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DISCUSSION

Network Analyses of the Circulation Flow of Community Currency

Nozomi KICHIJI* and Makoto NISHIBE**

*Department of Economics, Asahikawa University, 3–23 Nagayama, Asahikawa, Hokkaido 079–8501, Japan. E-mail: kichijin@asahikawa-u.ac.jp
**Graduate School of Economics, Hokkaido University, Kita 9, Nishi 7, Kita-ku, Sapporo, Hokkaido 060–0809, Japan. E-mail: nishibe@econ.hokudai.ac.jp

Abstract

The Japanese economy is emerging from a long-term recession following the bubble and is in the economic recovery phase. However, problems stemming from the widening economic disparity and the decline of local economy have risen. The local economy received a heavy blow from the reduction in public investment because of public sector reform combined with depopulation and aging. Under these circumstances, community currency attracts much attention as a tool that can simultaneously solve the twin problems of the decline of the local economy and the decay of the community. However, little research and few studies have been conducted to quantify the extent to which community currency revitalizes the local economy. We participated in the Tomamae-cho community currency experiment and investigated its circulation flow. This paper highlights the circulation flow of community currency using several network analyses. The following results are presented: (1) various distributions of the networks obey a power-law distribution; (2) the networks display the characteristics of a "Small World" similar to those of organisms, (3) directional and weighted network analyses are important; and (4) the double triangle system is effective due to its complementarity effect because commercial transactions facilitate circulation flow of community currency for non-commercial transactions, and non-commercial transactions expand commercial transactions in the local economy.

Keywords: Power Law, Zipf's Law, community currencies, social experiment, network analysis, Hokkaido economy.

1. Introduction

The current economic problems in Hokkaido can be summarized in three points: predominance of the service sector, a big deficit of interregional trading, and rapid depopulation.

The proportion of the secondary sector in the Hokkaido Prefecture is below the national average, and that of the service sector is far greater than the national average.

JEL: Z13, R11, L14.

Since the proportion of the construction industry within the secondary sector is greater than the national average, the recent reduction in public investment has had a significant impact on the economy of Hokkaido. Due to the enormous central and local government deficits, the promotion of decentralization and the administrative and financial reforms are on the move. Consequently, the great deal of tax transfers from the central government to local governments, which covered the deficits of interregional trading and enabled the heavy public investment in construction sector to stimulate local economies, can no longer be continued. In addition, the process of depopulation is much faster than that in other rural areas of Japan.

Thus the Hokkaido economy is faced with far more severe conditions in comparison to all the other prefectures. A policy of restructuring local areas must be planned and introduced to address the problems of depopulation and aging, which are spreading throughout Hokkaido. In other words, it is necessary to activate the local economy and revitalize the communities to solve such problems. However, as economic development supported by the central government cannot be maintained, there exist very few methods for regenerating a regional economy. Even if it were possible to be supported by the central government, local economic development based on a wasteful economy must be reconsidered from the viewpoint of environmental preservation. In addition to the existing woes of Hokkaido, in the latter half of the 1990s, the region suffered from a long economic depression caused by a negative wealth effect resulting from the collapse of the bubble economy. Japanese banks were reluctant to lend money, and forced their borrowers to withdraw funds because of devastating bad debts. In 1997, both Hokkaido Takushoku Bank Ltd.(the largest commercial bank in Hokkaido) and Yamaichi Securities Co. Ltd. (the forth largest security company in Japan) collapsed, and the economic situation was as desperate as the overall financial crisis.

Under these circumstances, the amount of legal tender circulating in local economies drastically fell and community currencies (CCs)[1)] have attracted much attention in Japan[2)]. Toshiharu Kato (Kato, 1998, 2001) proposed a special kind of community

[1)] Community currencies possess the following characteristics for accomplishing the aim of revitalizing local economies and communities: (1) circulation in relatively small geographical areas or communities of interest, (2) non-governmentally operated and issued, (3) non-convertible or restricted convertibility; and (4) zero or negative interest-bearing. It is also called local currencies or complementary currencies, with slightly different connotations. For example, local currencies often mean CCs that circulate in confined local areas such as towns or villages. However, in this paper, we use only the term “community currency (CC)” to avoid any confusion in terminology.

currency called “Eco-money” that was supposed to activate mutual aids and stimulate social welfare and volunteer activities among citizens and regenerate local communities. Kuriyama-cho, Takarazuka City, Himeji City, Toyama City, Yamato City and others grappled with it after 2000, based on his ideas, and succeeded not only in achieving the original goals to some extent but also in connecting the compartmentalized public administration sectors horizontally. However, Eco-money seems to have its own drawbacks.

Eco-money is completely separate from commercial transactions in the market economy because it is designed for use in social welfare and volunteer activities only. Moreover, Eco-money tends to accumulate in the hands of participants (in particular younger generations) who have made significant contributions such as providing a snow shovel or personal shop to other participants (especially elderly people) because they cannot locate the desired services. As a result, Eco-money does not enjoy smooth circulation among participants.

The author Makoto Nishibe (Nishibe, 2004) proposed the “double triangle system (DTS)” (See Fig. 1) as a solution to the aforementioned problems concerning Eco-money. It involved a community currency circulation scheme especially designed to enable smooth flow of currency among participants without any stagnation. Using only the minor cycle (a small triangle), where CC only mediates non-commercial transactions such as volunteer activities and mutual aid among the local residents, would eventually lead to stagnation halfway through the circulation as was seen in case of Eco-money. To avoid this, it is necessary to introduce the major cycle (a large triangle) as a driving force where CC mediates commercial transactions of goods and services offered by businesses and industries, the municipality, civil groups, and NPOs, and by making the major cycle encompass and drive the minor cycle to forge a complementary relationship between commercial and non-commercial transactions in an integrated cycle of CC. In DTS, when the participants obtain CC in compensation for non-commercial transactions, they can spend it for commercial transactions and the CC can circulate more smoothly and speedily without unintended hoards. This connection between non-commercial and subsequent commercial transactions can simultaneously create new purchasing power (effective demand) for the participants to buy goods and services in the local shops or markets. The creation of effective demand via non-commercial transactions increases the

[2] After full liberalization of capital movements in the early 1980s, free capital flows generated new risks concerning instability. Because of this situation, CCs have spread all over the world, particularly to Western countries since their second boom in the 1980s, following the first one in the 1930s.

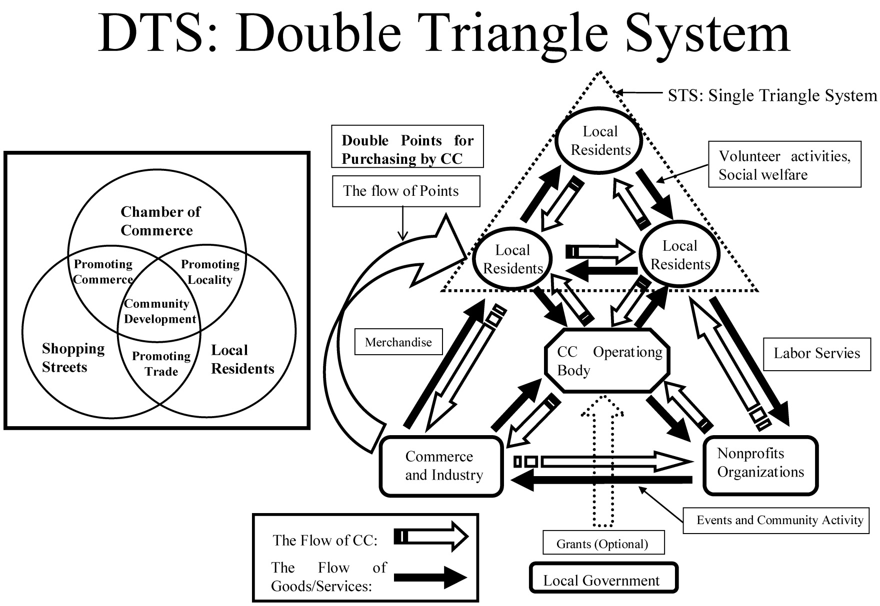

Fig. 1. Double triangle system.

volume of commercial transactions and stimulates the local economy. On the other hand, if shoppers obtain CC through commercial transactions, or if individuals purchase CC by legal tender and request any volunteer work or mutual aid, the recipients of CC offering the non-commercial transaction will expect them to accept CC because they can use it for their shopping. This definitely increases the probability of realization of non-commercial transactions and can lead to a growth in the volume of non-commercial transactions as well.

Therefore, the merits of DTS stemming from a complementary relationship between commercial and non-commercial transactions in the scheme are twofold as follows: (1) non-commercial transactions of social welfare and volunteer activities create new purchasing power for local shops that has not existed before and lead to an increase in the volume of commercial transactions, thus energizing the local economy and (2) commercial transactions of commodities in the local market create new opportunities for volunteer workers to spend the CC earned through non-commercial transactions for shopping at the local mall, which increase the volume of non-commercial transactions and regenerates the local community.

Consequently, we believe that adopting DTS would enable simultaneous achievement of both economic activation and community revitalization in rural areas. The Hokkaido Commerce and Industry Association decided to execute an experimental circulation based on DTS, and planned to choose the implementation group from local commercial and industrial associations. The Tomamae-cho Commerce and Industry Association was selected from several candidates. The experimental circulation of Tomamae-cho community currency (CC) was conducted over 91 days (or three months), from November 22, 2004 to February 20, 2005.

The purpose of this paper is to demonstrate the network properties of the Tomamae-cho CC system and the DTS and demonstrate whether DTS is effective as a CC system. If we can confirm theoretically and empirically that DTS functions successfully in a local economy, we can expect it to be useful for improving the conditions of settlement in order to restrain the process of depopulation. We investigate the characteristics of the network using network analyses (Nishibe *et al.*, 2005; Kichiji and Nishibe, 2006). It is necessary to describe the Tomamae-cho CC system before we investigate its network properties.

