CSCanada
Canadian Social Science
Vol. 9, No. 3, 2013, pp. 24-29
DOI:10.3968/j.css.1923669720130903.4283

ISSN 1712-8056[Print]
ISSN 1923-6697[Online]
www.cscanada.net
www.cscanada.org

A Simulation Model of New Product Diffusion Based on Small World Network

WU Chunxu[a],*; ZHANG Yuying[b]

[a]School of Management, University of Science and Technology of China, Hefei, China.
[b]School of Management, University of Science and Technology of China, Hefei, China.
*Corresponding author.

Supported by General Program of National Natural Science Foundation of China (71171182).

Received 8 March 2013; accepted 5 May 2013

Abstract

This paper studies the impact of consumer network structure on the diffusion of new products. Taking a communication product for example, we study its diffusion through simulation based on small world network. We find that the greater the proportion of initial adopters is, the faster the new products diffuses, and it's marginal benefit is decreasing. The social network's connection can be divided into weak links and strong links with different functions. The more the weak links are, the faster the new products diffuse. For the rise in marketing costs, enterprises need to improve the possibility of the success of new product diffusion with comprehensive consideration.

Key words: New product diffusion; Small world network; Consumer network

WU Chunxu, ZHANGYuying (2013). A Simulation Model of New Product Diffusion Based on Small World Network. *Canadian Social Science*, *9*(3), 24-29. Available from: http://www.cscanada.net/index.php/css/article/view/j.css.1923669720130903.4283 DOI: http://dx.doi.org/10.3968/j.css.1923669720130903.4283.

INTRODUCTION

The process of new products diffusion is the adoption by consumers, which is affected by the consumer network structure. Consumer's decision is affected by various factors, not only by the impact of individuals but also by the impact of social relations. With the rapid development of communication technology and Internet, the communication between the consumers is more convenient and frequent, increasing the effect of social relationships in consumer decision-making. Therefore, the study of impact of the social network structure in new products diffusion is important.

In practice, some companies come to realize the impact of social network structure in new products diffusion; they start to take some strategies to speed up the effective diffusion of new products. The launch of "family planning" in mobile communications industry utilizes the effect of social network, aiming at accelerating the diffusion process and enhancing customer locked. "Family planning" business requires a main card customer can set 1-4 family numbers, main and auxiliary card customers enjoy call concessions among home network together. But The business requires that the sub-card customer must be a local mobile phone number, The main card customer must commit to stay in the mobile network within one year and so on. "Family planning" to attract family members and acquaintances to join the same network by call concessions, but for the customer without the family network means that the call cost increases relativly. Its essence is to influence the diffusion process by distinguishing the type of relationship. However, there is no clear answer that how social relationships affect diffusion and how privilege is adjusted as the network structure. What other network characteristics will affect the diffusion of new products is still to be studied.

Recently, some scholars study the diffusion of early diffusion model, the effect of social relationships and other factors on the diffusion of new products from the perspective of organization and management. Duan Wenqi et al. (2007) studied the influence of proportion of the initial adoption and network structure with complex network method; they analyzed the influence of network structure from the number distribution of consumers' neighbors. Zsolt Katona et al. (2011) studied the influence of consumer neighbor's network structure on the diffusion of new products, they thought that the possibility of new products to be adopted is proportional to the number of adopters among consumer's neighbors, and the connection density of adopters groups had a positive effect on the decision-making of their neighbors. Choi and Lee (2010) studied the influence of structure of rule network, small network and random network on new products diffusion with small world method; they thought the diffusion of new products in small-world networks was the fastest with the biggest market penetration.

In June 1998, the professor Watts and Strogatz raised the model of small world network (1998), they indicated that the network which had a shorter average path length and higher clustering coefficient belonged to the small-world network. Some scholars have found that many networks in reality, such as movie actor collaboration network, scientific collaboration network, cellular network, phone call network, and social network are small-world networks (Li, 2005),which means the beginning of research in network structure's influence on new products diffusion with small-world network method (Choi, Kim & Lee 2010; Aral, 2011). In 1973 American sociologist Mark Granovetter raised the weak links theory which divided the social relationships into strong links and weak links (Granovetter, 1973).It enabled the further study of the social network structure's influence on new products diffusion.

