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The Effect of the Network Structure Differences on the Diffusion of Items

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Abstract

This paper presents a multiagent-based simulation approach to the effect of network structure difference on the diffusion of items. Recently, the rapid spread of information and communication technology induces multiplexing of our communication space. As a result, diffusion of products in the market has been changed because the communication affects our behaviors and state of own mind. Network externality is an effect that value of a product depends on the market penetration. It has been known that markets of products having network externality are greatly influenced by interpersonal communication. In this paper, we constructed two network, "offline network" and "online network" that refer to networks before and after the development of information and communication technologies, focusing on such changes and analyzed the differences between network structures. We verified the effect that difference of network structures affects the diffusion of items in network effect markets. We discussed the property of diffusion process in each network and how easily monopolistic diffusion can occur depending on the network structures.

Introduction

Recently, a socializing method and other parties of association have been changed because of the development of information and communication technologies such as the Internet and mobile phones. For example, mobile phones make it possible to communicate with anyone, anytime, and the Internet and Social Network Service (SNS) make it easy for people who have something in common to communicate through online communities. It is thought that communication and exchanging information with others, and their behavior, affects our own actions and psychology. The network effect (also called network externality or demand-side economies of scale) in markets is an example of interaction with others producing a major effect on individuals (Katz and Shapiro, 1985). Briefly, the network effect means that as the number of users an item has increases, that item becomes more attractive to others. In this situation, it is thought that the diffusion rate of items within one group of friends affects the decision about whether or not to buy something. When two similar items are in a race to be the most popular, it is common for only one item to be shared exclusively because of positive feedback and items selling faster if they are already doing well. This phenomenon is called "winner-takes-all" by Arthur (1996).

There has been much previous research about the network effect (e.g., Ozawa and Nakayama (2010); Weitzel et al. (2003)). Kaneko et al. (2006, 2005) constructed a model that considered the asymmetricity of information and analyzed customers' purchase decision-making processes. In the model each consumer had different information with respect to others' purchase behavior, and they reported that the market becomes inefficient if customers are unaware of each other's behavior. Kawamura and Ohuchi (2005) analyzed the effectiveness of the present strategy, in which businesses provide their services without charge. They examined the effectiveness of two present strategies: a simple present strategy and friend present strategy, and discussed the effectiveness of present strategies in different network structures. Iba et al. (2001) analyzed the format competition of video cassette recorders, that is to say a typical standard race interaction between customers, by the artificial market model with multiagent approach. The simulation observed the emergence of locality, which is caused by the local influence, and the results showed that the local clusters provide the brakes on the winner-take-all phenomenon. Mizutani (2002) proposed a simulation model with evincive individual relationships. He used network structures that describe the relationship in urban and provincial areas, and showed that differences to these structures can affect the diffusion race.

In a network effect market, the situation at the early stage is significant in terms of the final diffusion result (Liebowits and Margolis, 1994). Therefore, we need to examine the early stage and come up with a definition for the customer group that decides to buy an item at the early stage and how the diffusion process proceeds from that point. Additionally, it seems to be important to study acquaintance network structures that show the relationships between customers.

We propose a model that draws on Mizutani (2002)'s model that focuses on the relationship between network structure differences and the diffusion state. First, we de-

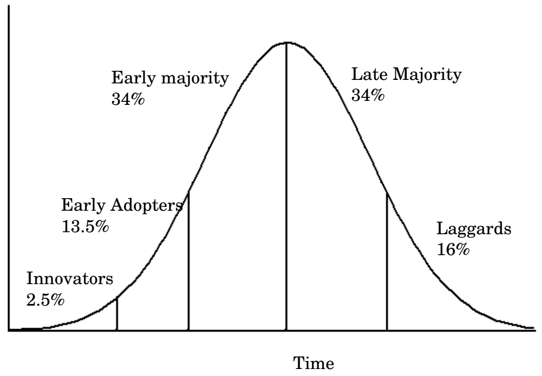

Figure 1: Innovator theory: five types of customers to adopt a new item and their population distribution.

fine the customer group that decides to buy an item at an early stage and add conservative buying to the purchase model for realistic simulation. In the real world, it is well-known that buying patterns are related to differences in a customer's character (Rogers, 2010). Therefore, we constructed an agent model that considers innovator theory and classifies customers into five categories in order to analyze the acquaintance networks in each category. We also added conservative buying in the purchase model in order to make it possible to analyze realistic diffusion process. We show the differences of acquaintance networks that each adopting category has as well as network structure differences, and then discuss how these differences the affect the diffusion and the process of the diffusion of items.

