# The User's Communication Patterns on A Mobile Social Network Site

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## ABSTRACT
Given that users are simultaneously connected in multiple communication channels in a social networking service site (e.g., chat, message, and group message), we explore user's collective networking behavior. We collected the data from a mobile social networking site with 4.8 million registered users. The empirical estimation shows interesting results: (1) there are cross-effects across the communication channels: substitute effects for "chat and message" and complementary effects for "message and group message" and "chat and group message" (2) there is significant local network effect but global network effect is not observed, (3) users utilize communication channels for different purposes according to their networking activity level (conveying simple information vs. building sophisticated inter-relationship), and (4) we identify the distinct evolutionary trajectories of an individual user's networking behavior by channel: negative slopes for chat and message vs. upward trend for a group message. Our experimental study shows that we can better predict the word of mouth (WOM) effects by understanding users' collective networking behavior across diverse channels.

## Categories and Subject Descriptors
J.4 [**Computer Applications**]: Social and Behavior Sciences-Economics

## General Terms
Management, Economics Experimentation

## Keywords
Mobile Social Network; Multiple Communication Channels; Evolution of Networking Behavior; Cross-Effects

## 1. INTRODUCTION
Social networking sites (SNSs, also called social networking service sites) have shown phenomenal growth. In 2011, the number of social network users worldwide was bit more than 1.17 billion and the number has reached 1.40 billion in 2012, showing around 20% increase. The number of Facebook users is expected to exceed 1 billion in 2013. Given the phenomenal online/mobile social network activities, previous studies have been exploring a social network structure (the interactivity among users and their network formation) as an emergent property of social interactions [1, 2] and/or the managerial implication of the social relations as its economic outcome [3-6].


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Previous studies have not substantively addressed multiple relationships among users, even though users are generally connected through diverse/multiple channels. In practice, social networking sites basically provide numerous communication venues for users to share their views, preferences, or experiences with others including the evaluation of a certain product or service (e.g., chat, message, group message and blogging). There are very few studies that explore multiplex relationships in social networks. The only prior work we are aware of is a recent paper by Ansari et al. [1]. They examine the structure of social relationships across three networks separately developed for different purposes (friendship, communication, and music download across artists). Also, in business-to-business (B2B) settings rather than a social network, Tuli et al. [7] investigates the effect of multiple connections between a supplier and a consumer (e.g., marking, R&D, servers, and licensing). In contrast to the relationships among different types of connections, this study focuses on the multiple communication channels commonly available in a SNS. We have three research goals: (1) examining how users communicate through diverse communication channels in a SNS, (2) understanding users' sociological behavior (including network and blogging activities), and (3) its dynamics over time and its variations across users, particularly according to a user's networking activity level.

Methodologically speaking, we estimate the system of structural equations via three-stage least squares estimation. Therefore, our generalized simultaneous equations model enables us to release the assumption of a symmetric interaction in dependence patterns [8] and account for potential asymmetric dependency across channels [9].

## 2. RESEARCH QUESTIONS
We first aim to analyze the *interpersonal communication structure across multiple communication channels* (on multiplex communication networks) in a SNS site. As shown in general social network and social media sites, users communicate real time through diverse communication channels with peers of their acquaintances. Particularly, this study focuses on users' social interactions in the three most popular communication channels (chat, message, and group message). We can intuitively classify the cross-effects between two channels into four scenarios on two dimensions (substitute versus complement and symmetric versus asymmetric). Given the four scenarios on the 2 by 2 matrix, we attempt to identify the nature of the cross-effects in each combination of the three channels.

Once the cross-effects are verified, we subsequently aim to answer a natural question of the *heterogeneous configurations of communication structure among users*. Particularly, we examine the dynamics of the cross-effects depending on a user's networking activity level (communication frequency).

Our next question is to examine *the evolution of tie strength between two users over time, particularly by communication channels*. Then, we can understand the dynamics of a user's communication channel choices over time by comparing the estimated trajectories in addition to the mutual dependency (cross-effects) among channels at time *t* that is our first research question.

In this study, we develop two kinds of network size: (1) local network size (measured by the number of peers connected to a user) and (2) whole network size (measured by the total number of active users at time *t* in a SNS). The local network size on the tie strength is an interesting empirical question. Similarly, we examine how the whole network size representing social environment (rather than individual user's propensity) affects the tie strength of a specific connection.