2. The Tomamae-cho CC System

The name Tomamae-cho CC is composed of two elements: Tomamae-cho ("town" in Japanese) and Chiiki-Tuka ("Community Currency"[3]). Tomamae-cho is a small town in the northern part of Hokkaido in Japan, with a population of about 4,300. Its main industries are fishing, forestry, and commerce. Tomamae-cho has recently been facing problems such as scarcity of job opportunities and spillover of purchasing power to relatively large neighboring towns (with populations of 8,000 or more), in addition to long-term depopulation and aging, as is the case for other rural areas of Japan. In 2004, the Tomamae-cho Commerce and Industry Association, in collaboration with the Tomamae-cho municipal government, decided to introduce a CC for the purpose of both economic renewal and community revitalization. This was done on an experimental basis. The Tomamae-cho CC system is an integrated system with a reusable gift certificate (See Figs. 2–3) and a shopping stamp (See Fig. 4). Anyone can purchase and use Tomamae-cho CC anywhere for social welfare and volunteer activities, but its usage for commercial transactions is restricted to specific business partners within Tomamae-cho. Tomamae-cho CC, represented by "P," has a linear equivalence to yen currency.

[3] This is a gift certificate legally redeemable into yen, so that retailers may use it repeatedly for other people or exchange it for money upon receipt from their customers.

Circulation operates in three ways: (1) Units are issued by the Commerce and Industry Association and the municipal government of Tomamae-cho when participants purchase CC with yen[4]; (2) participants are paid in CC for the services or goods they supply to others; (3) once participants accumulate 250 stamps (500 points), they can convert these to a 500P note at the issuing office. Participants receive stamps equivalent to 2% of the amount paid in either CC or conventional money if the trading partner is a specific

Fig. 2. Front side of Tomamae-cho CC.

利用者記載欄	いつ（月日）	だれから（氏名）	住所	どうして
記載例	10／20	菊地　太郎	古丹別	買い物のお手伝い
1	／			
2	／			
3	／			
4	／			
6	／			

最終取扱特定事業者

印

注意事項
- ●本券は現金引換えおよび売買は出来ません。
- ●本券による購入の際は、釣銭は支払われません。
- ●本券はステッカーを掲示している特定事業者のところで買い物及びサービスがご利用できます。
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Fig. 3. Reverse side of Tomamae-cho CC.

Fig. 4. 2-point stamps.

4) 500 yen can purchase a 500P note plus 10P-stamps as its 2 percent premium.

business partner within the scheme. Moreover, individual members and specific business partners also receive a 2% dividend in stamps of the amount paid when purchasing CC at the issuing office. Therefore, individual members can benefit from a 4% premium if they purchase CC with yen and use it with specific business partners. The CC system is designed to function as a strong incentive for the individual use of CC. Shops participated as specific business partners in the experimental circulation of Tomamae-cho CC, and only such partners can exchange CC for money. Under this experiment, specific business partners have to accept the condition that they purchase stamps in advance and repay the 2% dividend of the amount received in stamps. In 2000, 67.5% of Tomamae-cho's purchasing power spilled over to relatively large neighboring towns. The specific business partners had the advantage of including the purchasing power of these towns by accepting and using Tomamae-cho CC. Forty nine specific business partners and 12 group partners agreed to cooperate in the experimental circulation of Tomamae-cho CC. The recirculation of CC within the town was encouraged by the redemption cost of 5 yen on exchanging a 500P note for money.

3. Follow-up Method for Tomamae-cho CC

We participated in the CC experiment and investigated its circulation flow in a unique way. Before the experimental circulation in 2004, our investigation team requested the issuing agents to devise an entry space on the reverse of each CC note in order for recipients to record transaction dates, their names and addresses, and the purposes of use, up to a maximum of five recipients. We also asked the participants to agree to cooperate in our investigation. After the circulation experiment of Tomamae-cho CC, we collected all the currency notes that had been returned to the issuing agents in exchange for yen, and then created an adjacency matrix from the acquired data in order to analyze the circulation flow of the CC notes using several network theories.

4. Statistical Data on the Experimental Circulation of Tomamae-cho CC

Table 1 shows the main statistical data on the experimental circulation of Tomamae-cho CC. All Tomamae-cho CCs are scheduled to expire at the end of the experimental period. From Table 1, the velocity of the CC is 5.078. This is 6 to 7 times higher than that of yen because the limitation of the period and the circulation domain of the CC enhances its velocity.

Table 1. Statistical data on Tomamae-cho CC.

Experiment period	11/22/2004 to 2/20/2005
Number of CCs issued	2,192(4/8/2005)
Total participants (individual, specific business, group)	272 actors
Turnover of each CC	
Number of CC with turnover 1	1,764
turnover 2	314
turnover 3	77
turnover 4	37
turnover 5	0
Total number of circulations of CC	2,771
Total amount	138,5500P
Average amount per participant	5,093.75P
Velocity of CC (year)	5.078

5. Analyses of the Circulation Flow of Tomamae-cho CC

We review the relationship between the adjacency matrix and the network before performing several network analyses.

5.1 Adjacency matrix

The most common form of matrix in network analysis is a very simple square matrix with as many rows and columns as actors (nodes, vertices) in the data set (Scott, 2000; Kanamitsu, 2003; Yasuda, 2001; Masuda and Konno, 2005). The "elements," or scores in the cells of the matrix, record information about the ties (links, edges) between each pair of actors. In our case, "actors" means participants in the experimental circulation of Tomamae-cho CC, and a tie between person A and person B means that person A dealt with person B using CC.

The simplest and most common matrix is a binary matrix. That is, if a tie is present, 1 (one) is entered in a cell, else 0 (zero). This kind of matrix is called an "adjacency matrix" (See Fig. 5(a)). An adjacency matrix may be "symmetric" or "asymmetric." Dealings between person A and person B using CC can also be either symmetric or asymmetric. For example, person A buys goods and services from person B and gives the CC to person B. Person B does not buy anything from person A. In this case, the element in our adjacency matrix showing the relationship of person A to person B would be scored "1" while that showing the relationship of person B to person A would be scored "0." That is, in an asymmetric matrix, $X_{i,j}$ is not necessarily equal to $X_{j,i}$.

In our case, an adjacency matrix is either binary or valued, since the flow of the CC

(a)

$$\begin{bmatrix} 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 \\ 1 & 0 & 0 & 1 & 0 \end{bmatrix}$$

(b)

$$\begin{bmatrix} 0 & 500 & 1000 & 500 & 500 \\ 0 & 0 & 0 & 0 & 0 \\ 500 & 0 & 0 & 0 & 0 \\ 0 & 1000 & 2000 & 0 & 0 \\ 1500 & 0 & 0 & 1000 & 0 \end{bmatrix}$$

(c)

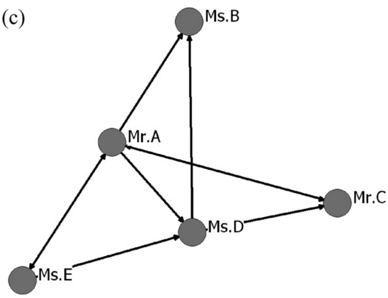

Fig. 5. (a) Adjacency matrix. (b) Adjacency matrix (valued). (c) Network of CC.

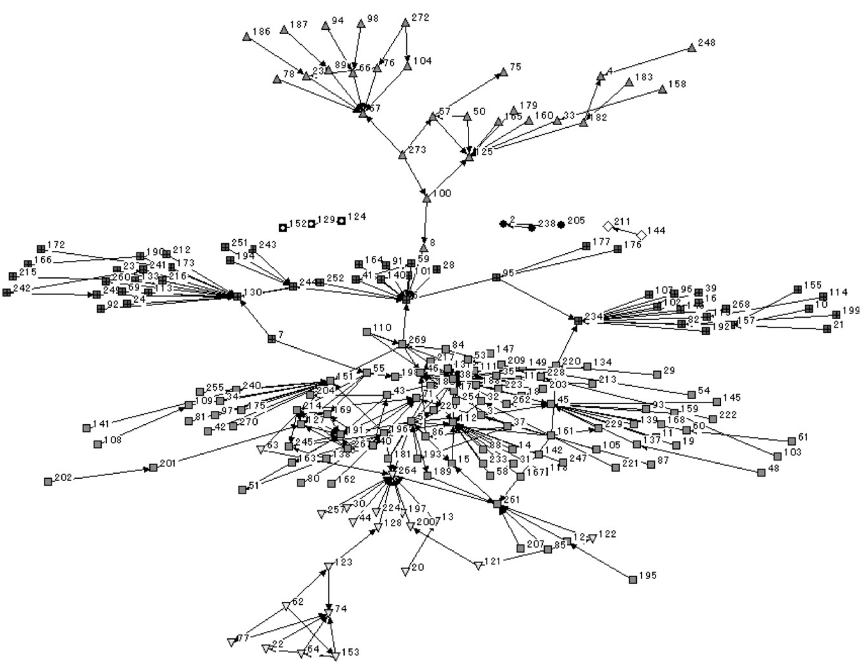

Fig. 6. Network graph of Tomamae-cho CC.

can be represented by the volume of transactions (See Fig. 5(b)). Let us look at a simple example. The directional graph of the Tomamae-cho CC network (TCCN) among persons A, B, C, D, and E is shown in Fig. 5(c). Moreover, in our case, we can show the TCCN at the district level (e.g., Kotanbetsu district, Tomamae district and Sankei district), which will be discussed in detail elsewhere. Figure 6 is the Network Graph of Tomamae-cho CC.

