented models (SAOMs; Snijders 2001; Snijders, van de Bunt, and Steglich 2010). SAOMs are an ideal tool for the analysis at hand, as they allow for estimating the relative contributions of reciprocity, homophily, and transitivity to the friendship choices of individuals, controlling for one another. Furthermore, their interaction can be readily incorporated into an analysis.

SAOMs model the evolution of a network between multiple observed time-points. Although data are observed as network panels, it is assumed that the network changes continuously in time, decomposing the network evolution into a series of discrete changes, each of which affects only one tie. The longitudinal nature of the model, which assumes networks evolve continuously, with friendships being created and broken, aligns with the theoretical model introduced above.[7] Inference on network evolution mechanisms is made on the simulated series of tie changes, employing a generalized linear model framework. This explicitly takes the perspective of the individuals who change their outgoing ties. As the statistical core of the SAOM is a multinomial choice model, it allows for inference on how actors change their friendships in response to opportunity constraints and their preferences. Both opportunities and preferences are contained in the model parameterization.

Actor-oriented models are by now widely used in the analysis of longitudinal network data (in this journal in Stadtfeld and Block 2017; Boda 2018). Introductions to the statistical model can be found in Snijders (2001) and Snijders (2005). Nontechnical introductions are given by Snijders et al. (2010).

The conducted analyses use three additional features of SAOMs. First, the ASSIST data contain longitudinal data of 10 different networks. To use the statistical power of all joint data rather than interpret each analyzed network by itself, parameters estimated for the schools are combined in a meta-analysis using the procedure proposed by Snijders and Baerveldt (2003).

Second, to corroborate the assumptions outlined in the theory section, an SAOM for multiple networks is used to analyze what adolescents do with their friends. The surveyed activities form a series of networks, in which the participants nominate amongst their friends with whom they do what. These activity networks are nested within the friendship network. The multiple, interdependent networks can be analyzed using SAOMs, in which a tie in one network can be dependent on a specific network configuration as well as on the presence of a tie in another network. The technical details for the analysis of multiple networks are outlined in Snijders, Lomi, and Torlo (2013).

Third, to illustrate how the interrelation of reciprocity, transitivity, and homophily can impact overall network structure as discussed in the section on macro-level consequences, SAOMs are used to conduct counterfactual simulations. As the SAOM specifies a complete model of network evolution given a set of parameters and an initial network, estimated parameters are used to simulate likely network structures under the model. This is compared to simulated networks under a counterfactual model, in which all interaction parameters are set to zero and the intercept parameter is adjusted to produce networks with the density of the observed network. Both simulated networks are compared to the actually observed network to assess the extent to which either model can reflect observed network structure.

Model specification. There are five outlined hypotheses and two dimensions of homophily for both data sets, resulting in a total of seven relevant parameters. Given the collinearity between the different statistics associated with the parameters, including all interactions at once runs the risk of asking too much from the analyzed data. Thus, a series of models is estimated that tests subsets of the hypotheses with a final model incorporating all interactions at once.

The first model tests the interaction between multiple transitive embedding, analyzing whether the first triplet in which a friendship is embedded is more important than consecutive ones. This is a replication of previous studies that found similar patterns (see the section on past empirical work). From the second model onwards, only one transitivity parameter is included in the analyses that models the decreasing returns to multiple embedding (technically a GWESP term; Snijders et al. 2006). Equally, all models from the second onwards include the interaction between transitivity and reciprocity, as this has been found pervasively in previous studies (discussed in Block 2015). The second model further tests the interaction between reciprocity and homophily. The third model estimates parameters for the interaction between homophily and transitivity; the fourth model includes the interaction between multiple dimensions of homophily. The fifth model includes all interactions and is used in the simulation study at the end of the results section.

Similar to other statistical models, including the appropriate control effects is crucial when modeling network data. The selection of control effects in the analyses in this article is based on recent literature employing SAOMs (Labun, Wittek, and Steglich 2016; Fujimoto, Snijders, and Valente 2017). All effects used in any of the analyses, their mathematical formulation, as well as a brief description of their interpretation are given in Table S1 of the online supplement.

Results

Corroboration of Assumptions

First, I analyze whether assumptions 1 through 3 can be supported by the (limited) data on activities from the Glasgow data. These assumptions state that reciprocated friends meet in dyadic interactions, homophilous friends spend time together in organized activities, and transitively tied friends spend time together in socially defined group activities. Table 1 presents the results of the activity analysis.

Table 1a shows the relevant parameter estimates that predict secret sharing. Secret sharing is understood as an interaction that happens in dyadic situations. Consistent with the formulated assumption, the analysis shows that sharing secrets is related to reciprocated friendship, as indicated by the positive and significant *incoming friendship* parameter. Being of the same sex or receiving similar amounts of pocket money has no impact on sharing secrets between adolescents.

The parameter estimates for what predicts jointly taking part in organized activities are presented in Table 1b. Organized activities are exogenous group–based activities (e.g., sports teams, extracurricular activities, etc.). A reciprocated friendship is no predictor of doing activities together. Adolescents are equally likely to do activities with one-sided, as well as with mutual, friends. The only significant estimate in this analysis is the *same-sex* parameter; adolescents mainly do organized activities with friends of the same sex. This supports the assumption that exogenous, group-based activities are connected to homophily on specific dimensions.