This paper study the influence of the proportion of initial adopters and social network structure on new products diffusion with the simulation method of small world network, considering a communications company's "family planning" products.The paper's innovation is the research of social network structure's influence on new products diffusion from different types of relationship. The following results can be used for enterprise management: The increasing of the number of initial adopters can accelerate the diffusion but has a diminishing marginal, companies need to trade-off between the benefits and costs by expanding the scale of the initial adopters; Different type of relationship between the consumers has different effects on diffusion, enterprise needs to consider comprehensively to improve the possibility of success diffusion.

1. NEW PRODUCTS DIFFUSION MODEL

Each node in the network represents a consumer, connected nodes are called neighbor. Whether the consumer adopt the new products is influenced by consumers neighbors adoption.The more adopters among neighbors, the greater the impact on consumers' decision-making and the easier for consumers to adopt new products.

1.1 Adoption Network

A new product's adoption network is constituted through the dissemination of information, the exchange of evaluation of the product, using new product to conduct business and so on by consumers (Bass, 1969). The adoption network is the consumer's social network essentially.

Take a customers network of communication company for example, Social network structure can be described as:Social network is composed of families, each family has m Members and each members maintain close contact;Each customer may recognize people out of the home because of work, career or Internet chat room,such relationship exists between the various families, which was created in random.According to Watts and Strogatz's small world network model (Watts, & Strogatz, 1998), the article establishes such a network: Each node in network is on behalf of a customer, the connection between nodes means the customer knows each other. First, we establish n families (Xian, Mei, 2009), each family has m members, the node in family connects with each other.Second,we judge the possibility of each edge to be connected between families,The edges judgment on all nodes that may arise between families.Set the probability of random connection as p (Choi, Kim, & Lee 2010; Li, Zhai, & Zuo, 2008), when judge the connection of each edge,we generate a random number r between (0,1).if $r \le p$,we establish this edge, or do not.

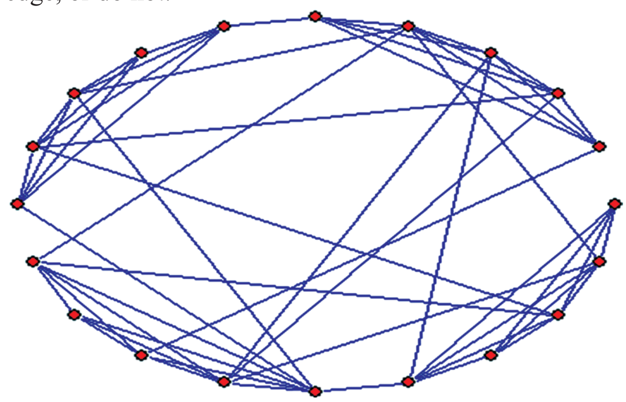

Figure 1
A Social Network

Figure 1 is a social network with $n = 4$, $m = 5$, $p = 0.1$ generates by Pajek.We calculat the average path length of the network is 1.9263, the clustering coefficient is 0.5726 by Pajek.According to the small-world network model raised by Watts and Strogatz (1998),the network established in this paper has the shorter average path length and the higher clustering coefficient,which is a kind of small world (Strogatz, 2001).

1.2 Utility Function

Consumer's behavior of adoption is mainly determined by the expected utility they received from adopting product. In this paper, we mainly consider the influence of adjacent node which called neighbors on consumer's utility. Assuming that there are only two possible states "0" and "1" for consumers in network,"0" indicates that consumer donot adopt the product, knowing as potential adopters; "1" indicates that consumer adopt the product, knowing as adopters.All potential adopters make decisions at the same time at time t, decision-making is no longer changed after consumer adopt the new product.

