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Innovation Diffusion with Network Effects and Bandwagon Effects Based on Complex Networks

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Abstract: Network effects and bandwagon effects are both well-known in the study of innovation diffusion. However, their influences on the individual adoption behavior are not the same. In this paper, we distinguish the differences between them from two aspects: the origin of demand and the influenced individuals. Based on the configuration of complex networks, we propose a diffusion model that includes the interactions between network effects and bandwagon effects. It is found that the innovation adoption rates depend closely on the individuals' preference between bandwagon effects and network effects. And the bandwagon effects are affected by the weight of neighbor relationships. Moreover, the network effects are composed of local network effects and global network effects and a trade-off between them is necessary to improve the diffusion of innovation.

Keywords: innovation diffusion, network effects, bandwagon effects, complex networks

1. INTRODUCTION

It is widely recognized in behavioral science that people are often inclined to follow a current or fashionable taste for superficial reasons rather than for any proof of the objective utility [1]. These phenomena coincide with the definition of bandwagon effect [2]. In fact, the phrase "jump on the bandwagon" first appeared in American politics in 1848 when Dan Rice, a famous and popular circus clown of the time, used his bandwagon and its music to gain attention for his political campaign appearances. Investigations have shown that a crucial part of the voters will change their decisions to support the likely winner based on the results of pre-election polls [3]-[4]. People like being identified with a winner to obtain the sense of social safety. This kind of psychological demand also exists in economic behavior, which is described as "the extent to which the demand for a commodity is increased due to the fact that others are also consuming the same commodity." [5]. The kernel of this marketing strategy is to convince the customers to adopt the commodity by adding bandwagon pressure. In the context of innovation diffusion, the concept of commodities can be generalized to innovation products [6]. Therefore, it can be said that people's decision-making behaviors are affected by psychological demand to some extent.

In practice, not only the psychological demand but also the objective usefulness of the product affects people's decision-making behavior. As mentioned above, the bandwagon pressure has direct correlation with the number of adopters. The more adopters in the society, the greater bandwagon pressure it will be. While for the usefulness of the innovation product, it seems irrelevant to the number of adopters. This is true for some products without externalities, such as the fuel, the food, and so on. The usefulness of such products only depends on the physical properties of itself. Thus, the usefulness is a linear function of the quantity of the product. However, the utilities of some products with externalities are relative to the number of users. Take the telephone network for instance. If there exists only one telephone in the network one can easily judge that the usefulness of it should be zero because no connection can be found in this case. By this way, the usefulness of such network is measured by the number of possible connections between two telephones. With the increase in telephones, the usefulness of this network will also increase, but in a nonlinear way. Precisely, maximum number of connections for N nodes network is $N(N-1)/2$, which is called the Metcalfe's law—"the value of a network grows as the square of the number of users" [7]. This measureable value is a function of the number of adopters but has nothing to do with the user's psychological satisfaction. Katz and Shapiro [8] named the externalities as "network

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effects" and they affected the innovation diffusion in numerous industries including information technology and communications [9].

As mentioned above, both bandwagon effects and network effects are sensitive to the number of adopters. In recent years, these two kinds of effects have been frequently investigated [10]-[16] and many interesting results have been achieved [7],[17]-[18]. A well known example is Microsoft who has succeeded in setting standards in the PC operating systems industry due to bandwagon effects and network externalities [19]. Nevertheless, the distinct differences between network effects and bandwagon effects are seldom discussed. In fact, the bandwagon effects are users' subjective psychological phenomena, while the network effects are objective and measurable. Moreover, the bandwagon effects and network effects can influence the individual decision-making behavior independently. Therefore, it is necessary to make a rigorous identification between network effects and bandwagon effects. Based on the differences, we can discuss the corresponding questions as follows. How do network effects and bandwagon effects act on individual decision-making behavior during the diffusion process? Which one is more important for the innovation diffusion? Are there any interactions between them? In this paper, we composed a "small-world" network configuration [20] and a social threshold model [21]-[24] to obtain some interesting results.

The rest of this paper is structured as follows. Section 2 discusses the differences between network effects and bandwagon effects. Section 3 proposes a threshold model of innovation diffusion with network effects and bandwagon effects. Section 4 reports the results of simulations and presents the discussion of the results, and finally in Section 5 we conclude the remarks.