Finally, Table 1c shows the parameter estimates for predictors of with whom adolescents hang about. The incoming friendship parameter is estimated to be significantly negative. This means that situations in which a group of adolescents just hangs about is related to one-sided friendships. On the other hand, hanging about together is positively related to same-sex friendships as well as friendships between adolescents who receive similar amounts of pocket money. The interpretation is not as straight forward as for the previous two analyses that directly supported the assumptions. First, this group-based activity is related to homophily on sex and socioeconomic status, suggesting that particular groups of adolescents meet to hang about. This supports the assumption to some extent, as hanging about can be understood as a group-based activity; however, intuitively, the circles are socially defined rather than exogenously defined. A complication is that in the data collection, the exact phrasing was "we don't do much, we just hang about." Thus, this question might not properly capture the concept of socially defined social circles but a residual category for friendships that do not fall in the other categories and are groups that literally hang about in the streets. Its negative relation to reciprocity further shows that it might be especially one sided and thus not very close.

Additional analyses tested whether embedding of a friendship in a transitive triplet influences what activities friends do together. However, embedding in a transitive structure did not show a significant effect for any activity (sharing secrets, doing activities, or hanging about). Importantly, due to the sparseness of these networks, the estimated standard errors are very large, limiting the confidence in the obtained results. Consequently, there is no evidence supporting that endogenous, group-based social circles are related to transitive friendships. However, it is not

Table 1: Activity analysis Glasgow data.

a) Secret Sharing Network

	estimate (s.e.)
Outdegree	$-5.98^{\dagger}$ (0.35)
Friendship	5.00 fixed
Incoming Friendship	0.87^{*} (0.36)
Same Sex	0.00 (0.32)
Pocket Money Similarity	1.10 (0.98)

b) Organized Activities Network

	estimate (s.e.)
Outdegree	$-6.02^{\dagger}$ (0.29)
Friendship	5.00 fixed
Incoming Friendship	-0.48 (0.26)
Same Sex	$0.94^{\dagger}$ (0.24)
Pocket Money Similarity	0.20 (0.53)

c) Hanging about Network

	estimate (s.e.)
Outdegree	$-4.84^{\dagger}$ (0.19)
Friendship	5.00 fixed
Incoming Friendship	$-1.17^{\dagger}$ (0.31)
Same Sex	$0.66^{\dagger}$ (0.22)
Pocket Money Similarity	1.01^{*} (0.49)

Notes: s.e., standard error. * $p < 0.05$; † $p < 0.01$.

clear whether one of the mentioned activities qualifies as an endogenous, group-based social circle or whether results are due to limited statistical power.

Main Interaction Analysis

Table 2 and Table 3 show the results of the SAOM analyses on the five interactions outlined in the main hypotheses. Results of the full model specifications as well as interpretation of control parameters are presented in the supplementary material. Model 1 analyzes the interaction between multiple transitive embedding (hypothesis 1). For both data sets the parameter for embedding in the first transitive triplet is about three to four times larger than the parameter for embedding in each additional triplet. This means that having one friend in common strongly increases the chances to become and stay friends; the effect of additional friends is much lower, being equivalent to a negative interaction between multiple embedding in transitive triplets.

From model 2 onward, all analyses include the interaction term between reciprocity and the weighted transitivity term (hypothesis 2). The parameter estimate in both data sets is consistently negative, strongly significant, and of substantial size. Parameter size ranges from about 33 percent of the main transitivity parameter in model 3 of the ASSIST data to 57 percent in model 4 of the ASSIST data. Thus, once a tie is reciprocated, the importance of transitive embedding decreases substantially. Model 2 additionally tests the interaction between reciprocity and homophily (hypothesis 3). In both data sets, all interactions are significantly negative and range in size between 65 percent and 98 percent of the main homophily parameter. The interactions almost entirely offset the main homophily effects; consequently, homophily mainly operates on one-sided ties, whereas mutual ties are not more likely to be established or maintained if they are homophilous compared to heterophilous ties.

Model 3 tests hypothesis 4, the interaction between transitivity and homophily. Three of four modeled interactions are significantly negative; only the interaction between pocket money homophily and transitivity in the Glasgow data is not significant. For the other parameters, the size is similar in relative magnitude to the homophily parameter in model 2. The interpretation is that once a friendship is transitively embedded (i.e., friends have a joint friend), homophily becomes much less important and vice versa.

Model 4 focuses on the interaction between multiple dimensions of homophily[8] (hypothesis 5). The parameter estimates in both models are significantly negative. For the ASSIST data, this means that being of the same sex is less important of a predictor of friendship if people are in the same form and vice versa. In the Glasgow data, once two adolescents receive similar amounts of pocket money, the importance of whether they are of the same sex decreases strongly and vice versa.

The full model for either data set includes all interactions. In the ASSIST data with more statistical power, five of six parameters remain significantly negative and of substantial size. In the Glasgow data that consist of one network three of six parameter estimates remain significantly negative. However, given the large collinearity of the different interactions, including all of them might be asking too much from data of this size. Additionally, parameter interpretation is very difficult

Table 2: Results from the SAOM analysis of of Glasgow data.

