Research on Consumer Purchase Behavior Diffusion across Market Using Cellular Automata

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Abstract

The goal of this article is to offer new theoretical propositions to advance consumer behavior diffusion research and to provide a cellular automata method for diffusion modeling. We construct a cellular automata model (CAD) that captures the consumer learning mechanism in the purchase behavior diffusion which result in the new product diffusion. The results show that the cellular automata model successfully examined the purchase behavior diffusion on different products both in China and America to compare consumer behavior in different segmentation market for implication on new product marketing.

Keywords: purchase behavior, diffusion, cellular automata

1. Introduction

Diffusion traditionally has been defined as "the process by which an innovation is communicated through certain channels over time among the member of a social system" (Rogers, 1995). As a communication theory, diffusion theory is frequently looked to for guidance on the dissemination of new technologies, new products, new services, and new regulatory initiatives (Gatignon & Robertson, 1985). The diffusion literatures on the modeling of the new product or innovation diffusion offered a lot of frameworks for the study of communications of information, ideas, and products. The details of those diffusion models in this area are available in some reviews (e.g. Mahajan et al., 1990; Sultan et al., 1990; Hauser et al., 2006). However, consumer learning mechanism was more hidden in the modeling of diffusion.

In general, Consumer behavior researchers have concerned to the applicability of hypotheses developed in the general diffusion area to consumer research (Gatignon & Robertson, 1985). Marketing science researchers have contributed to suggest models to describe and forecast the innovation diffusion (Mahajan et al., 1990). An integration of the behavioral and modeling literatures on diffusion could be beneficial to both constituencies (Gatignon & Robertson, 1985).

The goal of this article is to offer new theoretical propositions to advance consumer behavior diffusion research using cellular automata method for diffusion modeling. We demonstrate our points in two ways. Firstly, we construct a cellular automata (CA) model that captures the complex behavior diffusion dynamics and enables an in-depth analysis of the growth. This model shows the learning mechanism in the behavior diffusion which result in the new product diffusion process. Secondly, we use the CA model to simulate the diffusion of cell phone, landline and internet both in America and China to compare different consumer behavior in different segmentation market.

The rest of this article continues as follows: Firstly, we briefly review the relevant researches regarding new product diffusion using cellular automata. Secondly, we present our model based on cellular automata and the flowchart of the cellular automata model for diffusion. Thirdly, we simulate the diffusion of cell phone, landline

and internet in different market to explore consumer behavior in different segmentation. Finally, we conclude by discussing the theoretical and practical implications.

2. New Product Market Diffusion and Cellular Automata

Owing to the complexity of consumer behavior, new product diffusion based on purchase decision through social interactions among consumers can be considered a complex system problem. One of appropriate and convenient technique to model such complex systems is cellular automata. The marketing sciences have recently exhibited an increasing interest in diffusion research using cellular automata method. Rouhaud analyzed how to use cellular automata to modeling interactions between complex consumer behaviors (Rouhaud, 2000). Goldenberg, Libai and Muller (2001a) studied heterogeneity effects on new product growth and they tried to establish the relation of macro effect and micro effect through cellular automata. They also used network theory and cellular automata to study the underlying process of Word-of-Mouth (2001b). They found the occurrence of saddles in the cross-market communications which can create a major slump in sales (2002). Cellular automata method was also used on modeling of the emergence of innovations (Goldenberg & Efroni, 2001c), resistance to innovations using multi-rule (Moldovan & Goldenberg, 2004), small world network complex systems using spatial divergence approach to predict the early success of new product (Garber et al., 2004), simulation of market diffusion of new product (Ma et al., 2008) and simulation of new service product diffusion (Ma et al., 2009).
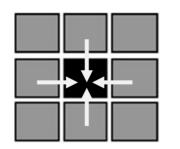
Therefore, cellular automata have been used to advance diffusion theory and model development as a sparking and prominent method (Goldenberg, 2001a).
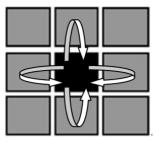
3. The Cellular Automata Model

Cellular automata evolve in discrete time steps, the state of a random center cell being affected by its neighbor states on the previous time step, namely the state of cell at time (t+1) decided by its neighbor cell at time t, and according to a definite set of local evolution rules (transfer rules). Usually, the typical neighbor squares are von Neumann and Moore neighbor (Chopard & Droz, 1998). Moore neighbor is the basic in this paper. In the cellular automata evolution, the state of the center cell (the black cell in Figure 1) updated according to a local evolution rule that depends on the state of the neighbors (the shaded cells in Figure 1).