**Table 1. Variables and Operational Definitions**

| Variable | Operational Definition |
|---|---|
| *i*, *j* | User index |
| *t* | Time index (month) |
| $Chat_{ijt}$ | The number of chat sessions user *i* and *j* share together at *t* |
| $Message_{ijt}$ | The number of messages user i sends to user *j* at *t* |
| $GroupMessage_{ijt}$ | The number of group messages user *i* sends in the groups users *i* and *j* are both engaged in at *t* |
| $Group_{ijt}$ | The number of groups users *i* and *j* belong to at *t* |
| $CumulChat_{ijt}$ | The number of chat sessions user *i* and receive *j* join together at *t* |
| $CumulMessage_{ijt}$ | The number of cumulative messages user *i* has sent to user *j* through *t* |
| $CumulGroupMessage_{ijt}$ | The number of cumulative group messages user *i* has sent in the groups users *i* and *j* are engaged through *t* |
| $Testimonial_{ijt}$ | 1 if user *i* leave a testimonial of user *j* at *t*, otherwise 0 |
| $ChatNetwork_{it}$ | The number of users user *i* is connected to at *t* |
| $MessageSentNetwork_{it}$ | The number of users user *i* sent messages to at *t* |
| $MessageReceivedNetwork_{it}$ | The number of users user *i* received messages from at *t* |
| $GroupNetwork_{it}$ | The number of users user *i* joins at *t* |
| $ChatActivity_{it}$ | The number of total chat sessions user *i* creates/joins at *t* |
| $MessageSent_{it}$ | The number of messages user *i* sent at *t* |
| $MessageReceived_{it}$ | The number of messages user *i* received at *t* |
| $GroupActivity_{it}$ | The number of groups user *i* joins at *t* |
| $GroupMessageSent_{it}$ | The number of group messages user i sends at *t* |
| $TestimonialSent_{it}$ | The number of testimonials user *i* sends at *t* |
| $TestimonialReceived_{it}$ | The number of testimonials user *i* receives at *t* |
| $WholeNetworkSize_{t}$ | The total number of active users at time *t* over the whole network |
| $WholeChatSize_{t}$ | The total number of chat sessions at time *t* over the whole network |
| $WholeMessageSize_{t}$ | The total number of messages sent at time *t* over the whole network |
| $WholeGroupMsgSize_{t}$ | The total number of group messages at time t over the whole network |
| $TimeSinceSingup_{it}$ | The elapsed time since user *i* signed up through *t* |
| $TimeSinceLinkage_{ijt}$ | The elapsed time since user *i* and *j* were connected through *t* |
| $Blog_{it}$ | 1 if the user *i* has blog at *t*, otherwise 0 |
| $Activitiy_{it}$ | The summation of $Chat_{ijt}$, $Message_{ijt}$ and $GroupMessage_{ijt}$ |

# 3. DATA AND METHOD

We collected the data from a mobile social networking site which has around 4.8 million registered users worldwide. The users primarily access our research site via mobile phones. As shown in general SNSs, our research site offers multiple communication channels that allow users to engage in interaction with others users (e.g., chat, message, group message, blog, and testimonial to be discussed later). We recorded all the connections and tie strength among the chosen users every month during our research period resulting in the monthly panel data of 1000 users.

## 3.1 Measurements

We classify all the measures into four groups: (1) tie strength, (2) local network activity, (3) whole network size, and (4) user profile, referring to the previous literature and considering our research site.

In modeling a network configuration, a user is generally defined as a vertex and any link (tie or connection) between vertexes (users) *i* and *j* is expressed as a social tie. Here, a tie is either directed or undirected depending on a connection type (communication type in our context) and it can be either symmetric or asymmetric when it is directed. In SNSs, communication activity is generally measured by the tie strength between two users [1]. We develop the measure of tie strength in each communication channel, respectively. The unit of time is a month so that we calibrate the tie strength between any two users in every month time horizon. The variables used throughout the paper and their symbols are listed in Table 1.

## 3.2 Econometric Model

We build our model to capture the variation of the tie strength in one channel with the communication frequencies in the other channels. Here, we describe the regression models along with their justifications in sequence.