		Model 1 est (s.e.)	Model 2 est (s.e.)	Model 3 est (s.e.)	Model 4 est (s.e.)	Full Model est (s.e.)
H1	Reciprocity	$2.00^{\dagger}$	$3.30^{\dagger}$	$2.77^{\dagger}$	$2.81^{\dagger}$	$3.14^{\dagger}$
		(0.11)	(0.28)	(0.16)	(0.15)	(0.30)
	First joint friend	$1.19^{\dagger}$				
		(0.14)				
	Additional joint friend	$0.43^{\dagger}$				
		(0.10)				
	Transitivity (weighted)		$2.17^{\dagger}$	$2.65^{\dagger}$	$2.18^{\dagger}$	$2.56^{\dagger}$
			(0.10)	(0.20)	(0.10)	(0.20)
	Same sex	$0.72^{\dagger}$	$0.81^{\dagger}$	$0.96^{\dagger}$	$0.74^{\dagger}$	$1.10^{\dagger}$
		(0.08)	(0.13)	(0.13)	(0.10)	(0.16)
	Money similarity	$1.12^{\dagger}$	$1.74^{\dagger}$	1.25^{*}	2.98^{*}	3.41^{*}
		(0.29)	(0.40)	(0.47)	(0.95)	(1.08)
H2	Transitivity * reciprocity		$-0.85^{\dagger}$	$-0.85^{\dagger}$	$-0.90^{\dagger}$	$-0.83^{\dagger}$
			(0.18)	(0.20)	(0.18)	(0.18)
H3	Same sex * reciprocity		-0.53^{*}			-0.38
			(0.26)			(0.29)
	Money similarity * reciprocity		-1.71^{*}			-1.56^{*}
			(0.73)			(0.76)
H4	Same sex * transitivity			-0.55^{*}		-0.47^{*}
				(0.19)		(0.20)
	Money similarity * transitivity			-0.27		0.06
				(0.62)		(0.57)
H5	Same sex * money similarity				-2.03^{*}	-1.88
					(0.94)	(1.04)

Notes: The table only shows parameters testing hypotheses and main effects comprising the interactions. Additional control parameters model the intercept (density), indegree and outdegree distributions, two paths, and attractivity and popularity for sex and pocket money. Full results and their interpretation are found in the online supplement. Estimation of parameters used Method of Moments. The number of iterations in phase 3 was 2,500. All models converged with an overall convergence ratio of < 0.25 and a convergence t-ratio for each parameter of < 0.1. est, estimate; H1, hypothesis 1; H2, hypothesis 2; H3, hypothesis 3; H4, hypothesis 4; H5, hypothesis 5; s.e., standard error. * $p < 0.05$; † $p < 0.01$.

Table 3: Results from the SAOM meta-analysis of ASSIST data.

		Model 1 est (s.e.)	Model 2 est (s.e.)	Model 3 est (s.e.)	Model 4 est (s.e.)	Full Model est (s.e.)
H1	Reciprocity	1.66* (0.05)	3.45* (0.12)	2.64* (0.06)	2.85* (0.06)	3.21* (0.11)
	First joint friend	1.25* (0.05)				
	Additional joint friend	0.31* (0.01)				
	Transitivity (weighted)		2.09* (0.05)	2.93* (0.12)	2.13* (0.05)	2.86* (0.12)
	Same sex	0.57* (0.06)	0.64* (0.06)	0.93* (0.09)	0.59* (0.07)	1.02* (0.10)
	Same form	0.37* (0.04)	0.53* (0.04)	0.78* (0.05)	0.58* (0.06)	0.89* (0.05)
H2	Transitivity * reciprocity		−1.10* (0.05)	−0.96* (0.05)	−1.21* (0.05)	−0.94* (0.05)
H3	Same sex * reciprocity		−0.56* (0.09)			−0.48* (0.08)
	Same form * reciprocity		−0.46* (0.05)			−0.34* (0.06)
H4	Same sex * transitivity			−0.75* (0.10)		−0.69* (0.10)
	Same form * transitivity			−0.55* (0.04)		−0.52* (0.04)
H5	Same sex * same form				−0.27* (0.07)	0.007 (0.046)

Notes: The table only shows parameters testing hypotheses and main effects comprising the interactions. Additional control parameters model the intercept (density), indegree and outdegree distributions, two paths, and attractivity and popularity for sex. Full results and their interpretation are found in the online supplement. Each school used in the meta-analysis was estimated by using Method of Moments. The number of iterations in phase 3 was 2,500. All models converged with an overall convergence ratio of < 0.25 and a convergence t-ratio for each parameter of < 0.1. est, estimate; H1, hypothesis 1; H2, hypothesis 2; H3, hypothesis 3; H4, hypothesis 4; H5, hypothesis 5; s.e., standard error. * $p < 0.01$.

for the interactions when all other interactions in addition to the main effects must be taken into account. Overall, the parameters from the discussed models are in the overwhelming majority in line with the hypotheses.

Extrapolation to Macro-Level Structures

Do the found negative interaction patterns between reciprocity, transitivity, and homophily indeed relate to overall network structure, especially the integration of the network, as proposed in the section on macro-level consequences? To explore this question, two sets of simulations of network evolution are conducted. Both use the Glasgow data, but results equally hold for the ASSIST data. One set of simulations uses the specification and parameters of the full model as specified in Table 2 and with the controls in Table S2 of the online supplement. This is termed the "compartmentalization model," as it includes the tendency of people to meet people in different social circles. The second set of simulations is identical to the first except that it excludes all interaction parameters from the model (those below the solid line in Table 2) and has an adjusted intercept to produce networks with the correct density. This model is termed the "additive model," as reciprocity, transitivity, and homophily are assumed to be additive and to not mitigate one another by a negative interaction.

One exemplary simulated network of either simulation and the observed network are depicted in Figure 5. Visual analysis of the networks shows that the observed network as well as the simulated network under the compartmentalized model show clear separation between sexes as indicated by color. Furthermore, a clear formation of subgroups is discernible. However, the networks remain quite integrated, with only one large component existing as well as the subgroups generally being connected to multiple other subgroups. Within a few steps, a connection between most people in the network can be established. The additive model, on the contrary, falls apart into multiple components that are densely connected within. At best, some of these have contact with other parts of the network through one tie. This results in a strong community structure and long paths between different people in the network.