Figure 1. One of the typical neighbor squares: Moore

The different evolution mechanisms of product and behavior diffusion were shown by the Figure 2. Product diffusion was based on the dissemination of information and behavior diffusion was based on the learning of behavior. For example, in the product diffusion mechanism, innovators (the shaded cells in Figure 2) are the information senders to an early adopter (the black cell in Figure 2). However, in the behavior diffusion mechanism, an early adopter (the black cell in Figure 2) is learning from innovators (the shaded cells in Figure 2). They may have verbal communication or only non-verbal watching.

(a) Product diffusion   (b) behavior diffusion

Figure 2. Illustration on evolution of product and behavior diffusion

We consider a cellular automata model on behavior diffusion in which the cell space is the system of behavior diffusion and can be assumed as grid system. Each consumer or potential consumer is a cell in the cell space which is two dimensions.

The purchase states denote by C. There are two states which are adopter: $C = 1$, representing the potential consumer who has purchased the new product and his state is stable during the whole evolution which means consumer can always be an adopter after purchase; non-adopter: $C = 0$, representing the potential consumer who has not purchased the new product.

Our cellular automata evolution rules R:

$$P(t+1) = p + (q/m)N(t) \tag{1}$$

where p is the purchase probability as a result of learning from the external environment and the value of p represent the influence power of external environment, q is purchase probability as a result of learning from other consumer and the value of q represent the influence power of internal environment, and P is the purchase probability as a result of external and internal learning. $N(t)$ is the cumulative number of previous buyers at time t. A random number P_0 is drawn in the range [0, 1]. If $P(t+1) > P_0$, and the state of the cell is $C = 0$ at t, then the probability of $C = 1$ at $(t+1)$ is $P(t+1)$ which result in the consumer moves from potential customer to purchaser (receiving the value of 0 to 1). Otherwise, the consumer remains a potential customer.

We run a stochastic process using this general cellular automata model. Each individual adoption probability is given by evolution rule at each cellular automata evolution step (CAES).

4. Simulation and Analysis on Purchase Behavior Diffusion

The purpose of this study is to illustrate purchase behavior diffusion which results in product growth across market using cellular automata. The case in this study came from China and America. The main reason for focusing on the case is considering the geographical effect on diffusion patterns in the competition market. We defined those products, with characters of durables and services, as mix services, including cell phones and landline telephones. We also defined those products with more characters of services as pure services such as internet and online banking. Therefore, we use the case of cell phone, landline phone and internet in China and cell phone and online banking in America to compare purchase behavior diffusion of mix services and services in different market.

4.1 Method

We begin our analysis by calculating evolution rules of purchase behavior diffusion in China. We use the ordinary least squares (OLS) procedure and nonlinear regression method to estimate the diffusion parameters of cell phone, landline and internet in China through the MAPLE software. The diffusion parameters of cell phone and online banking in America were from the report written by Libai et al. (2009). Goldenberg, Libai and Muller (2001a) examined values of p and q which are consistent with the already well known values of communication effects in the diffusion process using their cellular automata model whose rule is different with our CAD. The data of cell phone and landline in China comes from the statistics of Ministry of Information Industry of the People's Republic of China and the data of internet comes from the internet information center. Although Libai et al. (2009) proposed a service growth model with customer attrition, we still use Bass model (1969) as our basic model for estimation of parameter in this paper. The reason is Bass model has been used over forty years so that the model stability and applicability will be better. The basic model is:

$$S(T) = pm + (q - p)\, Y(T-1) - \frac{q}{m}[Y(T-1)]^2 \qquad (2)$$

where $S(T)$ is sales at T, and $Y(T-1)$ is cumulative sales through period $(T-1)$. The Eq.(2) can be transferred as follow:

