The Temporal Analysis of Networks for Community Activity

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Abstract. Using a questionnaire survey and a smartphone-based social experiment, we conducted a study of private non-profit organizations aiming to supply public goods during three periods. Using the data obtained, we identified a dynamic change in the communication by temporal network analysis and elucidated the relevant factors by panel analysis. From the result of this paper, it was shown that having effect by the period on network structure, and sex and Face to Face Communication where there were scale-free characteristics were unrelated to the information dispatch by the ICT.

Keywords: Social network · Temporal network analysis · Panel analysis

1 Introduction

In this paper, we aim to describe the communication situation of a private organization that dynamically provides local public goods. As an example, in most places, local inhabitants are not responsible for repairing roads. On one hand, it is possible to supply local public goods privately, but on the other hand, that cannot be achieved the purpose. Expense burdens, whether financial or non-financial, are incurred for the supply of local public goods by any means, but a free-rider problem emerges because of the character of public goods, including their non-excludability and non-competitiveness. Therefore, it is important to inform various area inhabitants of the necessity of the local public goods.

The contents of this paper are as follows. In Sect. 2, we survey the literature on this subject. In Sect. 3, we show the data and methods used in the social experiment described in this paper. We present the estimated result in Sect. 4 and the discussion in Sect. 5. In Sect. 6, we describe the conclusion and remarks.

2 Preceding Studies

There has been extensive research on the provision of private or local public goods. Because a free-rider problem arises from the character of public goods, it is known that local public goods will serve as very little provision. Aoki (1999) showed the

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conditions under which inhabitants of a Japanese rural area must behave cooperatively or else face permanent ostracism by their peers. Shiozu et al. (2013) extended the model of Aoki and described the condition of private provision of local public goods as a behavior based on reciprocity in an urban area.

Yamashita (2003) classified the problem into four patterns according to the structure of the network. If the network has a horizontal and open structure, information can be sent or taken from outside. To realize private provision of local public goods, the structure of the network is important.

Kawabata et al. (2011) showed that if information about the private provision of local public goods is offered to non-recipients of the benefit, their willingness to pay for the local public goods will rise by Contingent Value Method. It will be suggested that the provision of local public goods can be promoted.

3 Data and Methods

3.1 Data

With the cooperation of "Makishima Kizuna-no-kai," a non-profit organization (NPO) that performs community activities in the Makishima, Uji-city, Kyoto Prefecture, we conducted a social experiment involving an NPO member. We conducted the social experiment over 3 periods. The first term was from November 11 to December 10, 2013, and the number of cooperators was 20 (13 effective answers); the second term was from February 11 to March 27, 2015, and the number of cooperators was 30 (30 effective answers); and the third term was from August 1 to August 31, 2015, and the number of cooperators was 50 (47 effective answers). The ages of the cooperators were 30–70 years. Because the number of cooperators increased with the progress of the period, we could build unbalanced panel data. We obtained ethical approval for this social experiment from Doshisha University as well as informed consent from all cooperators. In a questionnaire, we asked participants less than five personal names and the frequency with which they talked. We provided them with a smartphone with GPS to collect the data on their locations and communication with other members during the period. Table 1 shows the terminal information used for the social trial run.

Table 1. Situation of the smartphone

Period	1	2–3
Career	NTT Docomo	NTT Docomo MVNO/IIJ mobile
Manufacturer	Fujitsu	ASUS
Product no.	ARROWS Kiss F-03E	ZenFone 5 (A500KL)
OS	Android 4.0.4	Android 4.4.2

3.1.1 95 % Home Range

In this paper, we estimated the 95 % home range from the actual GPS data for every time period of each cooperator. The formula is given by expression (1):

$$p(x) = \frac{1}{n}\sum_{i=1}^{n} K\left(\frac{x - X_i}{h}\right). \quad (1)$$

Here, $\{X_i\}_{i=1}^{n}$ shows the actual GPS value, K(.) is the kernel density function, n indicates number, and h expresses the band width. We used a fixed band width for kernel density estimation. The estimation was performed by R 3.1.2 with the package "adehabitat ver.1.8.18" by Calenge (2015).

The descriptive statistics of the questionnaire for each time period, as well as the social experimental data, are shown in Table 2.