A quantitative analysis of a large number of simulated networks that compares average metrics for simulations between the models and the observed network (available upon request) comes to the same conclusions. The compartmentalized model can reasonably reproduce metrics of the observed network that relate to network integration, such as modularity, the number of components, or average path length. Simulated networks from the additive model, on average, show a much stronger network segregation than the observed network. In conclusion, negative interactions between the main effects do ensure an integrated macro-level network structure that is in line with empirical observations.

Summary and Discussion

How do adolescents form and maintain their friendships? How are friendship patterns and evolution related to social interaction patterns? And how does this

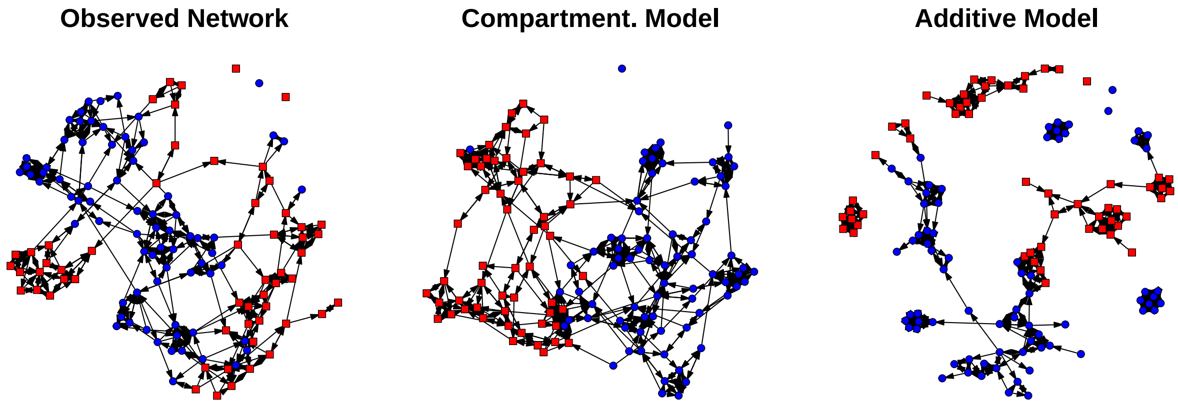

Figure 5: Glasgow data network at time 3 as observed and simulated under two models. Compartment., compartmentalizing.

relate to macro-level network regularities? This article contributes in three ways to these broad questions. First, the network embedding of a friendship provides information about the context and social situations in which it is formed and maintained. Situations in which individuals meet in social cliques, in the colloquial meaning, can be connected to transitive network embedding. Dyadic situations in which two adolescents spend time without others are related to reciprocal friendships. Homophily is connected to group-based activities and situations that are typical for a certain demographic group. These insights on friendship ties can be used to infer patterns in personal networks.

Second, when two individuals have one forum for interaction with one another, meeting in additional, other situations has decreasing returns. In other words, the first, joint forum for interaction in which people meet increases the likelihood for friendship formation and maintenance most; every additional social situation in which to meet is less important. For personal networks, this means that adolescents compartmentalize their friends. Some friends are embedded in social groups, others in demographic groups, and others in reciprocated dyads. From the relation between social situations and network evolution mechanisms, it can be inferred that different network structuring mechanisms mitigate and work in substitution of one another. Being indirectly tied to other individuals can overcome demographic differences that would otherwise make friendship formation unlikely. At the same time, homophily on one demographic dimension can overcome sociometric distance as well as differences on other homophilous dimensions. Furthermore, once a friendship is reciprocated, neither homophily nor transitive embedding seems to contribute much to the stability of a friendship. Overall, the empirical results of this article, jointly with previous literature, suggest that the three major network evolution mechanisms partly substitute one another, which is reflected by the negative interaction in the statistical model.

Third, this can be tied to overall network structure. Unintuitively, the compartmentalization of individual networks leads to an overall integration on the network level. This is because homophily and transitive closure in particular are attractive forces that lead to the formation of subgroups within a network. If these tendencies towards the formation of groups would reinforce one another, networks would Balkanize into cohesive clusters that have little contact with one another. The individual compartmentalization prohibits this Balkanization through the tendency of individuals to be members of multiple, nonoverlapping groups, making people potential bridges between different parts of the network.

The summarized key findings partly mirror and complement established findings and theories, bringing together multiple key contributions to the literature on interpersonal ties and interaction. A relation between interaction contexts and friendship patterns has been proposed for homophily (e.g., Feld 1981, 1982) and transitivity (e.g., Granovetter 1973). Consolidating these concepts into one framework of friendship evolution is a key contribution of this study. Equally, interactions between network evolution mechanisms have been analyzed empirically, notably multiple dimensions of transitivity, multiple homophily, or the relation between reciprocity and transitivity (see the section on past empirical work). However, these findings have not been related to one another.

Implications and Relation to Wider Literature

Research on the integration of networks can be motivated by its role in understanding individual outcomes, such as labor market success or physical and mental health, that depend substantially on social capital (Mouw 2006; Rivera et al. 2010; Dunbar 2018). The diversity of one's friendship network, as well as the kinds of resources these friends have to offer, are particularly important. Integration or segregation between different groups then becomes an important predictor for individual and group-level outcomes.

Given this insight, analyzing the patterns of association between different groups and people was of interest to sociologists from the very beginning of the discipline, with Simmel (1950) analyzing patterns of association between individuals. Blau's macrosociological theory of social structure is closely related. Blau (1977) deduces theoretically and shows empirically in collaboration with Schwartz (Blau and Schwartz 1984) how the relative size and intersection of group membership relate to patterns of integration and segregation. He uses a macrosocial perspective focusing on interaction patterns within a population, mostly leaving aside network mechanisms that influence people's tie formation within given constraints. Rather, his analysis focuses on analyzing these constraints. The study at hand complements these insights. The constraints on interaction are taken as given. How people form their ties in relation to membership in multiple, potentially intersecting groups is analyzed. The constrained environments analyzed in this article are school cohorts.