Innovator theory

Innovator theory is a sociological theory first proposed by Rogers (2010). In this theory, customers are classified into five categories (see Figure 1) on the basis of how quickly they develop a purchasing attitude toward new items.

- Innovators: 2.5% of all customers.
- Early adopters: 13.5% of all customers.
- Early majority: 34% of all customers.
- Late majority: 34% of all customers.
- Laggards: 16% of all customers.

The character of the customers in each of the categories is also analyzed. Early adopters tend to have a higher income, intelligence, a friendlier attitude toward science, and a more reasonable personality than late adopters.

Proposed Model

In this paper, we assume that if a new item, or two conflicting new items, appears in the market, there will be a network effect. If two new items exist in the same market, customers can choose whichever item is preferable to them. We assume that customers do not know the diffusion rate of item in an entire market; they only know the local popularity in their own acquaintance network.

In this section, we define an agent as a customer, and a network as both an acquaintance relationship network and a purchase action model.

Agent Model

We define agents as customers who exist in society. An agent is comprised of adopting an item ($adopting_i$), social attribute (AT_i), and its two derivative attributes: social position (SP_i) and threshold recognizing desire to buy (T_i).

$$agent_i(adopting_i, AT_i, SP_i, T_i). \quad (1)$$

$adopting_i$ describes three values: adopting item A or B, or not adopting. Agents can have only one item, and although they are allowed to replace on item with another, they cannot have two items at the same time.

$$adopting_i = 0 \ \ or \ \ 1 \ \ or \ \ 2. \quad (2)$$

Social attribute describes an agent's social position, e.g., age, occupation, educational background, and so on. Elements of the social attribute at_{ik} describe the real value from 0 to 1 randomly.

$$AT_i = (at_{i1}, \cdots, at_{ik}, \cdots, at_{iK}), \quad (3)$$

$$(1 < k < K).$$

Social position is calculated by the following equation using the social attribute.

$$SP_i = \sqrt{\sum_{k=1}^{K} at_{ik}^2}. \quad (4)$$

In the innovator theory, there is a positive correlation between the height of the social attribute and the speed of the purchase time. The agents are classified into five categories according to value of SP_i.

"Threshold recognizing the desire to buy" describes the speed of a purchasing attitude to a new item. Agents will decide to buy an item if the local popularity among their acquaintances is over their own threshold. Agents who have a low threshold have the desire to buy a new item in an early stage easily. On the other hand, agents who have high threshold get this desire in the late stage. They are cautious about buying new items, they do not buy any until the majority of their acquaintances have. The threshold recognizing the desire to buy is indicated by the following equation using the social position.

$$T_i = 0.5 - \frac{SP_i}{2 \max SP}, \tag{5}$$

where $maxSP$ means the max value of SP_i.

Network Model

The section describes a network model with an agent as a node and acquaintance relationships as links. Mizutani (2002)'s research included two different types of structures, strong network and weak network, based on the similarity of social attributes between people, namely homophily. Homophily refers to people making a relationship with someone and the giving priority to people with whom the social distance between them is close. Social distance is indicated by the social attribute. In the case of using several social attributes, they are treated as dimensions.

In the past, before the recent development of information and communication technologies, it was not as easy to contact others as it is now, so geography became a key factor in acquaintance relationships. However, these days it is possible to contact and communicate with people who have at least one thing in common with oneself, so homophily is getting weaker than before. In this study, we consider two networks, "offline network" and "online network", based on the homophily in Mizutani (2002). "Offline network" and "online network" refer to networks before and after the development of information and communication technologies.

- Offline Network

  This is the network before the development of information and communication technologies. Homophily has a significant influence and links are made between people with a similar social attribute in all dimensions, that is, birds of a feather. The offline network has an acquaintance relationship with strong inbreeding and is created by using all social attributes. Social distance ($padis_{ij}$), which is defined by using Euclidean distance in all social attributes, is indicated by the following equation.

$$padis_{ij} = \sqrt{\sum_{k=1}^{K} (at_{ik} - at_{jk})^2}. \tag{6}$$

- Online Network

  This is the network after the development of information and communication technologies. Homophily has a weaker influence and links are made between people with a similar social attribute in as little as one dimension. Heterophily is superior to homophily in this network.