2. THE DIFFERENCES BETWEEN NETWORK EFFECTS AND BANDWAGON EFFECTS

The diffusion of an innovation depends not only on the quality of the product but also on the quantity of adopters. Both bandwagon effects and network effects are correlated directly to the number of adopters. However, the mechanisms of these two types of effects are very different. The network effects are the origin of demand and the bandwagon effects are the influenced individuals.

2.1 The different motives of demand

The network effects mean that a potential adopter's utility evaluation of a product is often an increasing function of the number of other adopters purchasing compatible items [8]. Or in other words, if an individual adopts a compatible item, he/she gets the network utility from the externalities of that product. The compatibility benefits include the interchangeability of complementary products, the ease of communication between people or between people and machines, and the cost savings and demand-side economies of scale [25]. For example, the more individuals adopt the same technological product in the communication industry, the more chances there are for one individual to communicate with others. It has been pointed out that the network externalities (including direct and indirect) depend closely on the technical compatibility [26]-[30]. The technical compatibility means that individuals will have higher expectation to an innovation product if it is compatible with other individuals' products, so it is a physical characteristic of the product and corresponding service. Therefore, the individual adoption of an innovation product with network externalities is an objective result of the technical compatibility.

The bandwagon effects represent the aspiration of an individual to adopt an innovation in order to reinforce his sense of belonging and social safety, or in order to go along with a trend. They are purely psychological demand behaviors and bring the psychological satisfaction to the individual. During the diffusion process, the individual estimation on the innovation is influenced not only by his personal knowledge and experience but also by other individual decision-making behavior in the society. The bandwagon effects are created, for example, when the buying public can be convinced that a product or service is more fashionable than its competitors without objective evidence of the product's superiority [1]. The bandwagon pressure is generally formed by the individual's personal social network. Because each individual has a different relationship to the adopters, the influence on the individual behavior is different. The potential adopters are inclined toward the opinion of the more trusted adopter. Therefore, the bandwagon pressure affecting individual behavior is a subjective result of social psychological compatibility.

2.2 The difference of influenced individuals

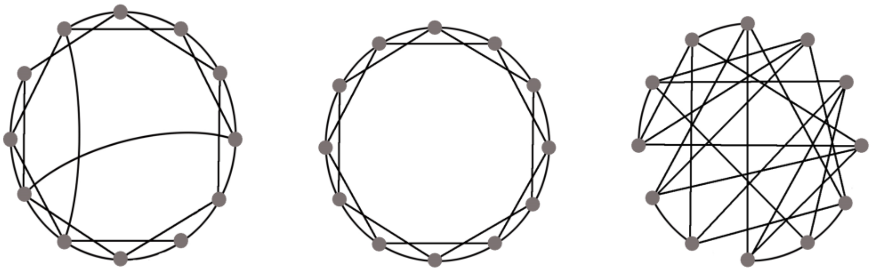
The network effects not only increase the potential adopters' utilities, but also increase the utilities of the previous adopters. Take the telephone system for example, the benefit of the technology to a potential user increases as soon as he/she joins into the system. Meanwhile, the benefit increases for the previous adopters since each one of them can communicate with more people [31]. This is identical with the Metcalfe's law mentioned above.

However, the bandwagon effects only increase the potential adopters' utilities. They do not increase the previous adopters' utilities. The bandwagon effect is a psychological phenomenon whereby people adopt an innovation as other people are using the same product, regardless of their own beliefs, which they may ignore or override. By bandwagon effects, the potential adopter will feel greater bandwagon pressure if the innovation has been accepted by more people. Therefore, the bandwagon pressure will urge the potential adopter to adopt the innovation. But this pressure doesn't increase the utilities of the previous adopters. The previous adopter is already a member of the public trend. He doesn't need to follow others anymore.

The technical compatibility of a product is a kind of physical characteristic and can be considered as an objective component of the utility function. We can see that the network effects will increase all of the individuals' (including the previous adopters and the potential adopters) utilities of an innovation product. However, the bandwagon effects only increase the potential adopters' utilities for their psychological satisfactions and can be regarded as a pure subjective component of the utility function.