The finding by Blau (1977) and colleagues (Blau and Schwartz 1984) that more heterogeneity in the composition of a population leads to larger intergroup contact, if dimensions are not highly correlated, is extended to friendships formed by individuals regarding their personal network. When individuals form ties, it seems that similarity on one dimension or embedding in informal network structures (transitivity) enables forming social bonds regardless of other differences. A study of a complete network of adults offers further support. Stadtfeld and Pentland (2015) show that cross-sex friendships in a housing community of adult couples are unlikely unless the cohabiting partner is already friends with the cross-sex other. The transitive connection of the partner to a cross-sex alter can overcome the difference between the sexes.

This suggests that segregation on demographic attributes might mainly be attributed to limited interaction opportunities, which might stem from, for example, organizational, residential, or occupational segregation. This is in line with previous research by Moody (2001), who suggests that much segregation in U.S. high schools can be attributed to organizational constraints that structure how students interact. Similarly, Mouw and Entwisle (2006) show that segregation in friendship patterns is highly induced by residential segregation. Both studies point to the importance of establishing contact in a social setting to enable integrated friendships. This proposition is further supported by research on the change in individual networks once institutionalized interaction opportunities disappear. Lubbers, Jariego, and Molina[9] find that immigrant adolescents in Spain who were well integrated while going to school can lose most of their ties to the native population once they graduate. This is attributed to loss of natural interaction opportunities in school, as a spontaneously emerged preference against interacting with individuals from the host country is unlikely. However, as recently pointed out by Schaefer, Simpkins, and Ettekal (2018), bringing adolescents together in voluntary activities is not always the solution to creating intergroup ties, as within those activities, homophilous preferences might exist.

Limitations and Challenges

I highlight three areas that I perceive as most important and relevant in terms of limitation and challenges. First, the corroboration of the assumptions is limited. The patterns of what adolescents do with their friends in the Glasgow data are in line with the assumptions. However, detailed data on places, times, and compositions of interactions are desirable to thoroughly analyze how friendship networks patterns relate to social circles. This is difficult using currently available survey data, as it places very high demand on survey participants given that they would have to give detailed accounts of where and when they spend time with whom. However, increasingly fine-grained data collected through social censors, such as mobile phones (e.g., Eagle, Pentland, and Lazer 2009; Raento, Oulasvirta, and Eagle 2009), can track the whereabouts of individuals in detail. In combination with traditional survey data, this might enable such analysis in the near future and give insights into how people interact with their friends and which interaction patterns relate to which friendships embedding.

Second, the data are only on an adolescent population. As outlined earlier, there are concrete reasons to focus on adolescence, as peer interaction in this period in life is crucial; the school is a clearly defined, relevant social setting; and it links with a large body of literature. However, this should not hide that segregation outcomes in particular would be highly interesting for adult populations. Complete network studies on adults, though, are rare for the simple reason that finding bounded environments in which "normal" adults interact with one another are difficult. Studies on polar research stations (Johnson, Boster, and Palinkas 2003) or prison inmates (Kreager et al. 2015) are hardly generalizable to a larger population when it comes to the formation of voluntary, informal contact. However, finding clearly bounded networks is crucial for currently available statistical network tools, even though advances are being made for other sampling strategies by now (Pattison et al. 2013; Stivala et al. 2016). Nevertheless, although studying school cohorts is the dominant approach to gain insight on network evolution empirically, we do not know enough about the networks of adults, and we can only claim limited generalizability of findings to other populations.

Third, the specification of a counterfactual simulation comes with making decisions that can be the subject of discussion. These simulations should be viewed as computer-assisted thought experiments rather than predictions of the outcomes of potential interventions. I opted for a straightforward specification of a counterfactual simulation that sets parameters of interest to zero and only adjusts the intercept among the other simulation parameters. The assumption underlying this approach is that the full estimated model is a "true reflection" of the world. A counterfactual world in this thought experiment is one in which networks evolve according to the same parameters except for the absence of interactions. I believe this to be a better counterfactual model than reestimating other model parameters, as these would differ from the true parameters. However, there does not seem to be an academic consensus on this matter.

Future Directions

A number of elaborations and implications of the theoretical model reveal themselves. First, in contemporary research, all kinds of qualitatively different relationships are called friendships even though they vary vastly in content and function, reflected by the various social and emotional needs friends satisfy (Fischer 1982). This is mirrored in the fact that there is no generally agreed upon definition of friendship in scholarly writing beyond the minimal compromise that a friendship implies positive affection and spending time together. Therefore, when we ask a person to nominate, for example, his or her 10 best friends in a network survey, we really do not know what their actual relationship to the nominated partners is like. This is especially problematic as one of the main reasons why we study friendship networks is that friends provide specific resources and influence one another, but the assumption that every friend has the capacity to and is met in the right context in which he or she can provide new information about a job, can buffer against depression, or can help to improve academic performance seems questionable. Knowing the context and thus the social circles in which friendships are embedded would greatly improve our ability to explain how much social capital of different sorts a person can access from his or her friends. The network configurations in which a friendship tie is embedded can give a first indication about the social circles in which the tie exists.