Choi and Lee (2010) studied the new product diffusion model under different network structure, and they created a utility function as criterion of whether the consumer adopt new product. Consumer *i*'s willingness to adopt the product at time *t* is:

$$U_{it} = Q_i + aN_{i(t\text{-}1)}\text{-}R_i \quad (1)$$

Choi and Lee believe that the potential adopters' decision-making are affected by product's intrinsic value, network effect and personal preference. Q_i represents the product's intrinsic value, R_i represents personal preference about adopting the product,both of them are assumed to follow a normal distribution, *a* represents the strength of the network effect, $N_{i(t\text{-}1)}$ represents the proportion of adopters among consumer i's neighbors, $aN_{i(t-1)}$ represents network effects generated by consumer's adoption of new product. Only if U_{it}> 0 consumer i adopt the product.

The paper assumes the total number of consumers is *N*, $i \in N\left(i = 1, 2, \cdots, N\right)$ represents consumer *i*.By adopting the new product,consumer can obtain the product's intrinsic value Q_i (represented by its quality or technical performance),and produce the adoption costs C_i(such as learning costs), Q_i and C_i are assumed to follow a normal distribution(Choi, Kim & Lee, 2010). In addition to product's intrinsic value Q_i and adoption costs C_i, the decision-making is also affected by neighbors'decision-making.The consumer's neighbors can be divided into neighbors in family and neighbors out of family, they alao can be called strong links and weak links correspondingly according to Granovetter's weak link theory (1973). U_{it}created in this paper is:

$$U_{\text{it}} = Q_i + a\left(\omega_1 \times \frac{n_{1i(t-1)}}{N_{1i(t-1)}} + \omega_2 \times \frac{n_{2i(t-1)}}{1+\left(N_{2i(t-1)}\right)^{\delta}}\right)\text{-}C_i \quad (2)$$

$n_{1i(t\text{-}1)}$ and $n_{2i(t\text{-}1)}$ represent the adopters' number of consumer *i*'s neighbors belong to strong links and neighbors belong to weak links respectively at time *t*-1. $N_{1i(t\text{-}1)}$and $N_{2i(t\text{-}1)}$ represent the total number of consumer *i*'s neighbors belong to strong links and neighbors belong to weak links. *a* represents the strength of the network effect. δ is scale factor which is intended to ensure the increasing of network effect generated by adopters decision-making.

This paper's innovation is to further expand the model of Choi and Lee, divide the network effect generated by adopters into network effect generated by strong links $a\times n_{1i(t\text{-}1)}/N_{1i(t\text{-}1)}$ and network effect generated by weak links $a\times n_{2i(t\text{-}1)}/N_{2i(t\text{-}1)}$, and give weights ω_1,$\omega_2$to them, especially $\omega_{1+}\omega_{2=1}$.By distinguishing the type of neighbors' relationships, we can study that how marketing strategy of family planning affect product diffusion.

After new products to be launched into market, enterprises obtain a certain number of initial adopters through advertising, free using or other means (Huang, Zhuang, & Yao, 200).Over time, the initial adopters decision-making begin to affect the decisions of adoption of potential adopters among their neighbors, Until all consumers have adopted the new product or there is no new consumer to adopt new products, the product diffusion is end.

2. MODEL SIMULATION

Let nodes whose Q_i>$C_i$to be initial adopters at time *t* = 0, recording these nodes' state to be 1, others' state to be 0. Calculating the values of U_{it} when consumer *i*'s state = 0 and it connects to one node with state = 1 at the same time at *t*=1,if U_{it}> 0, we change *i*'s state to be 1, or do not. When t ≥ 2 we do the same until the node with state = 1 is not increase, which means there is no new potential adopters to adopt new product, the diffusion is end. All potential adopters' decision-making determine the new products diffusion model.

Network size *N* refers to the total number of consumers, it affects the simulation results. If *N* is too small, the simulation results are not general; By the increasing of *N*, the simulation results are more and more close to the real situation; But if *N* is bigger enough, the increasing of *N* can only produce small change with emulator burdensome greatly increased and the longer run time. Therefore, in order to ensure the generalization of simulation results and take the speed of the computer into account, the network size selected in this paper is1000,and $n = 200$, $m = 5$. The simulation is implemented by mat lab; each process of simulation can be divided into 3 parts:

(1) Make $t := 0$, set the initial adopters, record nodes with Q_i> C_i as initial adopters, and record these nodes' state to be 1, the others to be 0.

(2) Make *t*:=*t*+1, caculate the values of U_{it} for all nodes with state = 0.Only if U_{it}>0 we change these nodes'state to be 1.