3. THE DIFFUSION MODEL

The relationships among people in a society can be considered as a kind of complex network in which the nodes and edges represent the individuals and direct social relationships, respectively. Intuitively speaking, the edge between two nodes means that the two corresponding social members have known each other. By employing concepts of network analysis such as degree distribution, average length of path, we can trace the whole process of the innovation diffusion. Social networks often have global structures that are not random, but display stylized characteristics like power law distribution of the links, high clustering coefficients and short paths between arbitrary couple of nodes [20],[32]. It has been pointed out [20] that there exists a very important parameter called rewiring probability r to construct the randomness of the network structure. As shown in Figure 1, $r=0$ means that the edges of a complete regular network are fixed so that the nodes in such kind of network are highly clustered but the average length of two nodes is large. While for $r=1$, all the edges of the regular network are rewired randomly and then the average length of any pair of nodes is very short but the clustering coefficient is low. However, in between these two limits there is an area ($0<r<1$) where the network is both highly clustered and short distance between each other. It is very similar to the network structure of our real-world society and called by the term "small-world". We will use the same method to generate a small-world-like network including $N=2000$ nodes to discuss the innovation diffusion influenced by network effects and bandwagon effects.



(a) $r=0$ (b) $0<r<1$ (c) $r=1$

Figure 1. The regular network structure changes with the rewiring probability *r*

On the other hand, if we take the heterogeneity of individuals' behavior into account, the threshold model is suitable to describe the dynamics of the innovation diffusion process. Historically, the threshold model is well-known in social science research including innovation, rumours and disease spreading [6], especially in modeling collective behaviors [23]-[24] and considering the heterogeneity of each individual [33]. The main idea of this frequently used model is that each individual has a personal threshold of utility value to decide whether to adopt the innovation product or not. The individual utility is continuously changed during the diffusion process so the diffusion rate can be considered as a time-dependent function.

As mentioned above, the network effects and bandwagon effects are two kinds of different forces to motivate the innovation diffusion. Their detailed characteristics can be described as follow.

It has been pointed out that the network effects are determined by two types of externalities corresponding to the technical compatibility, namely, local network externalities [13],[34]-36] and global network externalities [17,29,37,38]. Both of them have been widely investigated in many cases [9],[39]-[41]. Generally speaking, the global externalities mean that an individual evaluates the utility of an innovation by looking at the whole society to see the total number of adopters. While the local externalities mean that an individual's utility is only affected by the number of adopters beside him or that have direct relationships with him.

The bandwagon effects reflect the individual psychological demand. By empirical evidence, people often believe or adopt things merely because many other people believe or do the same thing. In this way, the individual utility on an innovation product is affected by the others and we assume that the influences are transferred by the social relationships. According to the individual location distribution, we can separate the social relationships into two groups, namely, "neighbor relationships" and "remote relationships". Just as the implication of their names, neighbor and remote represent the distance between two linked social members. Notably, these two kinds of relationships differ from the well-known "strong ties" and "weak ties" in information spreading [42]. Strong and weak ties depend on the combination of time, the emotional intensity, the intimacy and so on. However, the neighbor/remote relationships are determined only by the spatial distance, as it is shown in Figure 2.

From Figure 2 we can see that the solid lines connect each node to its neighbor so we named them "neighbor relationships". Dashed lines connect two nodes far away from each other so they are "remote relationships". For arbitrary node, both solid line and dash line connect it to other node in the network and the sum represents "relative ties". Each node has a utility function which changes with the interaction of bandwagon effects and network effects. We will illustrate the evolution of utility value in detail below. Once the utility value exceeds the individual's critical values, he/she will adopt the innovation and the corresponding node in Figure 2 will change from hollow to solid.

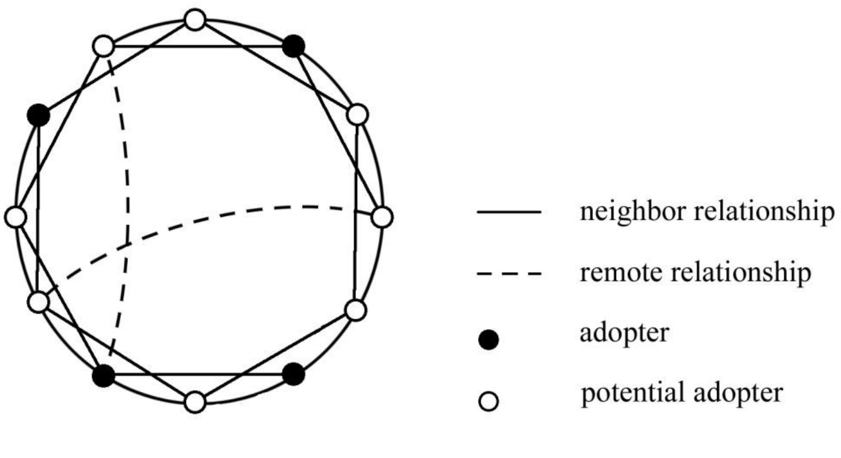


Figure 2. The sketch of innovation diffusion in a small-world like social network