Thinking one step further, research on social influence could benefit from considering social situations. In order for a person to be influenced by peers, it might not only matter whether they are friends but also in which context they meet. For example, it is possible that health-related behaviors (such as drinking) are especially salient in, say, situations that are stratified by gender (e.g., sport clubs; Pearson, Steglich, and Snijders 2006). Influence on these dimensions could be specific to gender-homophilous ties but not gender-heterophilous ones. More generally, if only specific contexts allow influence between individuals, then approximating these contexts by the network embedding of a friendship can help in understanding influence processes in more depth.

Finally, the proposed theoretical model might extend to other forms of ties embedded within networks. For example, advice relations (Snijders et al. 2013) are likely to form within the context of social settings that should equally be related to network evolution mechanisms. Indication that the outlined model might apply to corporate actors comes from Sorenson and Stuart (2008). They analyze the formation of coinvestment ties between venture capitalists with explicit reference to the settings in which these trust-intensive relationships are formed. Their findings of a negative interaction between network embedding and homophily are fully consistent with the model presented in this article. Future research might explore systematically which types of relations this model could be applied to.

In sum, the presented study might not only give insight into the evolution of friendship networks, taking the complex interdependencies of network mechanisms into account, but furthermore to speak to other areas of adolescent network and peer research and inspire future studies.

Notes

1 For other network mechanisms, such as dynamics of degree (as found in citation networks) or dynamics of hierarchy (as found in grooming networks), evidence of whether these manifest in friendship networks is inconclusive and seems to depend on the data source, analysis method, and model parameterization; their importance in structuring friendship networks is at best secondary compared to the major three mechanisms (see Rivera et al. 2010).

2 This diagnosis by Fischer (1982) remains valid until today and is exemplified by the vast number of adolescent network studies that elicit friendship networks in numerous ways as well as the lack of any discussion of the meaning of the concept friendship in articles on adolescent networks. See also Adams, Blieszner, and de Vries (2000) and related research.

3 In principle, four typical situations could be defined given that the two dimensions form a 2x2 table. However, the fourth, omitted type (dyadic, exogenous) is presumed to be rare and of limited relevance.

4 The Chief Scientist Office of the Scottish Home and Health Department funded the study under its Smoking Initiative (grant K/OPR/17/8).

5 http://www.stats.ox.ac.uk/s̃nijders/siena/Glasgow_data.htm (last accessed April 30, 2018).

6 The study was funded by the medical research council of the United Kingdom (project number ISRCTN55572965).

7 For a discussion of the advantages of the continuous-time network model compared to discrete-time models, see Block et al. (2018).

8 For the Glasgow data, this is a replication of Block and Grund (2014).

9 Workshop presentation at the "Social Influence in Dynamic Networks" seminar in Barcelona, Spain, from November 6 to 8, 2013.

References

Adams, Rebecca G., Rosemary Blieszner, and Brian de Vries. 2000. "Definitions of Friendship in the Third Age: Age, Gender, and Study Location Effects." *Journal of Aging Studies* 14:117–33. https://doi.org/10.1016/S0890-4065(00)80019-5.

Baumeister, Roy F., and Mark R. Leary. 1995. "The Need to Belong – Desire for Interpersonal Attachments as a Fundamental Human Motivation." *Psychological Bulletin* 117:497–529. https://doi.org/10.1037/0033-2909.117.3.497.

Blau, Peter M. 1977. "A Macrocosial Theory of Social Structure." *American Journal of Sociology* 83:26–54. https://doi.org/10.1086/226505.

Blau, Peter M., and Joseph E. Schwartz. 1984. *Crosscutting Social Circles: Testing a Macrostructural Theory of Intergroup Relations.* Orlando, FL: Academic Press.

Block, Per. 2015. "Reciprocity, Transitivity, and the Mysterious Three-Cycle." *Social Networks* 40:163–73. https://doi.org/10.1016/j.socnet.2014.10.005.

Block, Per, and Thomas Grund. 2014. "Multidimensional Homophily in Friendship Networks." *Network Science* 2:189–212. https://doi.org/10.1017/nws.2014.17.

Block, Per, Johan Koskinen, James Hollway, Christian Steglich, and Christoph Stadtfeld. 2018. "Change We Can Believe in: Comparing Longitudinal Network Models on Consistency, Interpretability and Predictive Power." *Social Networks* 52:180–91. https://doi.org/10.1016/j.socnet.2017.08.001.

Boda, Zsófia. 2018. "Social Influence on Observed Race." *Sociological Science* 5:29–57. https://doi.org/10.15195/v5.a3.

Burt, Ronald S. 1992. *Structural Holes: The Social Structure of Competition.* Cambridge, MA: Harvard University Press.

Campbell, Rona, Fenella Starkey, Jo C. Holliday, Suzanne Audrey, Michael J. Bloor, Nina Parry-Langdon, Rachael A. C. Hughes, and Laurence A. R. Moore. 2008. "An Informal School-Based Peer-Led Intervention for Smoking Prevention in Adolescence (ASSIST): A Cluster Randomised Trial." *The Lancet* 371:1595–602. https://doi.org/10.1016/S0140-6736(08)60692-3.

Coleman, James S. 1961. *The Adolescent Society*. Glencoe, IL: Free Press.

Cross, Jennifer L. M., and Nan Lin. 2008. "Access to Social Capital and Status Attainment in the United States: Racial/Ethnic and Gender Differences." Pp. 364–79 in *Social Capital: An International Research Program*, edited by N. Lin and B. H. Erickson. Oxford, UK: Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199234387.003.0161.

Dunbar, R. I. M. 2018. "The Anatomy of Friendship." *Trends in Cognitive Sciences* 22:32–51. https://doi.org/10.1016/j.tics.2017.10.004.