The first equation is to model the chat link between users *i* and *j* ($Chat_{ijt}$). The number of messages ($Message_{ijt}$) and the number of group messages ($GroupMessage_{ijt}$) are key explanatory variables. We add both $ChatActivity_{it}$ and $ChatActivity_{jt}$ in the equation to account for both users' local network activities in the chat communication channel. If the coefficients of $ChatActivity_{it}$ and $ChatActivity_{jt}$ are negative and significant, the chat activities with more diverse peers (the external expansion in a local network of chat) imply the weakening of the tie strength with each peer. Then, we can conclude that the resources allocated to the chat communication in a SNS (e.g., time) is limited at an individual level. On the other hand, if the coefficients are positive and significant, it indicates that the active users with more peers in a chat network are likely to have stronger ties with users connected in the network. To account for the initial conditions problem and the evolution of network activity, we add $TimeSinceSignup_{it}$ (to control the evolution of individual users' networking behavior over time) or $TimeSinceLinkage_{ijt}$ (to control the evolution of relationship between users over time) in our regression equation. We separately add one of the two variables in a regression model due to muticollinearity problem (correlation coefficient, $\rho = 0.98$). We include its square (and cube terms) in all the equations to more accurately incorporate state dependency.

$$\begin{aligned} Chat_{ijt} &= \alpha_0 + \alpha_1 Message_{ijt} + \alpha_2 GroupMessage_{ijt} \\ &+\alpha_3 ChatActivity_{it} + \alpha_4 ChatActivity_{jt} \\ &+\alpha_5 TimeSinceSignup_{it} + \alpha_6 TimeSinceSignup_{it}^2 \\ &+\alpha_7 TimeSinceSignup_{jt} + \alpha_8 TimeSinceSignup_{jt}^2 \\ &+\alpha_9 TimeSinceLinkage_{ijt} \\ &+\alpha_{10} TimeSinceLinkage_{ijt}^2 \\ &+\alpha_{11} WholeNetworkSize_t \text{ (or } WholeChatSize_t\text{)} \\ &+\alpha_{12} Blog_{it} + \alpha_{13} Blog_{jt} \\ &+\tau_{ij} + \delta_t + u_{ijt} \end{aligned} \quad (1)$$

Our basic model specification includes monthly time dummies to control periodic-specific noise. The other model specifications include (1) $WholeNetworkSize_t$ or (2) the respective measures of whole network activity in each communication channel ($WholeChatSize_t$, $WholeMessageSize_t$, and $WholeGroupMsgSize_t$) instead of monthly time dummies to avoid endogeneity problem due to an omitted variable and identify the social network effects. We adopt a link fixed effects model for all the equations in our panel data to control unobservable effects embedded in any pairs between users.

We model the tie strength of directed message link as measured by the number of messages user *i* sent to user *j* at time *t* in equation 2. The tie strength in chat and group message communication channels ($Chat_{ijt}$ and $GroupMessage_{ijt}$) are included in this equation to capture mutual interdependency across channels in our system of equations. We add the number of messages user i received from user *j* at time *t* ($Message_{ijt}$) in the regression model to control for the message exchange between two users. The equation includes $MessageSent_{it}$ and $MessageReceived_{it}$ to control for a user's local network activities in the message channel (how many messages the user send or receive in the whole network).

$$\begin{aligned} Message_{ijt} &= \beta_0 + \beta_1 Chat_{ijt} + \beta_2 GroupMessage_{ijt} \\ &+\beta_3 Message_{jit} + \beta_4 MessageSent_{it} \\ &+\beta_5 MessageReceived_{it} + \beta_6 TimeSinceSignup_{it} \\ &+\beta_7 TimeSinceSignup_{it}^2 \\ &+\beta_8 TimeSinceSignup_{jt} + \beta_9 TimeSinceSignup_{jt}^2 \\ &+\beta_{10} TimeSinceLinkage_{ijt} + \beta_{11} TimeSinceLinkage_{ijt}^2 \\ &+\beta_{12} WholeNetworkSize_t \text{(or } WholeMessageSize_t\text{)} \\ &+\beta_{13} Blog_{it} + \beta_{14} Blog_{jt} + \eta_{ij} + \psi_t + \varepsilon_{ijt} \end{aligned} \quad (2)$$

The third equation is developed to capture the variation of $GroupMessage_{ijt}$ with $Chat_{ijt}$ and $Message_{ijt}$ as key explanatory variables. We need to include $Group_{ijt}$ (the number of groups users *i* and *j* belong to together at time *t*) in the equation because both users *i* and *j* have to be engaged in the same group in order that a group message is effectively conveyed between the two users. Equation 3 also accounts for both users' group activities in the social network.