The network effects can increase the utilities continuously for all the individuals in the society. And the bandwagon effects can be treated as a kind of psychological demand of joining the main trend. Hence, the bandwagon pressure will not increase the utility for the individual as long as he adopted the innovation. Formally, the utility function for the i-th individual at time t can be written as

$$U_{i,t}=\begin{cases} I_i+aB_{i,t}+(1-a)D_{i,t} & s_{i,t}=0 \\ I_i+aB_i+(1-a)D_{i,t} & s_{i,t}=1 \end{cases} \tag{1}$$

where

$$B_{i,t}=\begin{cases} b\sum_{j=1,j\neq i}^{N} s_{j,t}\varphi_{i,j}U_{j,t-1}/n_{1,i}+(1-b)\sum_{j=1,j\neq i}^{N} s_{j,t}(1-\varphi_{i,j})U_{j,t-1}/n_{2,i} & n_{1,i},n_{2,i}\neq 0 \\ (1-b)\sum_{j=1,j\neq i}^{N} s_{j,t}(1-\varphi_{i,j})U_{j,t-1}/n_{2,i} & n_{1,i}=0,n_{2,i}\neq 0 \\ b\sum_{j=1,j\neq i}^{N} s_{j,t}\varphi_{i,j}U_{j,t-1}/n_{1,i} & n_{1,i}\neq 0,n_{2,i}=0 \end{cases} \tag{2}$$

And

$$D_{i,t}=c\sum_{j=1}^{n_1+n_2} s_{j,t-1}/(n_1+n_2)+(1-c)\sum_{k=1}^{N} s_{k,t-1}/N \tag{3}$$

In Eqs. (1), I_i is the initial utility of the *i*-th individual. It depends on the intrinsic quality of the innovation product and the individual personal preference so we assume that it follows a normal distribution. $B_{i,t}$ and $D_{i,t}$ represent the bandwagon effects and network effects for the *i*-th individual who hasn't adopted the innovation at time t, respectively. The value of bandwagon effects remains unchanged and is denoted by B_i when the individual whole utility is above his threshold value. And a is the weight of the individuals' preference between these two effects. "$s_{i,t}=0$" means the *i*-th individual doesn't adopt the innovation at time t and "$s_{i,t}=1$" is on the contrary. $t=t'$ is the critical time that the individual is adopting the innovation.

In Eqs. (2), $n_{1,i}$ and $n_{2,i}$ are the number of neighbor relationships and remote relationships of the *i*-th individual. "$\varphi_{i,j}=0$" means the individual relationship of *i*-th and *j*-th is remote, while "$\varphi_{i,j}=1$" means the neighbor. b is the coefficient of weight of these two kinds of relationships. We adopt $0.5\leq b<1$ because the remote relationships can not be stronger than the neighbor relationships. In fact, the bandwagon effects come from the psychological demand so they are hard to be quantified. Nevertheless, the adopters always share their comments on the product with others by daily communication. The comments depend closely on the utility function so we assume that the utility values can be transferred to the potential adopters to form the bandwagon pressure.

In Eqs. (3), the total number of individuals that have direct relationships ("relative ties") with the *i*-th individual can be written as $n_{1,i}+n_{2,i}$. "$\delta_{i,j}=1$" means the individuals *i*-th and *j*-th have a connection, while "$\delta_{i,j}=0$" is on the contrary. The adopters among them will form local network externalities to increase the utility function for the *i*-th individual. The global network externalities for the *i*-th individual are based on the number of adopters of the whole society. The weight of local externalities and global externalities can be written as c and $(1-c)$, respectively.

4. RESULTS AND DISCUSSION

Within the threshold model mentioned above, we perform our simulation on a society with 2000 members where each member has 26 social relationships with others on average. Below are some results and corresponding discussion.

4.1 The weight of bandwagon effects and network effects in the innovation diffusion

Firstly, we perform the simulation in a small-world network with a rewiring probability $r = 0.06$ because most of the social networks are something like "small-world". In the case of $b = 0.8$ and $c = 0.2$, the diffusion rate p changes with the vary of parameter a, as shown in Figure 3.