5.2 General characteristics of the TCCN from the aspect of degree

Before we analyze the network properties, we must address the terminology. The terminology used in some network analyses is confusing. In mathematics, "vertex" and "edge" are used; however, in social network analysis, "actor" and "tie" are used. Moreover, in physics, "node" (vertex) and "link" (edge) are used. We use "actor" and "tie" in the context of social network analysis, and "node" and "link" in the context of network analysis in physics. We indicated the number of nodes, the average of degree , the clustering coefficient C[5] and the average path length l[6]. For comparison, we included the clustering coefficient C_{rand} and the average path length l_{rand} of a random graph of the same size and average degree.

In this section, we analyze the topology of the TCCN. This network is relatively small, being characterized by vertex=272 and edge=406. The network density is about 0.0055. The degree of the node ranges between 1 and 53, the in-degree of the node ranges

Table 2. General characteristics of several real networks.

	Size	k	$C(C_{rand})$	$l(l_{rand})$
TCCN	272	3	0.204 (0.011)	4.41 (5.1)
LET-Q	287	12.25	0.494 (0.043)	2.898 (2.26)
E. coli	282	7.35	0.32 (0.026)	2.9 (3.049)
C. elegans	282	14	0.28 (0.05)	2.65 (2.25)

[5] The clustering coefficient defines a measure of the level of cohesiveness around any given node. It is expressed as the fraction of connected neighbors $C_i = \frac{2e_i}{k_i(k_i-1)}$ where e_i is the number of links between the neighbors of the node i, and $k_i(k_i-1)$ is
the maximum number of possible interconnections among the neighbors of the node. C in Table 2 indicates the average value of the clustering coefficient.

[6] For non-directional, unweighted graphs, the number of edges in a path connecting vertices i and j is called the length of the path. A geodesic path (or the shortest path) between vertices i and j is one of the paths connecting these vertices with minimum length (many geodesic paths may exist between two vertices); the length of the geodesic path is the geodesic distance d_{ij} between vertices i and j.

between 1 and 53, and the out-degree of the node ranges between 1 and 15. The TCCN is asymmetrical about the in- and out-degrees.

The in-degree of the node represents the number of people to whom a participant in the TCCN sold goods and services. In contrast, the out-degree of the node represents the number of people from whom a participant purchased goods or services. The network balance[7)] of the TCCN is about 0.11. The overall reciprocity[8)] is 0.015. These results indicate that the participants polarized between receivers and payers of Tomamae-cho CC.

The clustering coefficient is large compared to that of the random graph, whereas the average path length is small compared to that of the random graph. This is a characteristic of "small-world" networks (Watts and Strogatz, 1998). We indicate that the TCCN is very similar to the network of an organism such as *E. coli* (Wagner and Fell, 2000) or *C. elegans* (Watts and Strogatz, 1998), as well as the other CC system of LETS-Q[9)]. The result indicates that the networks of socio-economic phenomena are comparable with the networks of natural phenomena. Since the average degree of the TCCN is small relative to the other networks, we found that the TCCN is in a growth process.

The information on the TCCN is provided by the degree distribution $P(k)$ defined as the probability that any given node has degree . It is essential to distinguish between an "exponential" network similar to the usual random graph, for which $P(k)$ decreases exponentially and rapidly, and scale-free networks, for which $P(k)$ decreases typically as a power law (Zipf, 1949; Albert and Barabási, 2002; Amaral *et al.*, 2000). In the present case, the degree probability distribution obeys a power-law distribution. The probability distribution $P(k)$ displays power-law decay $P(k){:}k^{-r_k}$ with an exponent $\gamma_k \approx 2.43$ (Kichiji and Nishibe, 2007). In Fig. 7, we adopt the cumulative distribution as the vertical axis. Therefore, in Fig. 7, the slope is 1.43.

Moreover, we examine the degree of similarity between the neighbors of a node. The relationships are measured by the average degree of the nearest neighbors of a given node k

[7)] Network balance is defined by the correlation coefficient of the in-degree and out-degree of each participant. (Wellman *et al.*, 1988).

[8)] The overall reciprocity is the value of Num ($X_{i,j}>0$ and $X_{j,i}>0$)/Num($X_{ij}>0$ or $X_{ji}>0$).

[9)] LETS stands for Local Exchange Trading System. This system embodies the most popular type of CC; it was initiated in 1983 by Michael Linton in Comox Valley, Vancouver Island, Canada, and is now used in more than 2,000 districts worldwide. Q is the "monetary" unit of LETS-Q; although it is not convertible into yen, it is assumed to be equivalent to yen. The CC system was initiated in Japan in November 2001 and is managed by an administrative committee called Q-hive.

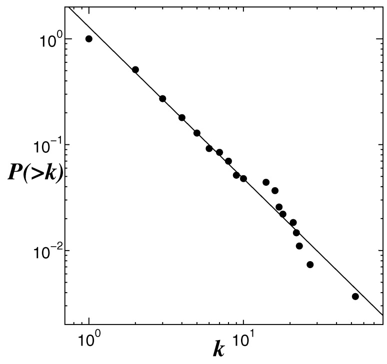

Fig. 7. Log-log plot of the cumulative probability function of the degree distribution of the TCCN. The straight line is a power-law fit and its slope is 1.43.

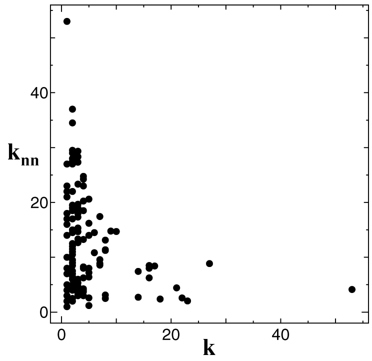

Fig. 8. Assortativity of the TCCN showing a slightly disassortative behavior.

$$k_{nn}(k) = \sum_{k'} k' P(k' \mid k) \,.$$

where k' is a neighbor of node k. The result obtained for the TCCN is shown in Fig. 8. Figure 8 shows a slightly disassortative behavior[10]. We also examine the Pearson correlation coefficient (r) of the degrees at both the ends of the edges. The value of r is -0.255. All social networks studied have significant assortative mixing. However, the technological and biological networks are all disassortative (Newman, 2002). The results

[10] Assortative mixing within degrees means a preference of high-degree vertices to attach to other high-degree vertices. In contrast, disassortative mixing means a preference of high-degree vertices to attach to low-degree vertices (Newman, 2002).

Table 3. Slope of Figs. 11(a)–12(c) and the monthly velocity.

	End of Dec.	End of Jan.	End of Feb.
In-degree	1.13 (R^2=0.985)	1.19 (R^2=0.983)	1.20 (R^2=0.962)
Out-degree	1.60 (R^2=0.991)	2.55(R^2=0.992)	2.52 (R^2=0.985)
Receipt	0.54 (R^2=0.972)	0.76 (R^2=0.963)	0.76 (R^2=0.963)
Payment	0.50 (R^2=0.953)	1.20 (R^2=0.981)	1.08 (R^2=0.987)
Velocity	1.1789	0.5138	0.8214

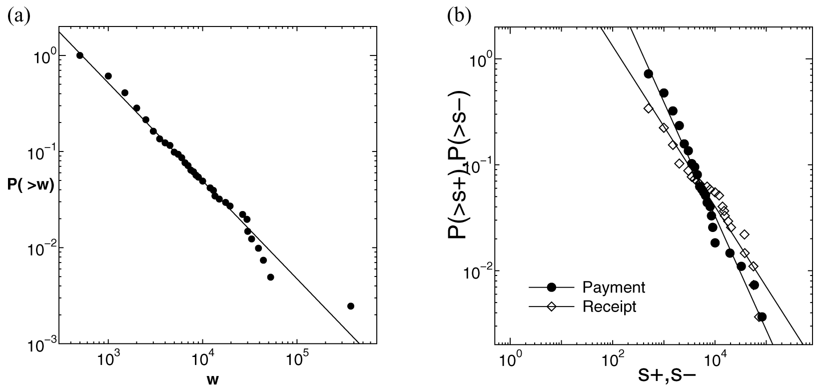

Fig. 9. (a) Log-log plot of the cumulative probability function of the link weights. The straight line is a power-law fit and its slope is 1.02. (b) Log-log plot of the cumulative probability function of the amount of payment and receipt distribution of the TCCN.

indicated that the TCCN is very similar to biological networks (e.g., a marine food web ($r=-0.247$), a neural network ($r=-0.163$), etc). In our case, this disassortative mixing meant that several specific business partners had large degrees, whereas the individual participants had small degrees.

6. Directional and Weighted Network Analysis of the TCCN

The value of the weights between pairs of participants ranges between 500P and $w_{max}=371{,}000P$ with an average value $\langle w\rangle\approx 3{,}405P$. The cumulative probability distribution $P(>w)$ that any edge has a weight w displays a power-law decay $P(>w):w^{-\gamma_w}$ with an exponent $\gamma_w\approx 1.02$[11] (Fig. 9(a)). The strength of a node is defined as

$$s(i)=\sum_j w_{i,j}$$

[11] In the case of the probability distribution, this can be expressed as an exponent of 2.02 (1.02+1).

In our case, however, the links are directional (symmetric, asymmetric). We classify the strength of a node into two categories, as a receiver and as a payer:

$$s_+(i) = \sum_j w_{i,j}$$

$$s_-(i) = \sum_j w_{i,j}$$

$s_+(i)$ corresponds to the total receipts of the participant i, and $s_-(i)$ corresponds to the total payments of the participant i. For the TCCN, the strength of a node as a receiver varies between 500P and 383,000P with an average value $\langle s_+ \rangle \approx 12{,}127P$[12]. As a payer, this varies between 500P and 415,500P with an average value $\langle s_- \rangle \approx 5.359P$[13]. The cumulative probability distribution of the strengths $P(s_+)$ and the strength $P(s_-)$ that any given node has a strength s is fitted by a power law $P(>s_\pm)$: $s_\pm^{-\gamma_s}$ with exponents $\gamma_{s_+} \approx 0.758$ and $\gamma_{s_-} \approx 1.08$, respectively (Fig. 9(b)). The slope of s_- is steeper than that of s_+. This result shows that the disparity in receipts is larger than that in payments. The cause of this high level of disparity in receipts is that 31 specific business partners received more than 90% of the total amount received. In addition, the top 10 specific business partners accounted for 83% of all specific business partners' receipts. In contrast, in payments, since the amount paid by the specific partners accounted for only 31% of the total, individual participants had a significant effect on the total amount paid.