$$\begin{aligned} GroupMessage_{ijt} &= \gamma_0 + \gamma_1 Chat_{ijt} + \gamma_2 Message_{ijt} \\ &+\gamma_3 Group_{ijt} + \gamma_4 GroupActivity_{it} \\ &+\gamma_5 GroupActivity_{jt} + \gamma_6 TimeSinceSignup_{it} \\ &+\gamma_7 TimeSinceSignup_{it}^2 + \gamma_8 TimeSinceSignup_{jt} \\ &+\gamma_9 TimeSinceSignup_{jt}^2 + \gamma_{10} TimeSinceLinkage_{ijt} \\ &+\gamma_{11} TimeSinceLinkage_{ijt}^2 \\ &+\gamma_{12} WholeNetworkSize_t \text{ (or } WholeGroupMsgSize_t\text{)} \\ &+\gamma_{13} Blog_{it} + \gamma_{14} Blog_{jt} + \chi_{ij} + \pi_t + \mu_{ijt} \end{aligned} \quad (3)$$

# 4. EMPIRICAL RESULTS AND DISCUSSION

## 4.1 Cross Effects among Channels

The results from 3SLS estimation are given in Table 2. Our estimation shows that all the coefficients of tie strength ($Chat_{ijt}$, $Message_{ijt}$, and $GroupMessage_{ijt}$) are significant indicating that the cross effects among channels exist. Furthermore, two coefficients in any combination of three channels show the same sign (either positive or negative) and this implies that the cross effects are symmetric in terms of influential direction. The direction of the cross effects between any two channels varies by combination: negative interdependency for "chat and message" and positive interdependency for "chat and group message" and "message and group message" based on all the model specifications (see Table 2).

Both the coefficient of message in the first equation (for chat) and the coefficient of chat in the second equation (for message) are negative and statistically significant (the estimates are -0.043 and -0.478 based on the second column of the pooled regression). These negative dependencies imply the substitutive relationship between chat and message. As user *i* communicates with user *j* with messages, user *i* is less likely to have chat sessions with user *j* and vice versa. In contrast to the substitutive relationship of chat and message, in the other two combinations ("chat and group message" and "message and group message"), the communication channels show complementary relationship, indicating that more communication in a channel induce more active communication in the other channel.

## 4.2 Evolution of Tie Strength

We examined the temporal interdependency among channels in previous section. We subsequently discuss their relationship over time by examining how tie strength evolves by channel. Table 3 summarizes the estimation results based on the linear and quadratic formulations of elapsed time variables ($TimeSinceLinkage_{ijt}$ and $TimeSinceSingup_{it}$).

All the coefficients are significant under both linear and quadratic formulations, indicating that a user's network activities vary over time in all three channels. The evolutionary trajectories show that the dynamics of the tie strength differ across channels. Under a linear formulation of $TimeSinceLinkage_{ijt}$, we identify three distinct trajectories by channel over time. The slopes for chat and message are negative, supporting the previous study reporting the decrease of activity in a SNS, whereas a group message shows upward trend (1.5293, $P<0.000$). The estimation based on the $TimeSinceSingup_{it}$ also shows qualitatively the same pattern (downward for chat and message and upward for group message).

The distinct trajectories across channels offer the insight on the dynamics of a user's channel choice over time in a SNS. As the elapsed time since a new connection between two users increases (or the elapsed time since a user sign up a SNS site increases), the user's communications in chat and message decrease while a group message-based communication increases. This indicates that as time passes (as users accumulate the experience of SNS), they prefer one-to-many communication to one-to-one communication activity. On the other hand, the information sharing through a direct and intimate communication is gradually converted to the communication through a group activity that is more efficient way of disseminating information.

## 4.3 Network Activities and Network Effects

The coefficients of all the individual network activity variables are positive and significant ($ChatActivity_{it}$, $ChatActivity_{jt}$, $MessageSent_{it}$, $MessageReceived_{it}$, $GroupActivity_{it}$ and $GroupActivity_{jt}$). They show that the tie strength is stronger for the user with more ties (peers, connections) than for the users with small ties. In other words, a user with more ties is likely to have stronger ties. This is easily understandable because online social networking activities do not require much time (compared to contacting acquaintances offline) and the network activity represents a user's favorable propensity on social relationship in a SNS. The identified positive relationship between network activity and tie strength can be the base of WOM marketing implementation because tie strength is generally well representative of communication reach. Here, communication reach measures the extent which a user has an influence on another user's decision. Users with many peers are more likely to disseminate information to the connected users than the users with small set of peers. In sum, the users with larger local network have high probability of network reach in each connection as well as greater network coverage.