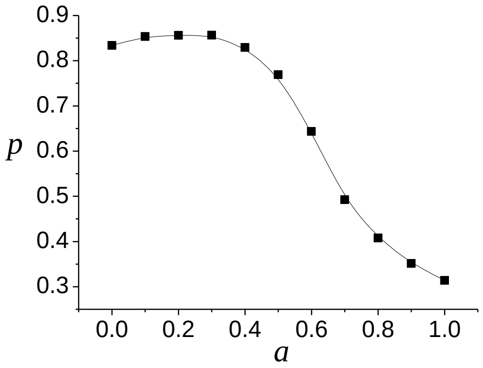


Figure 3. The diffusion rate (after 80 time steps) varying with the individuals' weight of preference between bandwagon effects and network effects

We can observe that the diffusion rate will firstly increase with the increase of a and then decrease until $a = 1$. Hence, there exists a peak on the curve so it is an optimal value of a for maximizing the diffusion rate. Or in other words, if we want to obtain the best diffusion rate, we should consider not only the network effects but also the bandwagon effects. The network effects and bandwagon effects influence the individual decision-adopting behavior from technical and psychological demand on the innovation. Therefore, a reasonable combination of these two kinds of effects is nontrivial for the optimization of innovation diffusion. We can also see that in two ultimate limits, i.e. $a = 0$ and $a = 1$, the diffusion rates are different. Obviously, $p(a = 0)$ is much greater than $p(a = 1)$. It means that the individuals' decision-making behaviors are mainly influenced by the technical demand that corresponds to the network effects.

The phenomena mentioned above are important to guide innovation in organizations. They should take two kinds of effects into account and find a rational weight between them. That is to say, if the innovating organization wants to perform a successful marketing effort they should firstly pay attention to the quality or technical compatibility of the products, meanwhile, they should also consider the exterior fad and style to meet the psychological demand of the customers.

4.2 The influence of neighbor relationships and remote relationships for bandwagon effects

The bandwagon effect is a kind of psychological phenomena. In the present study, we assume that (1) each individual utility can be transferred to others by social relationships and that (2) there are two kinds of relationships — "neighbor relationships" and "remote relationships", as shown in Eq. (2). The simulation is performed in the same network structure as mentioned in Section 4.1 and the coefficient $c = 0.8$. The diffusion rate varies with coefficient b is shown in Figure 4.

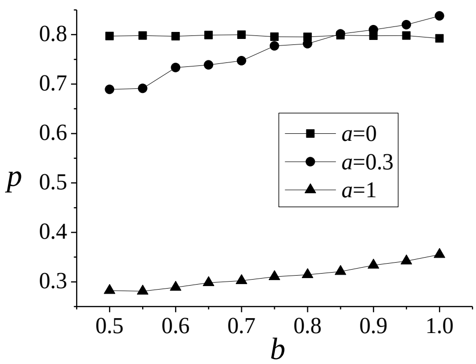


Figure 4. The diffusion rate (after 80 time steps) varying with the weight of "neighbor relationships" for some different values of *a*

It can be seen that the diffusion rates increase monotonically with the increase in coefficient b for different non-zero values of a. From Figure 4 one can see that for $a = 0.3$ the diffusion rates reach to high levels (all larger than 65%) for arbitrary b ranging from 0.5 to 1. In the cases of $a = 0$ and $a = 1$, the maximum diffusion rates are lower than that of $a = 0.3$ because only single influence from bandwagon effects or network effects can not optimize the diffusion, as claimed in Section 4.1. It is worth pointing out that for $a = 0$, which means that the diffusion rate is only affected by network effects, the diffusion rate does not vary with the increase in b because the bandwagon effects have been ignored in this case. From Section 4.1 we know that adding a little weight of bandwagon effects can improve the diffusion rate to some extent. Therefore, the diffusion rate is proportional to the bandwagon effects in certain conditions (e.g. $0<a \le 0.3$). We can see from Figure 4 that the bandwagon effects depend closely on the weight of "neighbor relationships". That is, the more consideration of neighbor relationships, the better of the bandwagon effects and thus the higher the diffusion rate. As we claimed above, the bandwagon effects reflect the group psychological phenomena. People's comments on the innovation product can radiate to his/her neighbors directly as a utility value like the description in Eq. (2). This result shows that the forming of bandwagon effects looks more likely in local areas. In our real society, the utility of neighborhood radiation is always stronger and faster than that of distant relationships. It can be used to understand the people's group behavior during the bandwagon pageant.

4.3 The influence of local externalities and global externalities for network effects

The influence of local externalities and global externalities can be expressed by the coefficient c as shown in Eq. (3). The simulation is performed in the same small-world network structure as before, i.e. $r = 0.06$. The coefficient $b = 0.8$. The simulation results are shown in Figure 5.