  The online network has an acquaintance relationship like weak-ties and is created by using at least one social attribute. First, we calculate the difference of each social attribute's element between $agent_i$ and $agent_j$, and next, we use the following equation to determine their minimum value of the difference ($prdis_{ij}$).

$$prdis_{ij} = \underset{k=1,\cdots,K}{\text{argmin}} \left(|at_{ik} - at_{jk}| \right). \tag{7}$$

In this paper, each network has same number (L) of links that exist in society fixedly in order to compare the effect that different network structures have on the diffusion of items. Links between $agent_i$ and $agent_j$ are composed in ascending order according to $padis_{ij}$ in all combinations of agent pairs. Clustering coefficient defined by Watts and Strogatz (1998) is well known as a measure of the degree to which people in a network tend to cluster together. The clustering coefficient of offline and online network was 0.404 and 0.046, respectively.

Purchase Action Model

We proposed a purchase action model based on the Engel-Blackwell-Miniard (EBM) model by Engel et al. (1994). In the EBM model, a customer's decision-making process to buy items includes the following sequential phases: "recognize desire," "collect information," "assess alternative before buying," " buy," "consumption," "assess alternative after buying," and "dispose." In this paper, we do not touch on "consumption," "assess alternative after buying," or "dispose" because our model focuses only on making the decision to buy items. Customers recognize their desire to buy something after collecting information because we assume that customers can only collect information about items their own acquaintances have purchased. Therefore, we define the process of a customer's decision making as a sequence of "collect information," "recognize desire," "assume alternative before buying," and "buy." Figure 2 shows the flowchart of the purchase action by a single agent.

Agents in the innovator category are customers who buy new items at the first stage, so we assumed that they make the decision to buy items not on the basis of the local popularity in their acquaintances but rather on their own judgment. Therefore, in this paper, we propose that innovators have a particular purchase action model if they have not used any items yet.

In this section, we first the innovator's particular purchase action model and then define each phase of the other purchase action model.

Innovator's Purchase Action Model

Innovators are the earliest customers to buy new items, so we define them as agents who have the desire to buy new items as soon as they appear on the market. We assume that they make the decision to buy new items themselves. We therefore define probability p[0,1] as the height of their assessment of item A. They buy item A with probability p and buy item B with probability $1 - p$. When they trade up

Table 1: Action-Decision Table

Using item	$N_a > N_b$	$N_b > N_a$	$N_a = N_b$
Item A	Hold item A	Trade up item B	Hold item A
Item B	Trade up item A	Hold item B	Hold item B
Non-adopting	Buy item A	Buy item B	Hold off

for another, they follow the same as purchase action model of the other categories.

"Collect Information" Phase

In this phase, agents collect information about who has which items among their acquaintance agents. We define Na as the number of users who own item A, Nb as the number of users who own item B, and Nn as the number of agents who are not having any items.

"Recognize Desire" Phase

In this phase, agents recognize desire when they meet the following equation.

$$\frac{Na}{Na+Nb+Nn} > T_i \ \ or \ \ \frac{Nb}{Na+Nb+Nn} > T_i. \quad (8)$$

If the agent does not recognize desire, the purchase action will finish.

"Assess Alternatives Before Buying" Phase

In this phase, agents recognize desire for an alternative item before buying and judge which they prefer by the following equation.

- $Na > Nb$: Item A is preferable.
- $Nb > Na$: Item B is preferable.
- $Na = Nb$: can not judge which item is preferable.

"Buy" Phase

Agents who have assessed alternatives are now ready to buy. They follow the action-decision table shown in Table 1 by a combination of judgment in an earlier phase and own item Agents will buy an item that is preferable if they have not used any yet. If an agent already has an item, the agent will trade up for another one if it is considered preferable.

Simulation

We performed simulations with the networks using the following parameters. Number of agent $N = 2500$, number of links $L = 25000$, and number of social attribute elements $K = 5$. No agents had any items at the default position. Agents were randomly selected one by one and allowed to perform a purchase action process. A step was finished when all agents were selected. Each agent could only perform one purchase action per step. The simulation was finished when all agents did not buy or trade items in a step, meaning the market had become convergent.