(3) Repeat step (2), until the number of nodes with state = 1 is not increasing at one time, the diffusion is end.

Each simulation process we use a two-dimensional array *state*[*i*][*t*] to record the change of the number of nodes with *state*=1 with the change of *t*, which means *State[i][t]=state[i][t-1]+the number of new nodes with state=1at* timet.We simulate 100 times and use the mean to make graphical analysis.

3. RESULTS AND ANALYSIS

The diffusion model refers to the locus of accumulated adopters over time, we can use the number of initial adopters, the rate of diffusion and diffusion depth to describe the diffusion model. The rate of diffusion can be described by the total time to be used, the longer the time it costs to diffusion, the slower the rate of diffusion; The diffusion depth can be described by the market share the product occupies when diffusion is reached a steady state. The paper study mainly the effect of the number of initial adopters, the numbers of weak links and the weights of weak links on the new product diffusion model.

3.1 Effect of the Number of Initial Adopters on Diffusion

Set consumers' total number to be 1000 and *n*=200, *m*=5, *p*=0.1, *a*=200 (Choi, Kim & Lee, 2010),$\omega_1=\omega_2=0.5$.

Table 1
Effect of the Number of Initial Adopters on Diffusion

Number of initial adopters	Rate of diffusion	Diffusion depth
5	17	40%
7	15	80%
9	12	95%
11	10	97%
13	8	100%
…	…	…
27	5	100%
29	4	100%
31	4	100%

Select five cases from Table 1 to make new product diffusion curves, as shown in Figure 2.

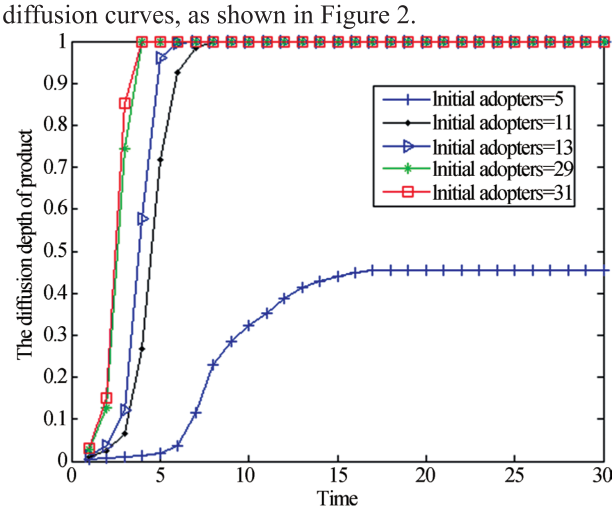

Figure 2
Effect of the Number of Initial Adopters on Diffusion

By adjusting the mean and variance of Q_i and C_i to change the number of initial adopters in order to study the effect of number of initial adopters to new product diffusion model. The results show that the more the initial adopters, the faster the rate of diffusion, the bigger the market share new product occupies. When the proportion of Initial adopters is smaller than 9‰, the rate of diffusion is slow and the diffusion depth is very low; When the proportion of Initial adopters is bigger than 9‰, the diffusion depth is higher than 95%. With the increase of the proportion of Initial adopters, the rate of diffusion is faster and faster. But when the proportion of Initial adopters continues to increase, the enhancement of the rate of diffusion has been slowing which means a diminishing marginal. This implies that enterprises can get the initial adopters as much as possible by the way of gifts, free using and so on, but these promotional measures can also produce certain costs, so policymakers need to determine the optimal size of the initial adopters, combining with the size of the market, the costs of product's promotion, profits and other factors to promote new products quickly and effectively to dominate the market.

3.2 Effect of Weight of Weak Links and Strong Links

We assume ω_2/ω_1 represents privilege of call among family members compared with call outside the family in family-planning business.As shown in Figure 3, when $\omega_1=0.6,\omega_2/\omega_1=0.8$which means the privilege is 83%, the family-planning business diffuses rapidly and occupies the whole market; when $\omega_1=0.7,\omega_2/\omega_1=0.43$which means the privilege is 43%, the rate of diffusion is lower than former; when $\omega_1=0.9,\omega_2/\omega_1=0.1$which means the privilege is 11%, the family-planning business diffuses slowly and the diffusion depth is very low.