Eagle, Nathan, Alex (Sandy) Pentland, and David Lazer. 2009. "Inferring Friendship Network Structure by Using Mobile Phone Data." *Proceedings of the National Academy of Sciences* 106:15274–8. https://doi.org/10.1073/pnas.0900282106.

Emerson, Richard M. 1976. "Social Exchange Theory." *Annual Review of Sociology* 2:335–62. https://doi.org/10.1146/annurev.so.02.080176.002003.

Feld, Scott L. 1981. "The Focused Organization of Social Ties." *American Journal of Sociology* 86:1015–35. https://doi.org/10.1086/227352.

Feld, Scott L. 1982. "Social Structural Determinants of Similarity among Associates." *American Sociological Review* 47:797–801. https://doi.org/10.2307/2095216.

Festinger, Leon, Stanley Schachter, and Kurt Back. 1950. *Social Pressures in Informal Groups*. Stanford, CA: Stanford University Press.

Fischer, Claude S. 1982. "What Do We Mean by 'Friend'? An Inductive Study." *Social Networks* 3:287–306. https://doi.org/10.1016/0378-8733(82)90004-1.

Fujimoto, Kayo, Tom A. B. Snijders, and Thomas W. Valente. 2017. "Popularity Breeds Contempt: The Evolution of Reputational Dislike Relations and Friendships in High School." *Social Networks* 48:100–09. https://doi.org/10.1016/j.socnet.2016.07.006.

Gould, Roger V. 2002. "The Origins of Status Hierarchies: A Formal Theory and Empirical Test." *American Journal of Sociology* 107:1143–78. https://doi.org/10.1086/341744.

Granovetter, Mark S. 1973. "The Strength of Weak Ties." *American Journal of Sociology* 78:1360–80. https://doi.org/10.1086/225469.

Heider, Fritz. 1958. *The Psychology of Interpersonal Relations*. New York, NY: Wiley. https://doi.org/10.1037/10628-000.

Igarashi, Tasuku. 2013. "Longitudinal Changes in Face-to-Face and Text Message-Mediated Friendship Networks." Pp. 248–59 in *Exponential Random Graph Models for Social Networks: Theories, Methods and Applications*, edited by D. Lusher, J. Koskinen, and G. Robins. Cambridge, UK: Cambridge University Press.

Johnson, Jeffrey C., James S. Boster, and Lawrence A. Palinkas. 2003. "Social Roles and the Evolution of Networks in Extreme and Isolated Environments." *Journal of Mathematical Sociology* 27:89–121. https://doi.org/10.1080/00222500305890.

Kossinets, Gueorgi, and Duncan J. Watts. 2009. "Origins of Homophily in an Evolving Social Network." *American Journal of Sociology* 115:405–50. https://doi.org/10.1086/599247.

Kreager, Derek A., David R. Schaefer, Martin Bouchard, Dana L. Haynie, Sara Wakefield, Jacob Young, and Gary Zajac. 2015. "Toward a Criminology of Inmate Networks." *Justice Quarterly* 8825:37–41.

Labun, Alona, Rafael P. M. Wittek, and Christian E. G. Steglich. 2016. "The Co-evolution of Power and Friendship Networks in an Organization." *Network Science* 4:364–84. https://doi.org/10.1017/nws.2016.7.

Leszczensky, Lars, and Sebastian Pink. 2015. "Ethnic Segregation of Friendship Networks in School: Testing a Rational-Choice Argument of Differences in Ethnic Homophily between Classroom- and Grade-Level Networks." *Social Networks* 42:18–26. https://doi.org/10.1016/j.socnet.2015.02.002.

Marsden, Peter V. 1990. "Network Data and Measurement." *Annual Review of Sociology* 16:435–63. https://doi.org/10.1146/annurev.so.16.080190.002251.

McPherson, J. Miller, and Lynn Smith-Lovin. 1987. "Homophily in Voluntary Organizations: Status Distance and the Composition of Face-to-Face Groups." *American Sociological Review* 52:370. https://doi.org/10.2307/2095356.

McPherson, Miller, Lynn Smith-Lovin, and James M. Cook. 2001. "Birds of a Feather: Homophily in Social Networks." *Annual Review of Sociology* 27:415–44. https://doi.org/10.1146/annurev.soc.27.1.415.

Moody, James. 2001. "Race, School Integration, and Friendship Segregation in America." *American Journal of Sociology* 107:679–716. https://doi.org/10.1086/338954.

Mouw, Ted. 2006. "Estimating the Causal Effect of Social Capital: A Review of Recent Research." *Annual Review of Sociology* 32:79–102. https://doi.org/10.1146/annurev.soc.32.061604.123150.

Mouw, Ted, and Barbara Entwisle. 2006. "Residential Segregation and Interracial Friendship in Schools." *American Journal of Sociology* 112:394–441. https://doi.org/10.1086/506415.

Pattison, Philippa, and Garry Robins. 2002. "Neighborhood-Based Models for Social Networks." *Sociological Methodology* 32:301–37. https://doi.org/10.1111/1467-9531.00119.

Pattison, Philippa, Garry Robins, Tom A. B. Snijders, and Peng Wang. 2013. "Conditional Estimation of Exponential Random Graph Models from Snowball Sampling Designs." *Journal of Mathematical Psychology* 57:284–96. https://doi.org/10.1016/j.jmp.2013.05.004.

Pearson, Michael, and Lynn Michell. 2000. "Smoke Rings: Social Network Analysis of Friendship Groups, Smoking and Drug-Taking." *Drugs: Education Prevention and Policy* 7:21–37.

Pearson, Michael, Christian E. G. Steglich, and Tom A. B. Snijders. 2006. "Homophily and Assimilation among Sport-Active Adolescent Substance Users." *Connections* 27:47–63.