Table 2. Descriptive statistics

	N	Min	Max	Average	S.D.
Period	150	1.00	3.00	2.0000	0.81923
Home range (m^2)	93	0.00	8281441.00	220775.2536	1000665.648
Female	150	0.00	1.00	0.4000	0.49154
Authority	95	0.00	0.10	0.0285	0.01881
Hub	96	0.00	0.14	0.0263	0.02846
Number of meeting	88	1.00	5.00	4.2159	1.10847
Effective number	84				

3.2 Methods

3.2.1 Social Network Analysis

To obtain the structure of the network of members who gathered for community activities, social network analysis was performed. Our data varied in time; therefore, temporal network analysis, which is a dynamic approach, was applied.

In social network analysis, the indicators for knowing the fundamental structure of the whole network include the diameter, clustering coefficient, and density. If the diameter is small and the density and cluster coefficient are large, it is an exclusive network. Conversely, if the diameter is large and the density and cluster coefficient are small, it is an open network. The dynamic state of the whole network can be analyzed using a time-series transmutation of these indicators.

In the social trial run of this paper, because we rented a smartphone for only research purposes, we could observe the relationship between cooperators. Therefore, it became possible to analyze the structure within the network.

When information dispatch was performed toward individual B from individual A, it was expressed with social network analysis using a directed graph. In other words, individual A is an information addresser and the individual B becomes a receiver. The degree can be calculated by setting the information dispatch frequency to the individual B to the weight from the individual A. A hub refers to an individual with a high degree of information dispatch, and an authority refers to an individual with a high degree of an information reception in a network.

Barabási and Albert (1999) showed that a vast majority has the character (scale-free nature) which is not so, although some network members are hubs or authorities.

3.2.2 Panel Analysis

Panel analysis was conducted using a hub according to the time period of each individual obtained by social network analysis and the value of an authority. This paper examined whether a scale-free network also exists in the local resident network in which it is gathered for the purpose of the private provision of local public goods. Because the number of social trial-run cooperators is increasing with time, as described in the preceding paragraph, unbalanced panel data can be obtained. Then, we examined whether a scale-free network exists, even as members increase in number over time.

A hub (information addresser) is considered to be a person who moves actively and talks with many people. Moreover, for males, there is little opportunity for connection with community activity when they work. Females have more opportunities to participate in community activity because they are expected her to join activities such as PTA. The distance for an individual may easily change over a time period, but because each subject was over 30 years old, it was thought that the members who spoke to them did not change dramatically. Moreover, it was thought that sex, for the most part, did not change. Therefore, it could be predicted that authority, distance, conversation number, and female coefficient also become significantly positive. The estimated equation is as follows. The subscript i of each variable expresses the individual and t expresses the experimental period (t = 1, 2, 3). The value of the home range is subjected to logarithmic conversion:

$$Hub_{it} = \alpha_0 + \alpha_1 A_{it} + \alpha_2 R_{it} + \alpha_3 N_{it} + \alpha_4 F_i + \mu_{it}; \quad \alpha_0, \alpha_1, \alpha_2, \alpha_3, \alpha_4 > 0 \tag{2}$$

Hub denotes a hub, A denotes authority, R denotes the home range, N denotes the number of meetings, F denotes a female dummy, alpha 0 denotes a constant term, and mu denotes an error term.

4 Results of Estimation

4.1 Social Network Analysis

Table 3 shows a summary of the whole network structure of each term. The estimation was performed by Gephi. Ver.0.8.2 Beta.

Table 3. A summary of the whole network structure of each term

Term	Diameter	Average cluster coefficient	Density
First term	3	0.707	0.276
Second term	3	0.273	0.028
Third term	2	0.739	0.092

As shown in Fig. 1, in each period, the values of density are low. Moreover, because the diameter does not change much, the communication-of-information speed

can be called comparatively quick in this network. Although the average cluster coefficient decreases greatly for the second term, it is recovered again. It is possible that this may be an exclusive network from the indicators of the first and third terms.

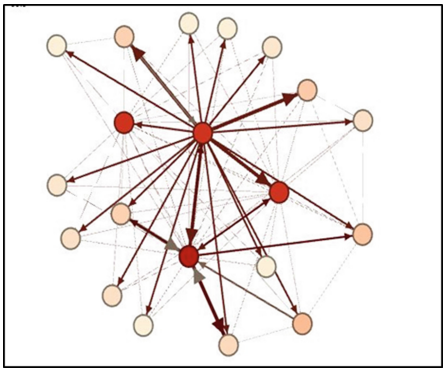

Fig. 1. Hub and authority in first term

Next, the scale-free network of the first term is checked using Fig. 1. In the diagram, the dark-colored circle expresses that the value of an authority or hub is high. In the first term, the value of the hub and authority of two points surrounded with a circle in the central part of Fig. 1 is high. Because these spots can be checked, there exists a scale-free nature for the first term.