The coefficients of $WholeNetworkSize_t$, $WholeMessageSize_t$, and $WholeGroupMsgSize_t$ are not significant. The results show that the local networking activities are more influential than the nature of whole network. This finding support the local network effects on specific online activities [10].

# 5. DIFFERENT CROSS EFFECTS DEPENDING ON USER ACTIVITY LEVEL

We have to carefully consider user characteristics in the social network dataset to elicit meaningful interpretation [5]. In this study, we split the whole sample into four groups based on the activity level to examine the potential difference of users' channel choices according to their activity-level in a SNS. Here, we measure the activity level with the summation of chat sessions, messages and group messages. We run our main model for each group and the results are given in Table 4. In the first, second and third groups being comprised of relatively low active users, the six estimates for mutual dependency across channels in the three equations are negative and statistically significant, indicating that three communication channels substitute each other. In the most active user group, only the cross effect between a message and a group message is substitutive while the other four coefficients are positive indicating complementary relationship. The different patterns of the cross effects show that users differently utilize communication channels depending on their activity level. We conclude that the less active users mainly utilize a SNS for simple information sharing while more active users build more sophisticated interactions in a SNS.

**Table 2. 3SLS Estimated Results on Relationship among Networking Activities**

| | Pooled | Model 1 | Model 2 | Model 3 | Model 4 |
|---|---|---|---|---|---|
| DV: $Chat_{ijt}$ | | | | | |
| $Message_{ijt}$ | -0.0418***<br>(0.0059) | -0.0415***<br>(0.0057) | -0.0415***<br>(0.0057) | -0.0406***<br>(0.0057) | -0.0407***<br>(0.0057) |
| $GroupMessage_{ijt}$ | 0.0010<br>(0.0006) | 0.0002<br>(0.0006) | 0.0001<br>(0.0006) | 0.0000<br>(0.0006) | 0.0000<br>(0.0006) |
| $ChatActivity_{it}$ | 0.0005***<br>(0.0000) | 0.0005***<br>(0.0000) | 0.0005***<br>(0.0000) | 0.0005***<br>(0.0000) | 0.0005***<br>(0.0000) |
| $ChatActivity_{jt}$ | 0.0007***<br>(0.0000) | 0.0007***<br>(0.0000) | 0.0007***<br>(0.0000) | 0.0007***<br>(0.0000) | 0.0007***<br>(0.0000) |
| $Blog_{it}$ | -0.1007<br>(0.0614) | -0.0911<br>(0.0616) | -0.0906<br>(0.0617) | -0.0837<br>(0.0615) | -0.0842<br>(0.0616) |
| $Blog_{jt}$ | -0.0348<br>(0.0594) | -0.0538<br>(0.0596) | -0.0542<br>(0.0597) | -0.0510<br>(0.0596) | -0.0517<br>(0.0596) |
| $WholeNetworkSize_t$ | | 0.0000<br>(0.0000) | 0.0000<br>(0.0000) | | |
| $WholeChatSize_{it}$ | | | | 0.0000*<br>(0.0000) | 0.0000*<br>(0.0000) |
| $TimeSinceLinkage_{ijt}$ | | -0.0337***<br>(0.0039) | | -0.0304***<br>(0.0037) | |
| $TimeSinceSingup_{it}$ | | | -0.0132***<br>(0.0015) | | -0.0120***<br>(0.0015) |
| $Constant$ | 0.4504***<br>(0.0301) | 0.4733***<br>(0.0286) | 0.4746***<br>(0.0285) | 0.4794***<br>(0.0285) | 0.4795***<br>(0.0285) |
| DV: $Message_{ijt}$ | | | | | |
| $Chat_{ijt}$ | -0.4611***<br>(0.0722) | -0.4640***<br>(0.0711) | -0.4600***<br>(0.0711) | -0.4692***<br>(0.0703) | -0.4669***<br>(0.0703) |
| $GroupMessage_{ijt}$ | 0.0164*** | 0.0169*** | 0.0170*** | 0.0170*** | 0.0172*** |