6.1 Relationship between degrees and transaction amounts

We show in Figs. 10(a)–(b) the strength of the nodes as a function of their degrees. There is a weak correlation between the strength of the nodes and their degrees. The correlation coefficients are positive. The correlation coefficient of the payments and the out-degrees is 0.316 and that of the receipts and the in-degrees is 0.485. These results suggest that weighted network analysis is indispensable for socio-economic network analysis because the degree relationship is sometimes far removed from the weighted relationship.

7. Dynamics of the TCCN

We examine the dynamics of the TCCN. Figures 11(a)–(c) shows the in-out degree of the distributions. These distributions seem to roughly obey a power-law distribution. However, the exponent of the out-degree distribution was twice as high as that of the in-

[12] The number of receivers is 114 persons.

[13] The number of payers is 258 persons.

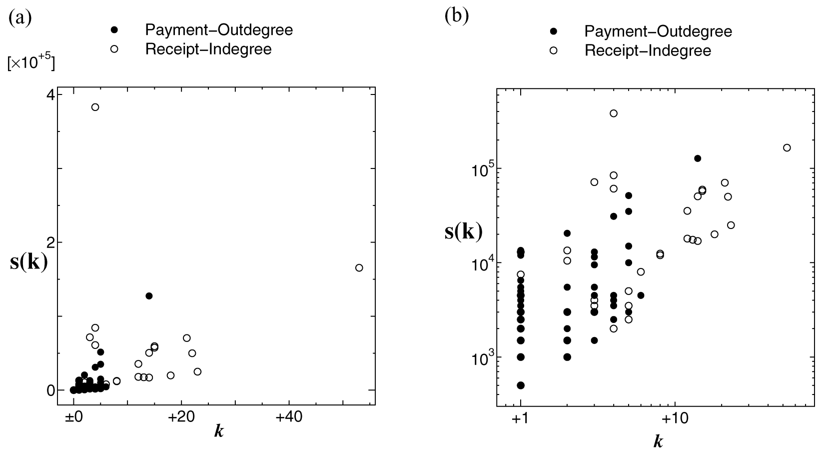

Fig. 10. (a) Relationship between the strength of the nodes and their degrees. (b) Log-log plot of the relationship between the strength of the nodes and their degrees.

degree distribution. In these distributions, the higher the exponent, the narrower the disparity among actors. The disparity of the out-degree distribution was smaller than that of the in-degree distribution. The reasons for this were that the specific business partners topped the list of the in-degree distribution as the receiver of the CC, and also that the disparity among the specific business partners was wide. The out-degree distribution reflects the trend for the individual participants to top the list of the distribution. If the disparity among the specific business partners is reduced, the slope of the distribution becomes more gradual; and if the disparity among individual participants widens, the slope of the out-degree distribution becomes sharper. Figures 12(a)–(c) shows the payment and receipt distributions of the TCCN. In-degree corresponds to the amount received, and out-degree corresponds to the amount paid. The transition of the exponent of the payment and receipt distributions is more clear than that of the in-out degree distributions.

The ratio of the exponents of in-degree (receipt) and out-degree (payment) may be one of the important indices for analyzing the flow of CC. Figure 13 shows the relationship between the velocity[14)] of the CC and the ratio of the exponents. The ratio of the exponents decreases with the velocity of the CC. This figure suggests that the peak

[14)] We define the velocity of the CC as the ratio between the transaction amount and the outstanding issue. On a monthly basis, the velocities at the end of Dec., Jan., and Feb. are 1.1789, 0.5138, and 0.8215, respectively.

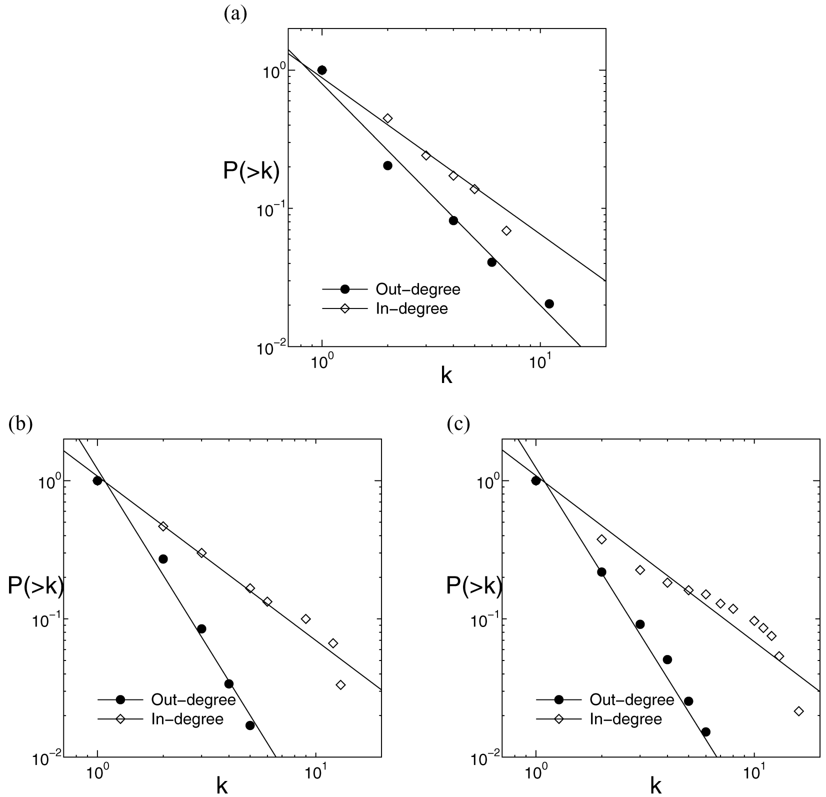

Fig. 11. (a) Log-log plot of the cumulative probability function of the in-out degree distribution 2004.12. (b) Log-log plot of the cumulative probability function of the in-out degree distribution 2005.1. (c) Log-log plot of the cumulative probability function of the in-out degree distribution 2005.2.

velocity of the CC corresponds to 1, which means that the exponent of in-degree (receipt) was equivalent to that of out-degree (payment). In natural phenomena, since the ratio mostly tends to be equal to 1 (Albert and Barabási, 2002), the maximum flow may occur at around 1. In our case, since the ratio is sometimes higher than 1, the flow of the CC may stand still. These results require further study.

In addition, we investigate the relationship between network centralization[15] and the

[15] Freeman's mathematical definition for network centralization (Freeman, 1979), the index of centralization of a network of actors, is represented by the ratio of the sum of actual difference between the degree of centrality of the most central actor and that of all the other actors in the network and the theoretical maximum possible sum of differences in actor degree centrality.

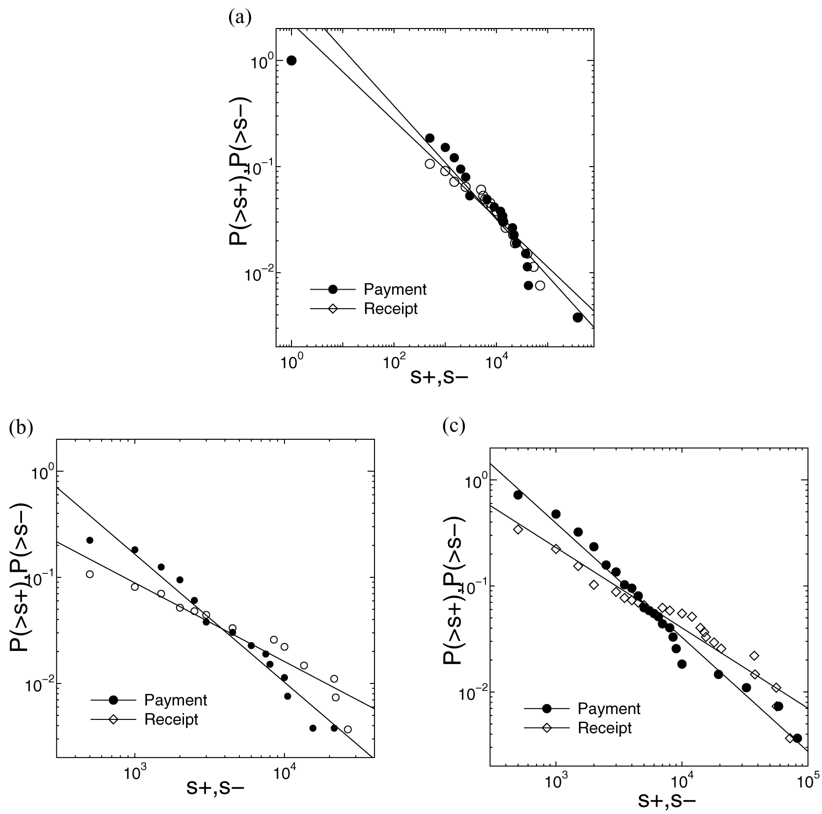

Fig. 12. (a) Log-log plot of the cumulative probability function of the amount of payment and receipt distribution 2004.12. (b) Log-log plot of the cumulative probability function of the amount of payment and receipt distribution 2005.1. (c) Log-log plot of the cumulative probability function of the amount of payment and receipt distribution 2005.2.

total monthly amount. Table 4 shows the correlation between the network centralization and the monthly transaction. When the network centralization rises, the flow of the CC increases, and vice versa. This result may show a characteristic of the flow of Tomamae-cho CC. Because of the size of the data, we need further investigation for statistical rigidity.