Raento, Mika, Antti Oulasvirta, and Nathan Eagle. 2009. "Smartphones: An Emerging Tool for Social Scientists." *Sociological Methods and Research* 37:426–54. https://doi.org/10.1177/0049124108330005.

Rivera, Mark T., Sara B. Soderstrom, and Brian Uzzi. 2010. "Dynamics of Dyads in Social Networks: Assortative, Relational, and Proximity Mechanisms." *Annual Review of Sociology* 36:91–115. https://doi.org/10.1146/annurev.soc.34.040507.134743.

Schaefer, David R., Sandra D. Simpkins, and Andrea V. Ettekal. 2018. "Can Extracurricular Activities Reduce Adolescent Race/Ethnic Friendship Segregation?" Pp. 315–39 in *Social Networks and the Life Course*, edited by D. A. Kreager, D. H. Felmlee, and D. F. Alwin. Cham, Switzerland: Springer. https://doi.org/10.1007/978-3-319-71544-5_15.

Simmel, Georg. 1950. *The Sociology of Georg Simmel*. New York, NY: Free Press.

Smetana, Judith G., Nicole Campione-Barr, and Aaron Metzger. 2006. "Adolescent Development in Interpersonal and Societal Contexts." *Annual Review of Psychology* 57:255–84. https://doi.org/10.1146/annurev.psych.57.102904.190124.

Snijders, Tom A. B. 2001. "The Statistical Evaluation of Social Network Dynamics." *Sociological Methodology* 31:1–33. https://doi.org/10.1111/0081-1750.00099.

Snijders, Tom A. B. 2005. "Models for Longitudinal Network Data." Pp. 215–47 in *Models and Methods in Social Network Analysis*, edited by P. Carrington, J. Scott, and S. Wasserman. New York, NY: Cambridge University Press. https://doi.org/10.1017/CBO9780511811395.011.

Snijders, Tom A. B., and Chris Baerveldt. 2003. "A Multilevel Network Study of the Effects of Delinquent Behavior on Friendship Evolution." *Journal of Mathematical Sociology* 27:123–51. https://doi.org/10.1080/00222500305892.

Snijders, Tom A. B., Alessandro Lomi, and Vanina J. Torlo. 2013. "A Model for the Multiplex Dynamics of Two-Mode and One-Mode Networks, with an Application to Employment Preference, Friendship, and Advice." *Social Networks* 35:265–76. https://doi.org/10.1016/j.socnet.2012.05.005.

Snijders, Tom A. B., Philippa Pattison, Garry Robins, and Mark S. Handcock. 2006. "New Specifications for Exponential Random Graph Models." *Sociological Methodology* 36:99–153. https://doi.org/10.1111/j.1467-9531.2006.00176.x.

Snijders, Tom A. B., Gerhard van de Bunt, and Christian E. G. Steglich. 2010. "Introduction to Stochastic Actor-Based Models for Network Dynamics." *Social Networks* 32:44–60. https://doi.org/10.1016/j.socnet.2009.02.004.

Sorenson, Olav, and Toby E. Stuart. 2008. "Bringing the Context Back In: Settings and the Search for Syndicate Partners in Venture Capital Investment Networks." *Administrative Science Quarterly* 53:266–94. https://doi.org/10.2189/asqu.53.2.266.

Stadtfeld, Christoph, and Per Block. 2017. "Interactions, Actors, and Time: Dynamic Network Actor Models for Relational Events." *Sociological Science* 4:318–52. https://doi.org/10.15195/v4.a14.

Stadtfeld, Christoph, and Alex Pentland. 2015. "Partnership Ties Shape Friendship Networks: A Dynamic Social Network Study." *Social Forces* 94:1–25. https://doi.org/10.1093/sf/sov079.

Steglich, Christian E. G., Philip Sinclair, Jo C. Holliday, and Laurence A. R. Moore. 2012. "Actor-Based Analysis of Peer Influence in A Stop Smoking In Schools Trial (ASSIST)." *Social Networks* 34:359–69. https://doi.org/10.1016/j.socnet.2010.07.001.

Steglich, Christian E. G., Tom A. B. Snijders, and Michael Pearson. 2010. "Dynamic Networks and Behavior: Separating Selection from Influence." *Sociological Methodology* 40:329–93. https://doi.org/10.1111/j.1467-9531.2010.01225.x.

Steinberg, Laurence, and Amanda S Morris. 2001. "Adolescent Development." *Annual Review of Psychology* 52:83–110. https://doi.org/10.1146/annurev.psych.52.1.83.

Stivala, Alex D., Johan Koskinen, David A. Rolls, Peng Wang, and Garry Robins. 2016. "Snowball Sampling for Estimating Exponential Random Graph Models for Large Networks." *Social Networks* 47:167–88. https://doi.org/10.1016/j.socnet.2015.11.003.

Turner, John C. 1987. *Rediscovering the Social Group: A Self-Categorization Theory*. Oxford, UK: Basil Blackwell.

Van De Bunt, Gerhard G., Marijtje A. J. Van Duijn, and Tom A. B. Snijders. 1999. "Friendship Networks through Time: An Actor-Oriented Dynamic Statistical Network Model." *Computational and Mathematical Organization Theory* 52:167–92. https://doi.org/10.1023/A:1009683123448.

Verbrugge, Lois M. 1977. "The Structure of Adult Friendship Choices." *Social Forces* 56:576–97. https://doi.org/10.1093/sf/56.2.576.

Watts, Duncan J. 1999. "Networks, Dynamics, and the Small-World Phenomenon." *American Journal of Sociology* 105:493–527. https://doi.org/10.1086/210318.

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