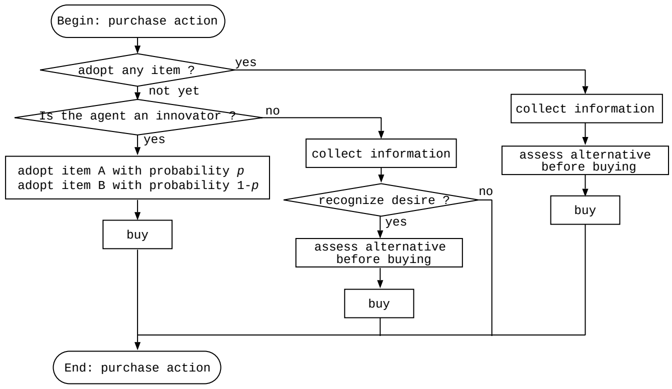

Figure 2: Flowchart of purchase action by a single agent.

First, we show the difference between the two networks. Next, we discuss the diffusion process in the case of one item in the market in simulation 1. Finally, we assume that two items are entering a diffusion race and discuss how often monopolistic occurs during the process in that situation.

Difference of Network Structures

First, we analyze the difference between the structures of the offline and online networks. We have constructed ten offline and online networks respectively and measured the distribution of which category each agent's acquaintances belong to. The results are shown in Table 2 and 3. Different agents in each adopter category have acquaintance relationships with agents in particular categories depending on the networks. In the offline network, an agent has an acquaintance relationship with an agent who has a similar buying attitude because there are many acquaintances between agents in the same category. In contrast, in the online network each agent has acquaintances with agents belonging to several categories. The number of common acquaintance that exists between two agents who have an acquaintance relationship with each other is also different. We counted the number of common acquaintances into linked agent pairs for 10,000 sample links extracted randomly from offline and online networks. As a result, the average number of common acquaintances in offline and online networks was 7.2 and 1.7, respectively. If there are many common acquaintances in a network, the transmission efficiency of the information is low because this network has a loop structure. It is in easily formed small groups that the network effect works both strongly and locally. In contrast, if there are relatively few common acquaintances in a network with the exception of having ring or linear structure, the transmission efficiency of information is high because the network has a hub structure and it is difficult to form a small group.

Simulation 1: The Diffusion Process for One Item

First, we assume that only one new item, A, appears in

Table 2: Acquaintance Relationship of Offline Network

	Innovators	Early Adopters	Early Majority	Late Majority	Laggards	Average # of acquaintance
Innovators	4.3 (35.2%)	7.7 (63.2%)	0.2 (1.6%)	0	0	12.2
Early Adopters	1.4 (8.2%)	9.8 (57.5%)	5.8 (34.3%)	0	0	17.0
Early Majority	0	2.3 (11.3%)	13.6 (67.0%)	4.4 (21.7%)	0	20.3
Late Majority	0	0	4.3 (20.5%)	14.5 (67.5%)	2.6 (12.0%)	21.4
Laggards	0	0	0	5.5 (27.4%)	14.4 (72.6%)	19.9

Table 3: Acquaintance Relationship of Online Network

	Innovators	Early Adopters	Early Majority	Late Majority	Laggards	Average # of acquaintance
Innovators	2.2 (10.9%)	7.2 (35.8%)	7.9 (39.1%)	2.7 (13.1%)	0.2 (1.1%)	20.2
Early Adopters	1.4 (6.7%)	5.2 (26.4%)	7.9 (40.1%)	4.4 (22.3%)	0.9 (4.5%)	19.8
Early Majority	0.6 (2.9%)	3.2 (15.6%)	7.8 (38.9%)	6.5 (32.0%)	2.1 (10.6%)	20.2
Late Majority	0.2 (1.0%)	1.7 (8.7%)	6.4 (32.2%)	7.7 (38.1%)	4.0 (20.0%)	20.0
Laggards	1.0 (0.2%)	0.7 (3.6%)	4.6 (22.9%)	8.5 (42.5%)	6.1 (30.8%)	19.9

the market, and we study the effect that network structure differences have on the diffusion process of this item. We set a probability that an innovator buying item A is equal to 1. The number of buyers in each step is shown in Figure 3, and the process of diffusion rate is shown in Figure 4. There is a clear difference in the diffusion processes. The online network's diffusion speed was slower than that in offline network at the early stage, but it increased quickly after the diffusion rate was over 15% (375 users).

The offline network had acquaintance relationships between agent pairs belonging to the same category and a lot of common acquaintances, and it was easy to form small groups that the network effect works both strongly and locally. Therefore, the diffusion moved ahead steadily. However, the diffusion speed into the entire market was slow because of poor transmission efficiency.