8. Effectiveness of DTS

In this section, we establish the fact that DTS increases both commercial and non-commercial transactions by creating complementary relationships between them in the course of circulation paths of CC. DTS can thus promote circulation efficiency of money

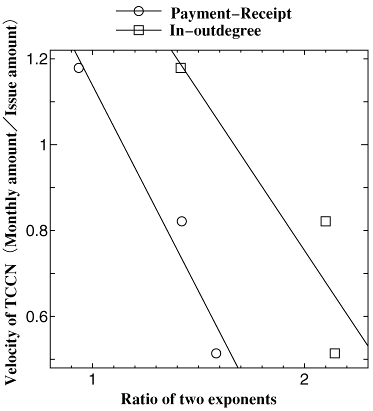

Fig. 13. Ratio of two exponents and the velocity of CC.

Table 4. Correlation between network centralization and transaction amount.

	In-degree	Out-degree	Transaction amount
End of Dec.	8.29	3.71	692000
End of Jan.	4.72	1.75	148500
End of Feb.	11.07	2.21	531500

and provide a solution to the problem observed in the implementation of Eco-money by preventing CC from stagnating halfway through the circulation. Therefore, we claim that DTS is an effective money system as CC as well as any currency in general since it can enhance viability and sustainability of currency system by bridging commercial transactions, which are conventionally classified in economic domain, and non-commercial transactions of volunteer activities and social services, which are conventionally classified in social or communal domains.

We explain the basic idea of DTS to focus on the present issue preliminary to the detailed discussion on it. It is often said that CC is meaningful because it can induce people to practice mutual help or reciprocity and create social capital in local communities. But if participants obtain CC in compensation only for non-commercial transactions as in the single triangle system (STS) (see Fig. 1), it might not be easy for them to find any items or services they want. Then CC will stand still in their hands and will not circulate in the system. When this frequently happens here and there, we must admit that CC is a good idea but STS is not viable. However, if they can spend it for commercial transactions as well in DTS, CC can continue to circulate more smoothly and speedy, changing its holders. As the result of this connection of non-commercial transactions to commercial transactions, DTS increases subsequent commercial transactions as well as non-commercial ones. In other words, it will create new purchasing power (effective demand) for the participants not only to buy goods and services in the local shoppers or local market but also to ask for volunteer activities and social services.

First, we demonstrate that there is a positive mutual complementarity effect between commercial and non-commercial transactions in DTS under the condition that the average turnover of currency (circulation frequency of money) is above 1. Let us use a numeric example in a simple model as in Fig. 14. This is a currency circulation tree diagram, which indicates all divergent circulation paths of a currency in DTS when the turnover is 3. If the face value is 1, the total transaction (X) is 3. Assume that a commercial transaction (c) occurs with probability 0.9 and a non-commercial transaction (nc) occurs with probability 0.1. Then, the expected total volume of commercial transactions (C) is 2.7 and the expected non-commercial transactions (NC) is 0.3.

If the currency is only usable for commercial transactions as in the case of legal tender, all non-commercial transactions must be removed from the tree diagram in Fig. 14. It follows that all subsequent commercial transactions with any non-commercial ones disappear and a single circulation path with three consecutive commercial transactions ($c-c-c$) remains as a possible event. Then, the expected total volume of commercial transactions without non-commercial ones (C') is considered as 2.439 ($=0.9+0.9^2+0.9^3$). On the other hand, if the currency is only usable for non-commercial transactions

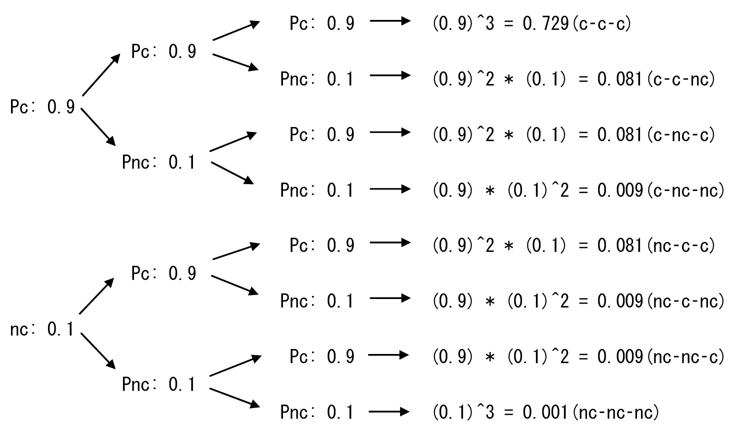

Fig. 14. The circulation paths tree diagram of the currency.

as in the case of Eco-money, all commercial transactions must be removed from the tree diagram in Fig. 14. It follows that all subsequent non-commercial transactions with any commercial ones disappear and a single circulation path with three consecutive non-commercial transactions ($nc-nc-nc$) remains as a possible event. Then, the expected total volume of non-commercial transactions without commercial ones (NC') is considered as 0.111 ($=0.1+0.1^2+0.1^3$). The sum of such commercial transactions and non-commercial ones thus obtained is $X'=C'+NC'=2.55$. This represents the total transactions in the case where commercial/non-commercial transactions would be realized separately with legal tender, and Eco-money.

Commercial transactions with legal tender are supposed to occur with a quite high probability except during a depression period when people expect deflation and tend to hoard money. Then, even though the probability of realization of consecutive commercial transactions decreases exponentially, it still remains relatively high. However, the probability of non-commercial ones must be low as in this case. Therefore, the probability of realization of three consecutive non-commercial transactions is extremely low. This is the cause of the problem faced by Eco-money. However, DTS can solve it by creating new circulation paths in the tree diagram. In the above numeric example, $(C/C')-1=(2.7/2.55)-1=0.107$, $(NC/NC')-1=(0.3/0.111)-1=1.702$, and $(X/X')-1=(3/2.55)-1=0.1765$. These represent the expected growth rate of commercial transactions, that of non-commercial transactions, and total transactions, respectively, when we introduce CC usable for both commercial and non-commercial transactions in DTS. The reason why commercial and non-commercial transactions can grow is that each kind of transaction functions as a mediator or a bridge to connect the other kind of preceding and succeeding transactions in a mutually complementary relationship. In other words, currencies can circulate faster when they crossover and connect two different transaction domains. Therefore, let us refer to this as DTS's "growth effect," "transaction complementarity effect," or "currency crossover effect."

Next, we present this proposition in more generic terms. Assuming that the probabilities of realization of commercial and non-commercial transactions are P_c ($0\leq P_c\leq 1$) and P_{nc} ($0\leq P_{nc}\leq 1$)[16], respectively, and that the average turnover (circulation velocity) of a currency note in a certain period r is ($0\leq r$), we get

[16] If $P_c=0$ and $P_{nc}=1$, then $C=C'=0$ and $NC=NC'$. If $P_c=1$ and $P_{nc}=0$, then $C=C'$ and $NC=NC'=0$. We ignore these trivial cases in the following discussion.

$$\frac{C}{C'} = \frac{r(1-P_c)}{1-P_c^r}$$

$$\frac{NC}{NC'} = \frac{r(1-P_{nc})}{1-P_{nc}^r} = \frac{rP_c}{1-(1-P_c)^r}$$

The proposition to be proved is formulated as

$$0 < P_c < 1, \quad r > 1 \Rightarrow \frac{C}{C'} > 1 \wedge \frac{NC}{NC'} > 1$$ [17)]

The inequality $\frac{C}{C'} > 1$ is reformulated as

$$\frac{C}{C'} = \frac{r(1-P_c)}{1-P_c^r} > 1 \Leftrightarrow P_c^r - rP_c + r - 1 > 0$$

Here, we regard the left side of the right inequality as the exponential function of r as

$$f_{Pc}(r) = P_c^r - rP_c + r - 1 \quad (0 \leq r,\ 0 \leq P_c \leq 1)$$

We can transform it into a polynomial expression and prove the above inequality.

$$\begin{aligned} f_{P_c}(r) &= P_c^r - rP_c + r - 1 \\ &= (P_c-1)^2(P_c^{r-2} + 2P_c^{r-3} + 3P_c^{r-4} + \cdots (r-3)P_c^2 + (r-2)P_c + (r-1)) \\ &= (P_c-1)^2 \sum_{i=1}^{r-1} iP_c^{r-i-1} > 0 \end{aligned}$$

We can also take the first and second derivatives of $f_{Pc}(r)$ as

$$f_{Pc}'(r) = lnP_c \cdot P_c^r - P_c + 1$$

$$f_{P_c}'(r) = 0 \Rightarrow r = \frac{1}{lnP_c} \ln\left(\frac{1-P_c}{-lnP_c}\right)$$

$$f_{Pc}''(r) = (lnP_c)^2 \cdot P_c^r > 1$$

and calculate the values of the function and the first derivatives by substituting 0 and 1 into r

$$f_{Pc}(0) = f_{Pc}(1) = 0$$

[17)] If $r=0$, then $\frac{C}{C'} = \frac{NC}{NC'} = 1$. This is also trivial.

$$f_{Pc}'(0)<0, \quad f_{Pc}'(1)>0$$

$$0<P_c<1 \Rightarrow lnP_c<0, \quad P_c>lnP_c+1$$

We further examine the function

$$r\geq 1 \Rightarrow f_{Pc}'(r)=lnP_c \cdot P_c^r-P_c+1>0$$

$$\lim_{r\to\infty} f_{P_c}'(r)=-P_c+1>0\,, \quad \lim_{r\to-\infty} f_{P_c}'(r)=-\infty$$

$$r\geq 1 \Rightarrow f_{Pc}(r)=P_c^r-rP_c^r+r-1\geq 0$$

$$0<r<1 \Rightarrow f_{Pc}(r)=P_c^r-rP_c+r-1<0$$

$$r\leq 0 \Rightarrow f_{Pc}(r)=P_c^r-rP_c+r-1\geq 0$$

and create a graph of the function as in Fig. 15.