$$S(T+1) = pm + (q - p)\, Y(T) - \frac{q}{m}[Y(T)]^2 \qquad (3)$$

The equation of $Y(T)$ is

$$Y(T) = m(1 - \exp(-t(p+q)))/(1 + q/p \exp(-t(p+q))) \qquad (4)$$

Then, the evolution rule is

$$
\begin{aligned}
P(T+1) &= p + (q/m)Y(T) \\
&= p + (q/m)m(1 - \exp(-t(p+q)))/(1 + q/p \exp(-t(p+q))) \\
&= p + q(1 - \exp(-t(p+q)))/(1 + q/p \exp(-t(p+q)))
\end{aligned} \qquad (5)
$$

The simulation will be implemented by software MATLAB and the curve will be drawn by software ORIGIN. The cell space is 100*100=10000.

4.2 Results

The results of estimating the parameters on cell phone are
$$p = 0.01066328872, q = 0.1682248740, m = 253328.0246$$

The results of estimating the parameters on landline are
$$p = 3.420058073, q = -2.039427576, m = 25941.99874$$

The results of estimating the parameters on internet are
$$p = 0.000519773676, q = 0.1672739465, m = 253461.7026$$

So, the rule 1 for cell phone is

$$
\begin{aligned}
P_C(T+1) &= p + q(1 - \exp(-t(p+q)))/(1 + q/p \exp(-t(p+q))) \\
&= 0.01066 + 0.16822(1 - \exp(-t(0.01066 + 0.16822)))/(1 + 0.16822/0.01066 \exp(-t(0.01066 + 0.16822)))
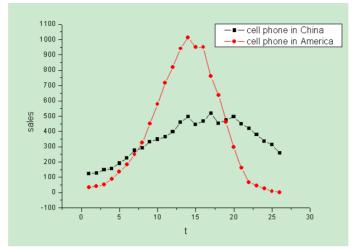\end{aligned}
$$
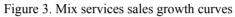
The rule 2 for landline is

$$
\begin{aligned}
P_L(T+1) &= p + q(1 - \exp(-t(p+q)))/(1 + q/p \exp(-t(p+q))) \\
&= 3.42006 - 2.03942(1 - \exp(-t(3.42006 - 2.03942)))/(1 + (-2.03942)/3.42006 \exp(-t(3.42006 - 2.03942)))
\end{aligned}
$$

The rule 3 for internet is

$$
\begin{aligned}
P_I(T+1) &= p + q(1 - \exp(-t(p+q)))/(1 + q/p \exp(-t(p+q))) \\
&= 0.00052 + 0.16727(1 - \exp(-t(0.00052 + 0.16727)))/(1 + 0.16727/0.00052 \exp(-t(0.00052 + 0.16727)))
\end{aligned}
$$

The simulation figures are shown by Figure 3 to Figure 8.

Figure 3. Mix services sales growth curves
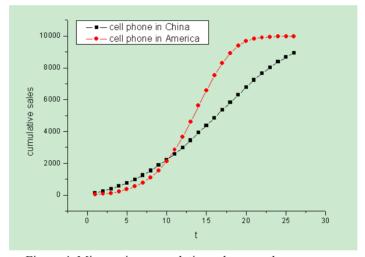

Figure 4. Mix services cumulative sales growth curves

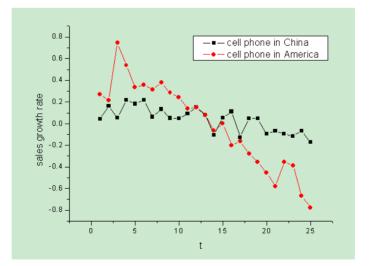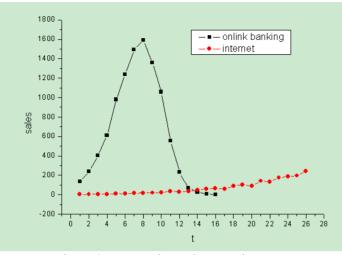

Figure 5. Mix services sales growth rate curves

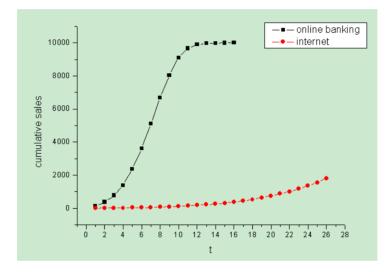Figure 6. Pure services sales growth curves