| | | | | | |
|---|---|---|---|---|---|
| | (0.0013) | (0.0014) | (0.0014) | (0.0014) | (0.0014) |
| *$Message_{jit}$* | 0.0498*** (0.0057) | 0.0498*** (0.0056) | 0.0497*** (0.0056) | 0.0499*** (0.0056) | 0.0498*** (0.0056) |
| *$MessageSent_{it}$* | 0.0001*** (0.0000) | 0.0001*** (0.0000) | 0.0001*** (0.0000) | 0.0001*** (0.0000) | 0.0001*** (0.0000) |
| *$MessageReceived_{it}$* | 0.0010*** (0.0000) | 0.0010*** (0.0000) | 0.0010*** (0.0000) | 0.0010*** (0.0000) | 0.0010*** (0.0000) |
| *$Blog_{it}$* | 0.6469*** (0.1587) | 0.5418** (0.1607) | 0.5350** (0.1609) | 0.5290** (0.1605) | 0.5186** (0.1608) |
| *$Blog_{jt}$* | 0.3458* (0.1438) | 0.3057* (0.1429) | 0.3058* (0.1429) | 0.3013* (0.1428) | 0.2999* (0.1428) |
| *$WholeNetworkSize_{t}$* | | 0.0000 (0.0000) | 0.0000 (0.0000) | | |
| *$WholeMessageSize_{it}$* | | | | 0.0000 (0.0000) | 0.0000 (0.0000) |
| *$TimeSinceLinkage_{ijt}$* | | -0.0278* (0.0113) | | -0.0290 (0.0151) | |
| *$TimeSinceSingup_{it}$* | | | -0.0103* (0.0044) | | -0.0107 (0.0059) |
| *Constant* | 1.4196*** (0.0696) | 1.3484*** (0.0711) | 1.3479*** (0.0710) | 1.3410*** (0.0710) | 1.3376*** (0.0710) |
| DV: *$GroupMessage_{ijt}$* | | | | | |
| *$Chat_{ijt}$* | 5.2400** (1.8827) | 1.7237 (1.8625) | 1.4268 (1.8617) | 1.8229 (1.8678) | 1.4856 (1.8666) |
| *$Message_{ijt}$* | 1.0830* (0.4466) | 1.9733*** (0.4346) | 1.9958*** (0.4345) | 1.9980*** (0.4334) | 2.0230*** (0.4333) |
| *$Group_{ijt}$* | 0.6577* (0.3052) | 0.7370* (0.2985) | 0.7445* (0.2982) | 0.7280* (0.2975) | 0.7351* (0.2971) |
| *$GroupActivity_{it}$* | 0.5577*** (0.0546) | 0.5211*** (0.0531) | 0.5165*** (0.0530) | 0.5164*** (0.0529) | 0.5119*** (0.0529) |
| *$GroupActivity_{jt}$* | 0.8498*** (0.0604) | 0.7999*** (0.0593) | 0.7942*** (0.0592) | 0.7899*** (0.0592) | 0.7844*** (0.0592) |
| *$Blog_{it}$* | 26.9090*** (4.6725) | 28.2843*** (4.6751) | 28.6447*** (4.6750) | 28.6003*** (4.6683) | 28.9305*** (4.6684) |
| *$WholeNetworkSize_{t}$* | | 0.0000 (0.0000) | 0.0000 (0.0000) | | |
| *$WholeGroupMsgSize_{it}$* | | | | 0.0000 (0.0000) | 0.0000 (0.0000) |
| *$TimeSinceLinkage_{ijt}$* | | 1.5293*** (0.3332) | | 2.1137*** (0.4492) | |
| *$TimeSinceSingup_{it}$* | | | 0.5462*** (0.1311) | | 0.7335*** (0.1766) |
| *Constant* | 30.1526*** (1.8876) | 30.7016*** (1.8616) | 30.5181*** (1.8608) | 31.0358*** (1.8562) | 30.8039*** (1.8553) |

Model1: link fixed effects model with time dummies
Models 2 and 3: link fixed effects model with the whole network size while controlling the evolution of linkage-based (signup-based) networking behavior
Model 4 and 5: link fixed effects model with the whole group message size while controlling the evolution of linkage-based (signup-based) networking behavior
Columns include parameter estimates with standard error in parentheses
*Significant at p< 0.05 **significant at p < 0.01 ***significant at p < 0.001