Then, the scale-free network of the second term is checked using Figs. 2 and 3. In the second term, one very large black spot exists in the central parts of Figs. 2 and 3. Because this spot expresses the same individual, it can be used to check that the scale-free network also exists for the second term.

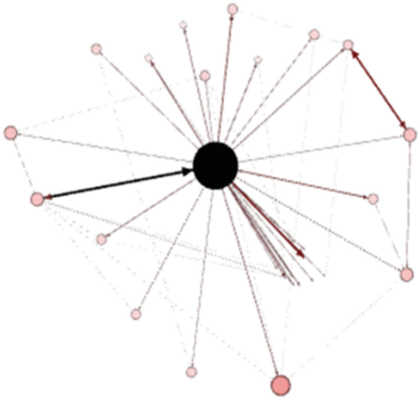

Fig. 2. Hub in second term

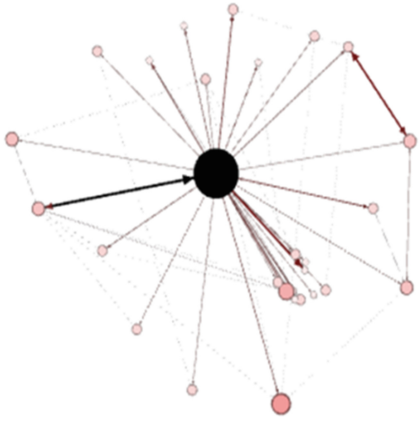

Fig. 3. Authority in second term

Then, we checked for a scale-free network for the third term using Figs. 4 and 5. One black circle exists in the central part in Figs. 4 and 5. Like the second term, because this spot expresses the same individual, it can be used to check whether a scale-free network also exists for the third term.

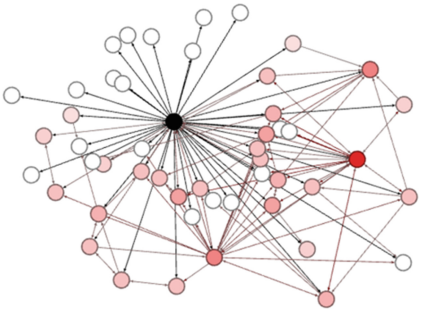

Fig. 4. Hub in third term

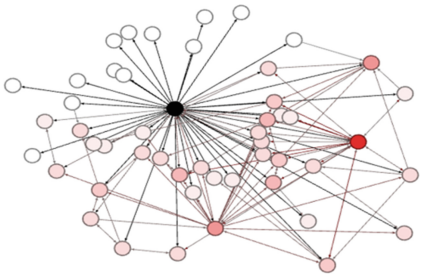

Fig. 5. Authority in third term

The abovementioned analysis revealed that a scale-free network clearly exists throughout the period, and one person has a scale-free network in the second and third terms.

4.2 Panel Analysis

Because sex was considered to be an individual attribute that does not change over a time period, we applied the fixed- and random-effect model. The estimation was performed using STATA Ver.12. Table 4 shows the result. The fixed-effect model was rejected on the basis of the result of the F-test. The result of Breusch and Pagan test supported pooling regression. We therefore adopted pooling regression.

Table 4. Comparison of models

F test, where all u_i = 0: F(47, 28) = 1.09 Prob > F = 0.4143 Breusch and Pagan Lagrangian multiplier test for random effects hub[id,t] = Xb + u[id] + e[id,t]		
	Var	sd = sqrt(Var)
hub	0.000745	0.027293
e	0.000666	0.025798
u	0	0
Test: Var(u) = 0 chibar2(01) = 0.00 Prob > chibar2 = 1.0000		

Excluding the effect of period, we added the variable “sex.” The result of pooling regression is shown in Table 5. The sample number is 79.