With regard to non-commercial transactions, we can replace P_c for P_{nc} in the above function $f_{Pc}(r)$ for commercial transactions and use the same discussion to prove that $\frac{NC}{NC'}>1$.

Then, we can conclude that

$$0<P_c<1, \quad r>1 \Rightarrow C>C' \wedge NC>NC'$$

$$0<P_c<1, \quad 0<r<1 \Rightarrow C<C' \wedge NC<NC'$$

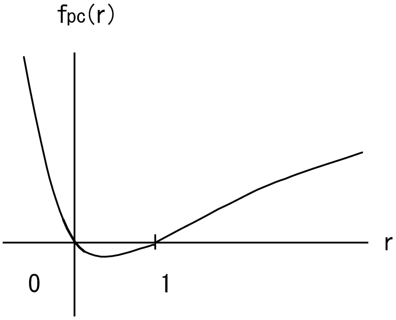

Fig. 15. Function of $f_{Pc}(r)$.

Namely, if the average turnover (circulation velocity) of the currency (r) is larger than 1, then the commercial and non-commercial transactions expected to be simultaneously realized in DTS (C and NC) are larger than those expected to be realized separately with different currencies specifically for each transaction (C' and NC'). Therefore, the total transactions in DTS ($X=C+NC$) are also larger than $X'=C'+NC'$, i.e., $X>X'$.

Tomamae-cho CC permits only specific business partners (local shops, stores, and companies) to convert the CC into legal tender (yen); however, we have so far ignored this factor for simplicity. Now, we introduce convertibility of the currency in the model and examine whether it affects the above results.

Specific business partners receive the currency notes after all the commercial transactions are made through the CC, and they have to make the following two-step decisions: (1) they decide whether or not to convert the received CC and (2) if the decision to convert is negative in (1), they decide whether to use it for commercial or non-commercial transactions[18]. We assume that the probability of conversion of the CC into yen done by specific business partners is P_y $(0 \leq P_y \leq 1)$. Then, the probability that specific business partners use the CC for commercial transaction is P_c' $(1-P_y)P_c$, and for non-commercial transactions is $P_{nc}'=(1-P_y)P_{nc}=(1-P_y)(1-P_c)$.

First, we take another numeric example. A new parameter P_y is set ($P_y=0.8$) and the other parameters are the same as before ($r=3$, $P_c=0.9$, $P_{nc}=0.1$). Figure 16 is the CC circulation tree diagram in this case.

The commercial transactions that remain when non-commercial transactions are removed are $C'=0.9+0.9\times0.18+0.9\times0.18^2=1.09116$. The total commercial transactions in DTS are $C=C'+0.09+0.0162+0.0162+0.009=1.22256$, and then, $C/C'=1.1204$ (see Fig. 17). The non-commercial transactions that remain when commercial transactions are removed are $NC'=0.111$, and the total non-commercial transactions are $NC=0.13584$ and $NC/NC'=1.2238$. In this example, commercial transactions grow at a rate of 12.04% and non-commercial ones grow at 22.38%.

In generic terms, we can express C' and C and show that $C'<C$.

$$C'=\frac{P_c(1-P_c'^{r})}{1-P_c'} \quad (P_c' \equiv (1-P_y)P_c)$$

$$C=C'+(1-P_c)P_c(2P_c'+2-P_c)<C'$$

[18] We observed that specific business partners converted the CC they received through non-commercial transactions in a very small volume. In the meantime we ignore it for simplicity.

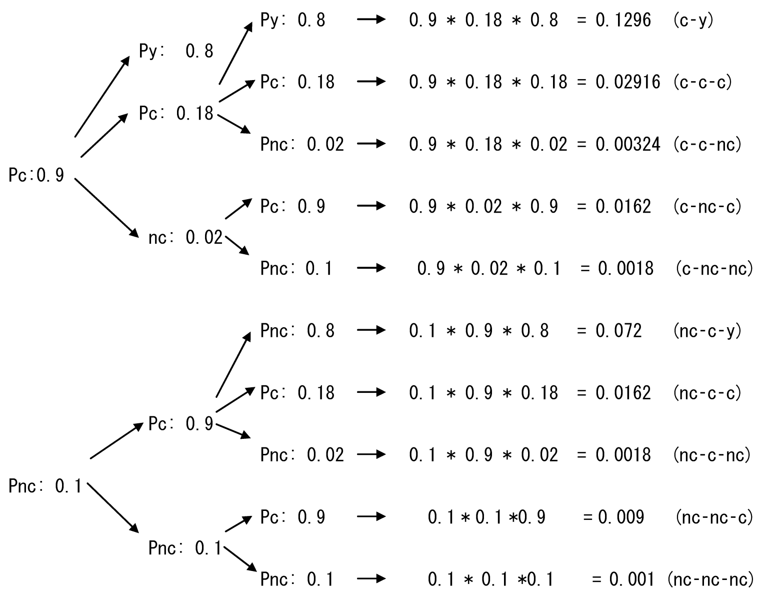

Fig. 16. The circulation paths tree diagram of the currency with conversion.

t	1		2		3	Sum	(ratio)
c	0.9	+	0.252	+	0.07056	= 1.22256	(40.752 %)
nc	0.1	+	0.028	+	0.00784	= 0.13584	(4.528 %)
y	0.0	+	0.72	+	0.92160	= 1.6416	(54.72 %)
	1		1		1	3	

Fig. 17. Event probabilities for each turnover.

$$2P_c'+2-P_c>1 \Rightarrow (1-P_c)P_c(2P_c'+2-P_c)>(1-P_c)P_c>0$$

Similarly, we can express NC' and NC and show that $NC'<NC$.

$$NC'=\frac{P_{nc}(1-P_{nc}^r)}{1-P_{nc}}$$

$$NC=NC'+P_c'P_{nc}(1+P_c'+2P_{nc})>NC'$$

In DTS with convertibility, the transaction complementarity effect to increase transactions still works. It is thus proved that DTS is effective in case of convertible currency notes. However, when convertibility is possible, the currencies go out of circulation rapidly. The percentage of currencies converted into yen at turnover 3 is

92.16%, which makes the circulation velocity of the currency tend to decrease; however, as long as $r>1$, its money crossover effect is still positive.

Next, we make the Tomamae-cho CC circulation diagram based on the above model with convertibility by using the real data obtained from the first circulation experiment. We can distinguish commercial transactions from non-commercial ones based on the data acquired from the reverse side of the Tomamae-cho CC notes. We define the combination of commercial and non-commercial transactions as the total transactions.

Figure 18 is the Tomamae-cho CC circulation tree diagram based on the real data. Note that the numbers in the square signify the number of currency notes that were converted subsequent to the commercial or non-commercial transaction at the reference turnover, and the numbers attached to arrows[19] signify the number of currency notes in circulation through the reference circulation path. We can see that all currency notes are circulated through only two paths ($c-c-c-c$ and $nc-c-c-c$), and if we take non-commercial transactions off the tree, $nc-c-c-c$ is no longer available. Later, we will compare this diagram of Tomamae-cho CC with the theoretically constructed model having the constant event probability through turnovers.

Table 5 shows the observed data in Tomamae-cho CC in terms of the volume of transactions and the number of currency notes issued or used in C, C', NC, and NC' at each turnover, and currency velocity calculated from the observed data. The maximum turnover of the currency is 4, which means that all currency notes were converted into yen after turnover 4. Table 6 shows the calculated values of P_c, P_{nc}, P_{cy} by using the real data in the Tomamae-cho CC[20]. Table 7 shows the observed values of C/C', NC/NC', C'/X, and NC'/X and also their calculated values by using a P_c, P_{nc}, P_{cy}, and P_{ny} in Table 6. Table 8 shows event probabilities of C, NC, and Y at each turnover and the average probability through all turnovers[21].

According to Table 5, the circulation velocity of CC in the total transactions X is 5.07, which is larger than that of any of other transactions, C, C', NC, and NC'. This indicates

19) Thickness of arrows visually symbolizes how large the numbers of currency notes through the circulation paths are. The dotted lines show the possible circulation paths that the currency notes did not flow.

20) P_{cy} and P_{ny} signify the probability of conversion after the commercial/ non-commercial transactions by specific business partners. P_c and P_{nc} are thought of as the ratios of the number of currency notes flowing in the commercial/non-commercial transactions at turnover 1 and the number of currency notes converted in yen after the transactions at turnover 1. These are calculated as $P_{cy}=1756/2013$ and $P_{ny}=8/180$.

21) Turnover 5 is added to enable the currency notes accepted at turnover 4 to be converted into yen.