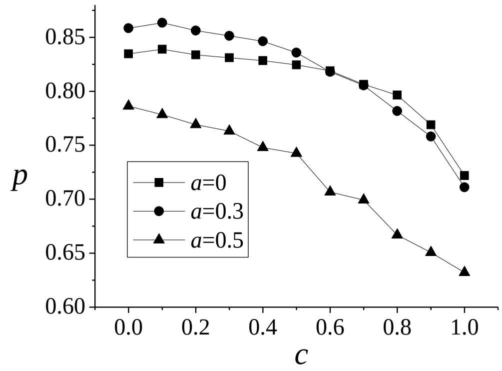


Figure 5. The diffusion rate (after 80 time steps) varying with respect of coefficient *c* for different values of *a*

For $a = 0$ and $a = 0.3$, we can see that the diffusion rates increase firstly and then decrease with the increase in c, so there exist maximal diffusion rates and the corresponding optimal values of c. However, this trend changes for $a = 0.5$. In this case, the diffusion rate decreases monotonically with the increase in c. Furthermore, the diffusion rate for $a = 0.5$ can not reach to higher percentages (larger than that of $a = 0$ and $a = 0.3$) for arbitrary c. This result is in accordance with that shown in Section 4.1. Hence, we only discuss the cases of $a = 0$ and $a = 0.3$ below.

Substituting $c = 1$ into Eq. (3) we can see that the second item of the right-hand side disappears. It means that the individuals only consider the network externalities by looking at the adopting-behavior of the other individuals who have direct social relationships with him. This can be considered as an instance of local externalities. In the case of $c = 0$, the individual considers the behavior of all N individuals among the society. This is an instance of global network externalities. From Figure 5, we found that the diffusion rates for $c = 0$ are always much larger than that for $c = 1$. It means that the global externalities are the main forces pushing the innovation diffusion. The simulation results also show clearly that neither $c = 0$ nor $c = 1$ can optimize the diffusion rate. The maximal values of diffusion rate exist in the area close to $c = 0.1$. Therefore, a little weight of local externalities can optimize the network effects and then the diffusion rates are improved. In our real world, it is reasonable that a person should look at both his neighbors and the whole society before he makes a decision to adopt the innovation or not.

From Figure 5, we also find an intersection close to $c = 0.6$. In the case of $c < 0.6$, the diffusion rates of $a = 0.3$ are larger than those of $a = 0$. Whereas, the situations are on the contrary for $c > 0.6$. As we mentioned above, a little weight of local externalities and bandwagon effects can improve the diffusion rate. However, too much weight of local externalities reduces the innovation diffusion rate and the bandwagon effects will make the situation worse. We should pay attention to this kind of negative feedback.

5. CONCLUDING REMARKS

In this paper, we considered innovation diffusion with network effects and bandwagon effects. Both of these effects increase the utility function as the number of adopters increases. However, the mechanisms between network effects and bandwagon effects are different from each other. However, their underlying mechanisms are what distinguish the two effects. Firstly, the network effects are caused by the technical compatibility of the innovation, while the bandwagon effects are purely psychological behavior. Secondly, the network effects increase not only the potential adopters' utilities, but also the utilities of the adopters. In comparison, the bandwagon effects only increase the potential adopters' utilities and will stop influencing the individual utility function as soon as he adopts the innovation.

Based on the "small-world" network structure, a threshold model of utility function including the network effects and bandwagon effects is proposed to simulate the innovation diffusion. The results show that in order to obtain the optimal innovation diffusion the following factors should be taken into account.

(1) The network effects are important for innovation adoption. However, we can not ignore the influence of bandwagon effects. Except for the technological quality and compatibility of innovation product, the consumers' psychological demand of fad and fashion from the product is also important to promote the innovation diffusion.

(2) If we consider the influence of bandwagon effects, direct social relationships can be separated into "neighbor relationships" and "remote relationships" according to the distance between two nodes in the network. The simulation results show that the bandwagon effects depend closely on the weight of "neighbor relationships". This conclusion coincides with the psychological origin of bandwagon effects [43].

(3) The network externalities can be distinguished by local externalities and global externalities. Both of them are important to the network effects. In our model, they are estimated by calculating the number of adopters among the personal network and the total network, respectively. It is shown that an individual decision-making behavior is affected not only by the number of adopters having direct social relationships with him but also by the number of adopters in the whole society. A reasonable weight between local and global network externalities is crucial for innovation diffusion.

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