Table 5. Result of pooling regression (1)

Hub	Coef.	Std. Err.	t	P > t
Authority	0.451647	0.151987	2.97	0.004
Home range	0.000791	0.001896	0.42	0.678
Female	0.011855	0.006234	1.9	0.061
Number of meeting	0.001981	0.002615	0.76	0.451
Cons	−0.00204	0.014353	−0.14	0.887

F(4,74) = 2.92 Prob > F = 0.0268 R-squared = 0.1362 Adj R-squared = 0.0895 Root MSE = 0.02604

When the symbol and t value of each coefficients were checked, the coefficient of authority became significantly positive. Moreover, the coefficient of females was positive. This means that females bear the role of being addressers of information.

Excluding the effect of sex, we added the variable period. The result of pooling regression is shown in Table 6. It also shows that the coefficient of authority becomes significantly positive by a 10 % p-value.

Table 6. Result of pooling regression (2)

Hub	Coef.	Std. Err.	t	P > t
Authority	0.345587	0.198391	1.74	0.086
Home Range	0.001239	0.001924	0.64	0.522
Period	−0.0027	0.005045	−0.54	0.594
Number of meeting	0.001062	0.002671	0.4	0.692
Cons	0.014061	0.022325	0.63	0.531

Prob > F = 0.1036 R-squared = 0.0975 Adj R-squared = 0.0487 Root MSE = 0.02662

5 Discussion

The structure of the whole network was clarified on the basis of the results of social network analysis. It was thought that the factor peculiar to the second term committed the 1st term and the 3rd term from each indicator having shown the in general same trend. In this social trial run, there was a member who participated in the first and third terms. It was also suggested that the presence of this individual caused the structure of the whole network to transmute. If it takes into consideration that it is also clear that an existence of the individual who exercises a strong leadership leads community activity as pointed out by many researches, it will also set to the NPO in this research. The degree of participation in community activity by an individual with a leadership position enables strengthening of the union power in a network.

When the number of participating members became 30 or more, from the standpoint of communication of information, it was shown that there will be only one member with a scale-free nature. If communication of information can be conducted only through the reception and transmission of e-mail, based on the presumed result of

this research, a scale-free nature may not be particularly related to the union power of the whole network. In other words, ICT can serve as the central figure of information reception and transmission, even if the leadership in a society is of middle or old age.

To analyze the leading factor affecting information reception and transmission, panel analysis was performed because the networks in question were temporal. To scrutinize a presumed result, parallelism with cross-section regression was performed. A presumed result is shown in Table 7.

Table 7. Result of cross-section regression

Hub	Coef.	Std. Err.	t	P > t
Authority	0.37116	0.195283	1.9	0.061
Home range	0.00067	0.001912	0.35	0.727
Period	−0.00328	0.004963	−0.66	0.511
Female	0.012103	0.00627	1.93	0.057
Number of meeting	0.001755	0.002647	0.66	0.509
Cons	0.009006	0.022081	0.41	0.685

F(5,73) = 2.4 Prob > F = 0.0449 R-squared = 0.1413 Adj R-squared = 0.0825 Root MSE = 0.02614

On comparing the results of the pooling and cross-sectional regressions, authority was found to be significantly positive in each model. Therefore, when a certain amount of sample size was secured, it could be checked that a scale-free network is achieved.

Based on the fact that the home range and number of meetings are not significant factors, the models show that geographical sphere or face-to-face communication is not necessarily connected with information dispatch.

Under pooling regression, sex was found to be a significant positive factor for all the models. This suggests that a female can become an information addresser more easily than a male. It was thought that there are many people taking the role that the woman is relatively engaged in a local action from youth, and information sends them for members.

6 Conclusion and Remarks

The purpose of this paper was to dynamically model the status of the communication of information across a structure that privately provides local public goods. From the result of temporal social network analysis, a member's degree of participation was found to heavily influence the union power of the whole network. On the other hand, when the network number exceeded fixed numbers, regardless of the leadership in a real society, the central figure of reception and transmission of information was performed by one person.

Moreover, panel analysis showed that the sex of members influenced the structure used for the common purpose of city planning. We showed that the relations from youth to a local activity influenced information dispatch. The existence of a scale-free

network and distance became clear from pooling regression. However, the number which talks by meeting does not influence. It can be inferred that face-to-face communication is unrelated to information dispatch by ICT.

The area of the geographical home range was not estimated to influence information dispatch. However, the LSCV method and an estimated method having high precision including Local Convex Hull are developed in the home range estimate. We performed home range estimation by this technique and tried to confirm the robustness of the result.

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