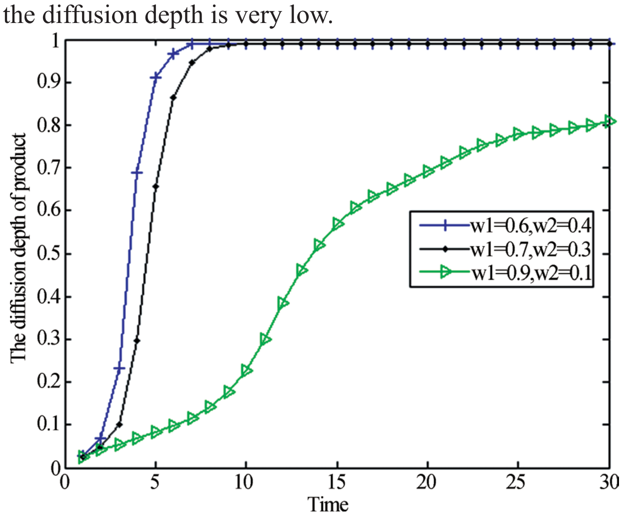

Figure 3
Effect of Weight of Weak Links and Strong Links

We observe the effect of the change of privilege on family-planning's diffusion by changing the weight of weak links and strong links in order to study the function of weak links in product diffusion. The bigger the privilege of call among family members, the more the customer to handle the business, the faster the family-planning diffused. When the privilege is too big, the call costs outside the family seem to be high relatively. For consumers who have more communication outside the family, it will produce more cost by adopting family-planning business,so they won't adpot it, the final resulting is the loss of customers, the family-planning business fail to diffuse. Therefore, to develop a reasonable privilege of family call is particularly important to the success of family-planning diffusion. According to Granovetter's weak links theory (Granovetter, 1973),the links outside family are weak links. The results show that the weak links have an essential role in the process of new product diffusion.

3.3 Effect of the Number of Weak Links

We change the number of weak links through adjusting the size of *p*, in order to study the effect of the change of weak links' number on new products diffusion. As shown in Figure 4.When *p*=0.01,the number of weak links in social network is the least, the rate of diffusion is slow and diffusion depth is very low; With the increasing of *p*,the number of weak links is increased which fastens the rate of diffusion and improves the diffusion depth.

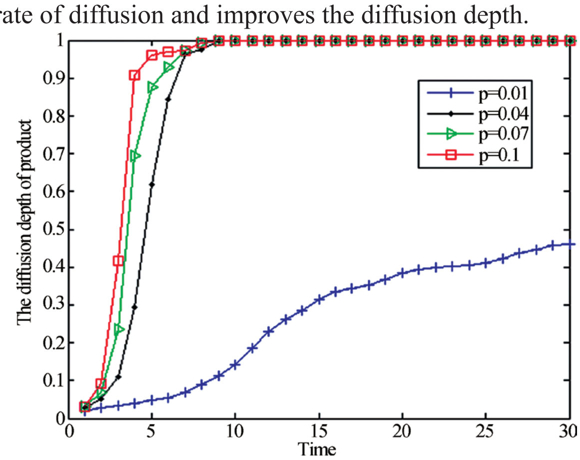

Figure 4
Effect of the Number of Weak Links

New communication products tend to use more complex technologies,they need some special "experts" such as technology enthusiasts to experience and operate. However, these experts are often derived from neighbors belong to weak links. This phenomenon determines that weak links have a stronger influence in the diffusion of communications products.

As shown in Figure 5, when privilege of family call remain constant, the increasing of the number of weak links can fasten the rate of diffusion; when privilege of family call is smaller, the increasing of the number of weak links can fasten the rate of diffusion and improve the diffusion depth greatly, the number of weak links plays a decisive role.

Harvard University graduate student Mark Granovetter made inquiries about the residents of the town of Newton, Massachusetts, how to find a job to explore the social network in 1960. He was surprised to find that those closely friends didn't play a better role than those weak links. Although weak links are not as strong as strong links,they has a lower cost and higher efficiency of transmission.Therefore,with the increasing of *p*,the weak links are more and more, the rate of diffusion is faster, the diffusion is easier to be success.