**Table 3. Estimation Results (Evolution of Tie Strength by Channel)**

| | *$Chat_{ijt}$* | | *$Message_{ijt}$* | | *$GroupMessage_{ijt}$* | |
|---|---|---|---|---|---|---|
| | Linear | Quadratic | Linear | Quadratic | Linear | Quadratic |
| *$TimeSinceLinkage_{ijt}$* | -0.0337*** (0.0039) | -0.0109 (0.0120) | -0.0278* (0.0113) | 0.0728* (0.0296) | 1.5293*** (0.3332) | 12.8158*** (0.7553) |
| $(TimeSinceLinkage_{ijt})^2$ | | -0.0018* (0.0009) | | -0.0078*** (0.0021) | | -0.8715*** (0.0531) |
| *Constant* | 0.4733*** (0.0286) | 0.4679*** (0.0300) | 1.3484*** (0.0711) | 1.3220*** (0.0695) | 30.7016*** (1.8616) | 30.0886*** (1.8620) |
| *$TimeSinceSingup_{it}$* | -0.0132*** | -0.0319*** | -0.0103* | -0.0441*** | 0.5462*** | 2.0071*** |

| | | | | | | |
|---|---|---|---|---|---|---|
| | (0.0015) | (0.0033) | (0.0044) | (0.0092) | (0.1311) | (0.2707) |
| $(TimeSinceSingup_{it})^2$ | | 0.0004***<br>(0.0001) | | 0.0007***<br>(0.0002) | | -0.0320***<br>(0.0050) |
| *Constant* | 0.4746***<br>(0.0285) | 0.4749***<br>(0.0283) | 1.3479***<br>(0.0710) | 1.3889***<br>(0.0700) | 30.5181***<br>(1.8608) | 29.9764***<br>(1.8715) |

**Table 4. Estimation Results (by User Activity Level)**

| | Most inactive | Relatively inactive | Relatively active | Most active |
|---|---|---|---|---|
| DV: $Chat_{ijt}$ | | | | |
| $Message_{ijt}$ | -0.7330***<br>(0.0195) | -0.7578***<br>(0.0244) | -0.6510***<br>(0.0357) | 0.1208***<br>(0.0257) |
| $GroupMessage_{ijt}$ | -0.6936***<br>(0.0317) | -0.7738***<br>(0.0306) | -0.6284***<br>(0.0377) | 0.0187***<br>(0.0021) |
| DV: $Message_{ijt}$ | | | | |
| $Chat_{ijt}$ | -0.8560***<br>(0.0211) | -1.0760***<br>(0.0322) | -1.2019***<br>(0.0754) | 0.5122**<br>(0.1897) |
| $GroupMessage_{ijt}$ | -0.7114***<br>(0.0407) | -0.8910***<br>(0.0433) | -0.8731***<br>(0.0397) | -0.0023<br>(0.0020) |
| DV: $GroupMessage_{ijt}$ | | | | |
| $Chat_{ijt}$ | -0.6454***<br>(0.0247) | -1.0433***<br>(0.0337) | -1.3921***<br>(0.0603) | 44.9511***<br>(3.7602) |
| $Message_{ijt}$ | -0.6803***<br>(0.0249) | -0.8953***<br>(0.0296) | -1.0053***<br>(0.0263) | -5.6870***<br>(1.0307) |

## 6. CONCLUSION, LIMITATION AND FUTURE RESEARCH DIRECTION

Despite the surging popularity of SNSs our understanding of how users utilize the sites is still limited. In particular, little work exists that examines how users are connected across multiple channels. In this paper, we estimate the cross effects across multiple communication channels. We believe that our paper takes a step in analyzing multiplex networks in a SNS.

Despite the interesting findings of this study, there are limitations. First of all, our models do not disentangle the situation-based contexts due to a lack of data (e.g., what contents are conveyed and the sequence of communication channels). There has also been considerable work on analyzing discussions or comments in blogs (e.g., text mining) as well as utilizing such communication content to predict its consequences such as user behavior, sales, stock market activity.

Some SNSs provide indirect communication or conversational mechanisms to their members. The users' involvement and their contribution through non-message-based interactions – for example, picture and video sharing (Flickr.com and YouTube.com), music recommendation (Last.fm), news voting (Digg.com) and social bookmarking (del.icio.us) – have become a major force behind the success of the SNSs. This has given rise to an interesting pattern of social action based interaction among users. This new type of user interactional modality should be another interesting subject. We cannot analyze how users' social networking behavior is connected to their offline connection and activities. Further research could also attempt to develop generalized framework for viral marketing given multiple connections among users.

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