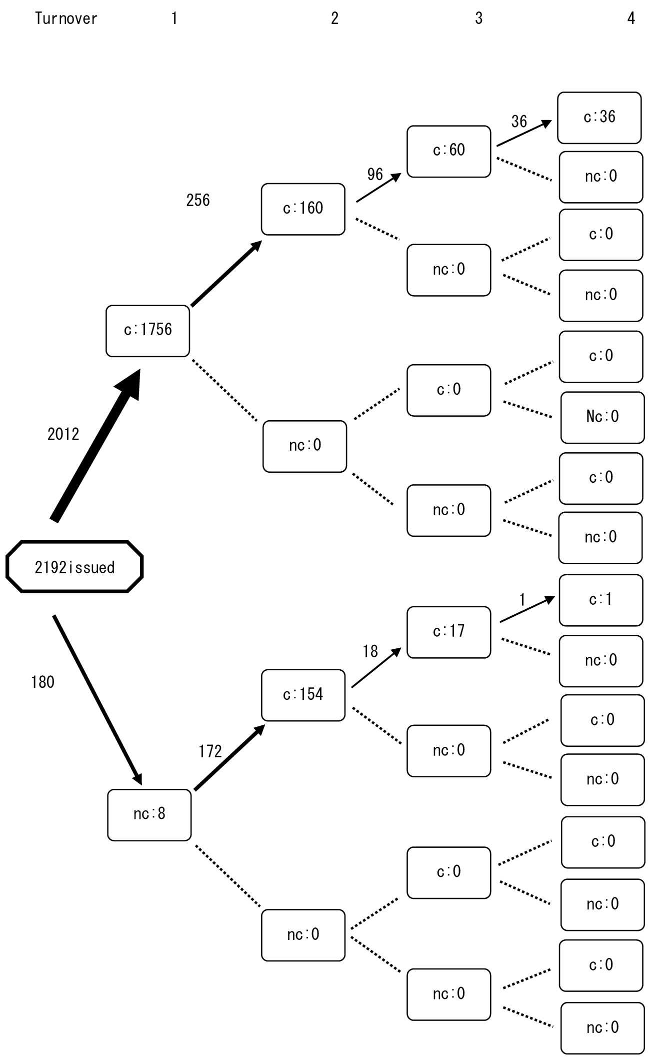

Fig. 18. The Tomamae-cho CC circulation tree diagram based on the real data.

that CC in DTS has higher circulation efficiency than legal tender and Eco-money. According to Table 7, the observed value of C/C' (1.080) is higher than the calculated one (1.009) and the observed value of NC/NC' (1) is lower than the calculated one (1.221). All non-commercial transactions have been done at turnover 1. This concentration of non-commercial transactions makes transaction complementarity effect work more for commercial transactions, but work nothing for non-commercial

Table 5. The commercial and non-commercial transaction of CC.

	Volume of transaction	Currencies issued/used	Circulation of velocity	Circulation of velocity p.a.
Total: X	2771	2192	1.26414	5.07046
Remaining commercial removing NC: C'	2400	2012	1.19284	4.78448
Remaining non-commercial removing C: NC'	180	180	1.00000	4.01099
Commercial only: C	2591	2184	1.18636	4.75846
Non-commercial only: NC	180	180	1.00000	4.01099
$C+NC=$	2771	2364	1.17217	4.70154
$C-C'=$	191	172	1.11047	4.45406
	T1	T2	T3	T4
Total: X	1764	314	77	37
Remaining commercial removing NC': C'	1756	160	60	36
Remaining non-commercial removing C: NC'	180	0	0	0
Commercial only: C	1910	177	61	36
Non-commercial only: NC	180	0	0	0
$C+NC=$	2090	177	61	36
$C-C'=$	154	17	1	0

Table 6. The caluculated value of P_c, P_{nc}, P_{cy}, P_{ny}.

Prob. of commercial transaction	$P_c = {}_{\text{Observed}}C/X=$	0.93504
Prob. of non-commercial transaction	$P_{nc} = {}_{\text{Observed}}NC/X=$	0.06496
Prob. of conversion after commercial transaction	${}_{\text{Observed}}P_{cy}=$	0.87276
Prob. of conversion after non-commercial transaction	${}_{\text{Observed}}P_{ny}=$	0.04444

Table 7. The observed and caluculated values of growth rates of C and NC.

DTS growth effect (C)	${}_{\text{Observed}}C/C'$	1.07958	${}_{\text{Calculated}}C/C'$	1.00880
DTS growth effect (NC)	${}_{\text{Observed}}NC/NC'$	1.00000	${}_{\text{Calculated}}NC/NC'$	1.22053
Rate. of C' to X	${}_{\text{Observed}}C'/X$	0.86611	${}_{\text{Calculated}}C'/X$	0.92689
Rate. of NC' to X	${}_{\text{Observed}}NC'/X$	0.06496	${}_{\text{Calculated}}NC'/X'$	0.05322

Table 8. Event probabilities at each turnover of Tomamae-cho CC.

Turnover	1	2	3	4	5	Total	Ratio
Commercial: *C*	0.91788	0.19526	0.26636	0.32456	0.00000	1.70406	0.34081
Non-commercial: *NC*	0.08212	0.00000	0.00000	0.00000	0.00000	0.08212	0.01642
Converted: *Y*	0.00000	0.80474	0.73364	0.67544	1.00000	3.21383	0.64277
Total	1	1	1	1	1	5	1

Table 9. Event probabilities at each turnover (reconstructed).

Turnover	1	2	3	4	5	Total	Ratio
Commercial: *C*	0.93504	0.16928	0.16928	0.16928	0.00000	1.44289	0.28858
Non-commercial: *NC*	0.06496	0.01176	0.01176	0.01176	0.00000	0.10024	0.02005
Converted: *Y*	0.00000	0.81896	0.81896	0.81896	1.00000	3.45687	0.69137
Total	1	1	1	1	1	5	1

transactions. This bias is also seen from Table 8 because each event probability is not constant through turnovers. The probability of non-commercial transactions drops to and stays at 0 through turnovers 2 to 4, probability of commercial transactions continues to increase after a big drop at turnover 2, and probability of conversion continues to decrease through turnovers 2 to 4.

Figure 19 is the circulation tree diagram of Tomamae-cho, which we reconstructed assuming that P_c, P_{nc}, P_{yc}, and P_{yn} are constant through turnovers 2 to 4 as in Table 9[22].

Figures 18 and 19 are similar in terms of the volume of total transactions (X), commercial transactions (C), and non-commercial transactions (NC) seen in Table 10. The currency notes circulate through all the possible branching paths in Fig. 19, though there are only two circulation paths (*c–c–c–c* and *nc–c–c–c*) in Fig. 18. However, these are still the two major paths with largest and second largest volumes of circular flow of the currency notes. There exist two other intermediate paths such as *c–nc–c–c* and *nc–nc–c–c* seen in Fig. 19.

Table 10 shows that C/C' is 1.084 and NC/NC' is 1.154, These are greater than the observed and calculated values excluding the calculated NC/NC' in Table 7 (observed $C/C' = 1.080$, calculated $C/C' = 1.009$, observed $NC/NC' = 1$, and calculated

[22] The probability of conversion at turnover 1 is 0 because conversion of unused currency notes is prohibited by the rule of the system.

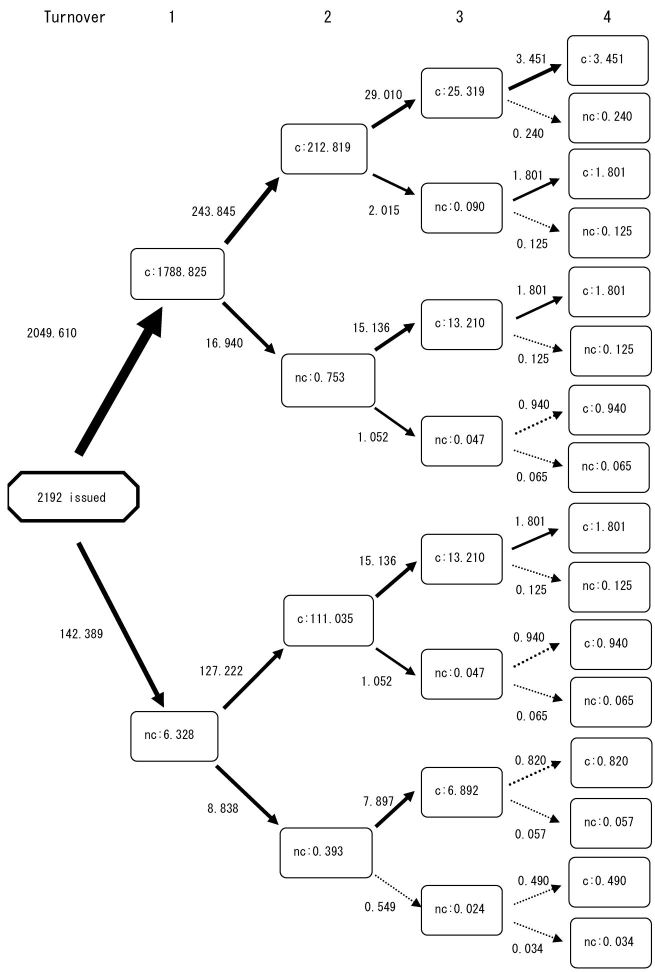

Fig. 19. The Tomamae-cho CC circulation tree diagram reconstructed assuming the constant event probability.

NC/*NC′* = 1.221). Constant probability of events equates the transaction complementarity effects between commercial and non-commercial transactions. This effect is also visible as the increase of circulation velocity of the currency notes in Table 11. Thus, we can conclude that DTS's effectiveness is theoretically and empirically demonstrated.

9. Importance of Dual Directional Transaction in DTS

We can also evaluate the significance of non-commercial transactions for the smooth

Table 10. The caluculated values of major variables (reconstructed).