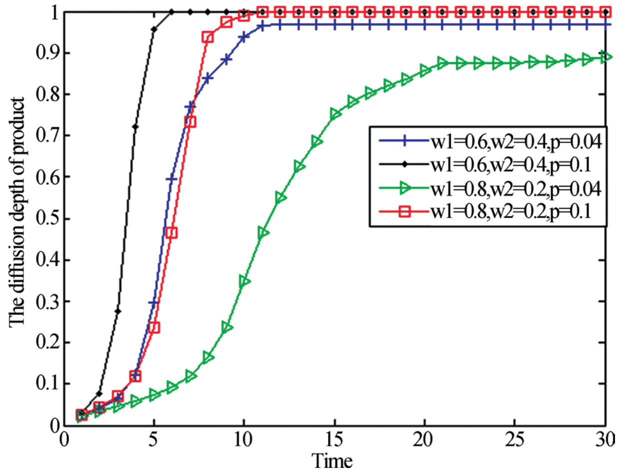

Figure 5
The Function of Weak Links Under Different Privilege

CONCLUSION

The paper studies the influence of social network structure on new products diffusion, taking a communication product that is "family-planning" for example.The paper build a small world network model to study how the number of initial adopters, the number of weak links and the change of weights of weak links and strong links affect the new products diffusion.We find that the increasing of initial adoption's scale which has a law of diminishing marginal effect can fasten the rate of diffusion and lead to more marketing costs. Companies need to make a trade-off between costs and benefits. Appropriate communication privilege existed among family members can prompt potential customers to adopt "family-planning" business, to the contrary, excessive communication privilege not only increases the company's costs,but also leads to the loss of consumers with various communication outside family.The weak links have a negligible importance in the social network. The results imply that enterprises can accelerate the rate of diffusion by establishing weak links. The results provide a reference for enterprises to develop new products' promotion strategy.

The limitations of the paper are that it only allows one new product to exist simultaneous, and assumes that the decision-making is no longer change after consumers adopt the new product. The further study can be the competition diffusion model among various products, how to determine a reasonable size of initial adopters or considering the repeat purchase behavior of consumers.

REFERENCES

Aral, S. (2011). Commentary-identifying social influence: A comment on opinion leadership and social contagion in new product diffusion. *Marketing Science*, *30*(2), 217-223.

Bass, F. M. (1969). A new product growth model for consumer durables. *Management Science*, *15*(5), 215 -227.

Choi, H., Kim, S. H., Lee, J. (2010). Role of network structure and network effects in diffusion of innovations. *Industrial Marketing Management*, *39,* 170-177.

Duan Wenqi, Chen Zhong, Hui Shumin (2007). Diffusion of new products in network markets based on complex networks: The role of adoption network and initial conditions. *Systems Engineering*, *25*(5), 15-19.

Granovetter, M. S. (1973). The strengths of weak ties. *American Journal of Sociology*, *78*(6), 1360-1380.

Huang Weiqiang, Zhuang Xintian, Yao Shuang (2009). Sampling strategies for diffusion of new products with network externality. *Journal of Management Sciences in China*, (4), 51-63.

Katona, Z., Zubcsek, P. P., Sarvary, M. (2011). Network effects and personal influences: The diffusion of an online social network. *Journal of Marketing Research*, *48*(3), 425-443.

Li Guangzheng, Zhai Longyu, Zuo Chuangui (2008). The simulation of the small-world networks based on matlab. *Science and Technology Information*, (17), 17-18.

Li Yong (2005). *Researches on the theory and application of complex network*, (Unpublished doctoral dissertation). South China University of Technology, China.

Strogatz, S. (2001). Exploring complex networks. *Nature*, 410, 268-276.

Watts, D., Strogatz, S. (1998). Collective dynamics of "small-world" networks. *Nature*, *393*(4), 440-442.

Xian Yubo, Mei Lin (2009). Diffusion of network product with indirect network efect —Research based upon complex network and computational economics. *Journal of Management Sciences in China*, (1), 70-81.