In contrast, the online network had acquaintance relationships between each agent and agents belonging to several categories and few common acquaintances, and it was difficult to form small groups. Therefore, the diffusion proceeded slowly at the early stage but spread into the entire market quickly after diffusion rate was over 15% because its structure resulted in a good transmission efficiency.

Simulation 2: Monopolistic Diffusion

Next, we assume that two contrasting items, A and B, are launched at the same time and are engaged in a diffusion race to get shares, and we study the effect of the network structure differences on the diffusion race. We looked into the relationship between probability p with which an innovator buys item A and the occurrence rate of monopolistic diffusion such that item A gets more than 90% share. We have conducted 100 simulation runs with every p from 0.25 to 0.75 at intervals of 0.05, and checked whether monopolistic diffusion occurred or not. The occurrence rate of monopolistic diffusion is shown in Figure 5. The results indicated that the online network had monopolistic diffusion more easily than that in offline network.

And we also looked into the diffusion process when monopolistic occurs. In the case of $p = 0.5$, we chose a result in which one item got a monopolistic share as a sample, the process of diffusion rate is shown in Figure 6. We assume that the majority as winner, the minority as loser in this result. In the offline network, minorities were left in small groups even though in such situation because it was easy to construct small groups that the network effect works both strongly and locally. In contrast, in the online network, the minority finally disappeared because it was difficult to construct small groups. Therefore, the online network is had monopolistic diffusion more easily than that in offline network.

Conclusion

We propose a model for describing the diffusion process. This model classifies agent into five categories on the basis of the speed of making a decision to buy a new item and analyzes the network structures belonging to the agent of each category. And we added conservative buying to the purchase model and analyzed the diffusion process, which Mizutani's model is not able to do. Next, we simulated two situations: diffusion of one item, and two items that enter a diffusion race. Results highlighted the differences in the diffusion process, the time needed to diffuse an entire market, and how easily monopolistic diffusion can occur depending on network structures.

It is a fact that human relationships are complicated. The

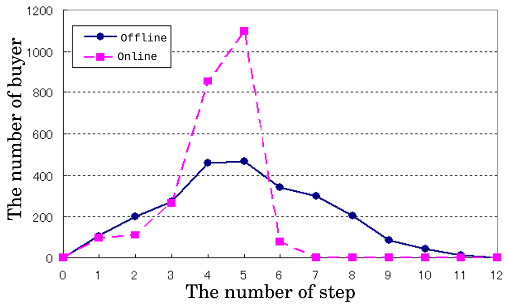

Figure 3: Number of buyer in each step.

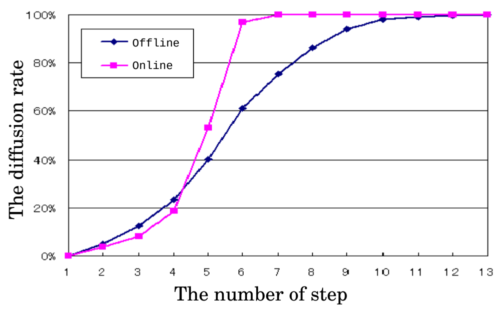

Figure 4: Process of diffusion rate.

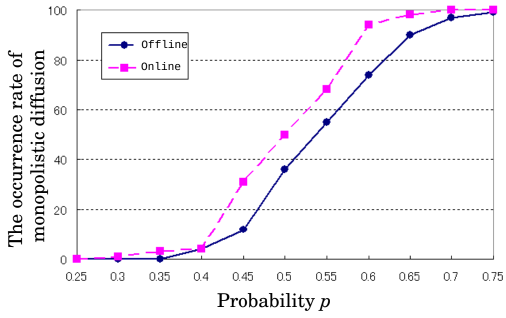

Figure 5: Monopolistic diffusion.

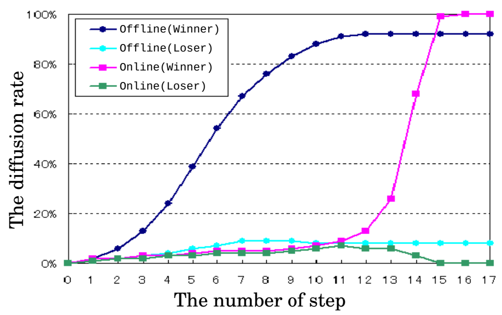

Figure 6: Process of diffusion rate.

model that we proposed in this paper only uses one of many possible factors, so our result does not describe a real diffusion process exactly but rather a potential one. We intend to develop a more realistic model as our future work.

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