	T 1	T 2	T3	T 4	Total
Number of notes: Z	1795.15388	324.99993	58.83894	13.00724	2192
Total transaction: X	1795.15388	649.99986	176.51683	52.02898	2673.69955
Number of notes used for C: Z_c	1908.28493	242.52260	30.96139	3.45144	2185.22035
Commercial transaction: C	1908.28493	485.04519	92.88417	13.80575	2500.02004
Number of notes used for NC: Z_{nc}	150.26784	10.57219	0.71036	0.03405	161.58444
Non-commercial transaction: NC	150.26784	21.14438	2.13108	0.13621	173.67951
Number of notes used for C and NC: Z_c+Z_{nc}	2058.55277	253.09479	31.67175	3.48549	2346.80479
Difference between NC and Z: $Z_c+Z_{nc}-Z$	263.39889	−71.90514	−27.16719	−9.52175	154.80479
Number of notes Removing NC: Z'_c	1789.69038	213.03389	25.55919	3.45144	2031.73491
Remaining C removing NC: C'	1789.69038	426.06779	76.67758	13.80575	2306.24150
Number of notes Removing : C: Z'_{nc}	132.37413	8.22442	0.51455	0.03405	141.14716
Remaining NC removing C: NC'	132.37413	16.44884	1.54366	0.13621	150.50284
C/C'	1.06627	1.13842	1.21136	1	1.08402
NC/NC'	1.13518	1.28546	1.38053	1	1.15399

Table 11. The circulation velocity of currency notes.

	In 91days of experiment period	Per annum
Circulation velocity (v)	1.21975	4.89242
Circulation velocity in C (C/Z_c)	1.14406	4.58881
Circulation velocity after removing NC (C'/Z_c')	1.13511	4.55291
Circulation velocity in NC (NC/Z_{nc})	1.07485	4.31122
Circulation velocity after removing C (NC'/Z_{nc}')	1.06628	4.27685

circulation of Tomamae-cho CC from a different angle because non-commercial transactions increase the reciprocity of total transactions. We employ “triad census” as an estimation method and use Pajek1.1.1. We can confirm how the non-commercial transactions helped smoothen the total transactions. The triad censuses for the total

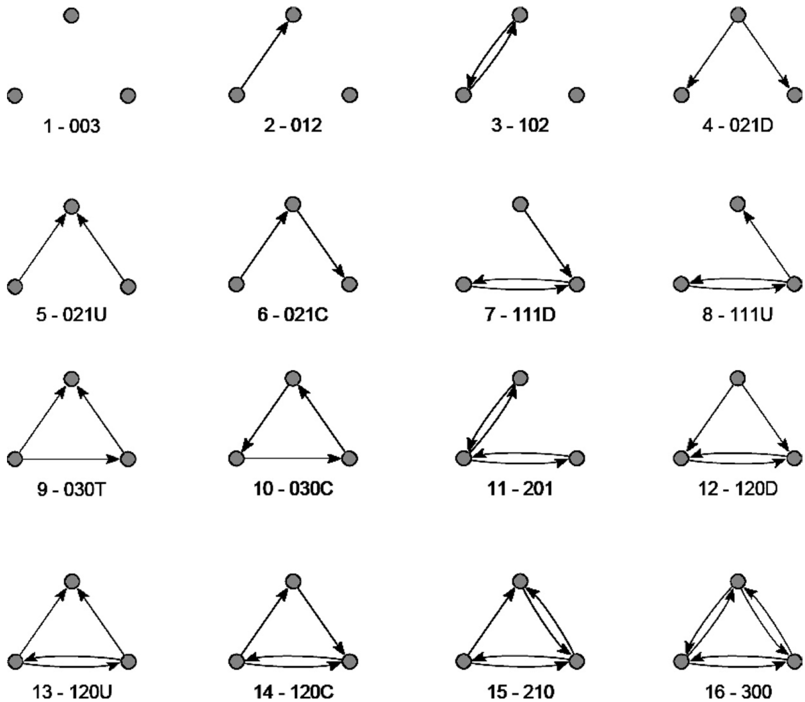

Fig. 20. Types of Triad.

transactions and for the commercial transactions data in Table 12 show many of the main findings. Figure 20 shows the types of triad. The Z scores in Table 12 indicate the deviations of the observed values from those expected by random digraph distribution (Wasserman and Faust, 1994; Kanamitsu, 2003). In the total transactions, the Z scores of 3-102, 5-021U, 9-030T, 7-111D, and 8-111U were greater than 1; this result shows the characteristics of the TCCN. However, in the commercial transactions, the Z scores of 3-102, 7-111D, and 8-111U were less than 0; the characteristics of the TCCN in the total transactions disappeared. 3-102 represented a two-way exchange between two people and specific business partners or cooperative groups. The vanished 3-102 means that the flow of CC altered from a two-way exchange to a one-way exchange. 7-111D and 8-111U were the same as 3-102. This result indicates that the non-commercial transactions facilitated two-way exchanges within Tomamae-cho CC. In the commercial transactions, since receivers were limited to the specific business partners, Tomamae-cho CC accumulated at the specific business partners and could not flow smoothly unless these specific trading partners were willing to make purchases from other participants with

Table 12. Triad censuses for TCCN.

Total transactions in Feb. 2005			Commercial transactions in Feb. 2005		
Triad type	Frequency	Z[23]	Triad type	Frequency	Z
3-102	380	1.21	3-102	0	−1
16-300	0	−1	16–300	0	−1
1-003	1576575	0	1-003	64855	0
4-021D	106	−0.38	4-021D	26	−0.29
5-021U	1135	5.59	5-021U	207	4.68
9-030T	31	13.92	9-030T	2	1
12-120D	1	158.51	12-120D	0	−1
13-120U	1	158.51	13-120U	0	−1
2-012	54851	−0.04	2–012	5194	−0.02
14-120C	0	−1	14-120C	0	−1
15-210	0	−1	15-210	0	−1
6-021C	231	−0.33	6-021C	16	−0.78
7-111D	37	16.81	7-111D	0	−1
8-111U	7	2.37	8-111U	0	−1
10-030C	0	−1	10-030C	0	−1
11-201	0	−1	11-201	0	−1

Tomamae-cho CC. Therefore, the non-commercial transactions are crucial for both community revitalization and economic activation. Tomamae-cho CC used in the non-commercial transactions are going to be absorbed by the commercial transactions in due time, and Tomamae-cho CC that are purchased for social welfare or volunteer activities are expected to put a brake on the spillover of purchasing power to other towns.

10. Concluding Remarks

CC is a "socio-cultural medium," which activates local economies and reinforces cooperation of communities and mutual aid. Our network analysis empirically shows that the aspects of the socio-cultural medium functioning successfully within the community help the aspects of the "economic medium" to act properly. We obtained four main results in this study: (1) various distributions of Tomamae-cho CC obey a power-law distribution; (2) the networks of the Tomamae-cho CC display the characteristics of a small-world networks similar to those of organisms; (3) directional and weighted network analyses are important because the directional graph often shows asymmetry of

[23] The Z score is the value of (frequency–expected frequency)/expected frequency.

the network, and the correlation coefficient between degree and weight is significantly less than 1; and (4) DTS is effective in the sense that it can increase the volumes of both commercial and non-commercial transactions by its "transaction complementarity effect" or "currency crossover effect," and that it can enhance dual directionality and reciprocity of transactions. We conclude that network analyses and currency circulation path analysis are both necessary to understand the flow of CC. The information acquired from our network analyses might provide relevant direction to researchers and decision-makers for addressing regional policies and planning.

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References

Albert, R. and A.-L. Barabási (2002) "Statistical Mechanics of Complex Networks," *Reviews of Modern Physics* 74: 47–96.

Amaral, L.A., A. Scala, M. Barthelemy and H.E. Stanley (2000) "Classes of Small-world Networks," *The Proceedings of the National Academy of Sciences of the United States of America* 97: 11149–11152.

Freeman, L.C. (1979) "Centrality in Social Networks: Conceptual Clarification," *Social Networks* 1: 215–239.

Kanamitsu, J. (2003) *Shakai Network Bunseki No Kiso* (in Japanese), Keiso Shobo, Tokyo.

Kato, T. (1998) *Eco Money* (in Japanese), Nihon Keizai Shinbun Sha, Tokyo.

——— (2001) *The New Millennium of Eco Money* (in Japanese), Keiso Shobo, Tokyo.

Kichiji, N. and M. Nishibe (2006) "*Network Analyses for CommunityCurrency"* (in Japanese), *Shinka Keizaigaku Ronshu* 10: 317–326.

——— (2007) "Power Law Distributions in Two Community Currencies," *The Proceedings of Topological Aspects of Critical Systems and Networks*: 59–64.

Masuda, N. and N. Konno (2005) "*Fukuzatsu Network No Kagaku"* (in Japanese), Sangyou

Tosho Kabushiki Gaisya, Tokyo.

Newman, M.E.J. (2002) “Assortative Mixing in Networks,” *Physical Review Letters* 89: 208701.

Nishibe, M. (2004) *Chiiki Tuka No Susume* (in Japanese), Hokkaido Shokoukai Rengou.

———, T. Kusago, H. Ippei, N. Kichiji, M. Yoshida, K. Kurita, K. Yamamoto, and S. Yoshii (2005) *The Report for the Circulation Flow of Tomamae-cho Community Currency* (in Japanese), Hokkaido Shokoukai Rengou.

Scott, J.P. (2000) *Social Network Analysis: A Handbook*, 2nd ed., Sage Publications Ltd., Thousand Oaks, CA.

Wagner, A. and D.A. Fell (2000) “The Small World of Metabolism,” *National Biotechnology* 18.11: 1121–1122.

Wasserman, S. and K. Faust (1994) *Social Network Analysis*, Cambridge University Press, Cambridge.

Watts, D.J. and S.H. Strogatz (1998) “Collective Dynamics of Small-world Networks,” *Nature* 393: 440–442.

Wellman, B., P. Carington and A. Hall (1988) “Networks as Personal Communities,” in B. Wellman and S.D. Berkowitz (eds) *Social Structure: A Network Approach*, Cambridge University Press, Cambridge, pp. 130–184.

Yasuda, Y. (2001) *Jissen Network Bunseki* (in Japanese), Shinyou Sha, Tokyo.

Zipf, G.K. (1949) *Human Behavior and the Principles of Least Effort*, Addison-Wesley, Cambridge.