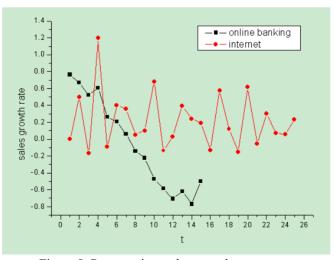Figure 7. Pure services cumulative sales growth curves

Figure 8. Pure services sales growth rate curves

Figure 3 shows the curve of cell phone sales in America is expected bell-shape curve. The curve of cell phone

sales in China always has the up and down tendency and did not show the whole bell-shape. According to Figure 4 and 5, the Sales growth rate of cell phone in America is sharp decline in despite of the cumulative sales curve is slowly grow. The Sales growth rate of cell phone in China is slowly decline in despite of the cumulative sales curve is sharp grow.

Figure 6 shows online banking sales in America is expected bell-shape curves. The curve of internet sales in China is almost a beeline with a little bit up tendency. According to Figure 7, the cumulative sales curve of online is smoothly rise and internet is very slowly rise. According to Figure 8,the Sales growth rate curve of internet is fluctuate around 0.2 growth rate line and online banking is sharp decline but rebound at step 14.
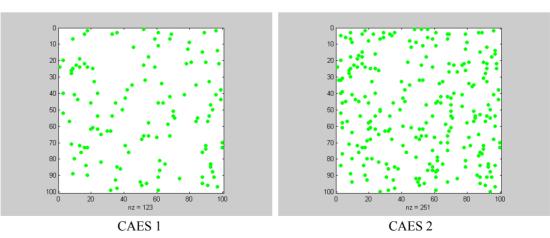
Comparing Figures 3 to 8, we find the geographical has distinct effect on market growth. The results indicate cell phone and online banking are mature markets in America more than in China. The fluctuate curve of cell phone in China might means the sales depend on the marketing strategy. But for internet in China, it is obvious that the curve of sales has no typical type which means internet may be a new and growing market.

Here, $P_{\text{internet}} < P_{\text{cell phones in America}} < P_{\text{cell phone in China}} < P_{\text{online banking}}$，$Q_{\text{internet}} < Q_{\text{cell phone in China}} < Q_{\text{cell phones in America}} < Q_{\text{online banking}}$.
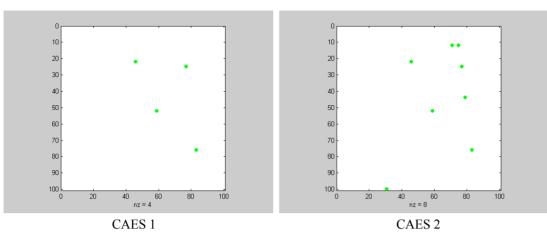
The values of p and q on internet are smallest and online banking are largest. We also found internet is only one which starts to takeoff now and online banking almost finished the product life circle evolution in our simulation. This may explain why the diffusion curve of internet has no shape and it is a new and growing market in China and online banking is close to a standard bell-shape and it is a very mature and will be saturation market. Compare the value of p and q, we found companies of cell phone may pay more attention on powerful marketing effort to enhance consumer learning from external environment so that the value of p in China is larger than the value in America. Unfortunately, it seems the power of consumer net work only work a little bit so that the value of q is so small, which means the contagion by consumer interpersonal diffusion is very weak. That might be a reason for the slowly decline sales growth rate of cell phone in China. Companies of cell phone in China might do more work on consumer interpersonal diffusion to enhance consumer learning from their social network which might result in a lot of imitation purchase behavior. Obviously, the effects of external and internal factors are very important reason for the new products shifting from developed area to developing area.
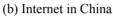
From figure 9, we can find if one cell appears in some area, then in the next cellular automata evolution step (CAES), some cells will be found around this cell. The results indicate the effect of diffusion distance on the convergence of consumer purchase behavior. About the effect of diffusion distance, let it goes to our next research.
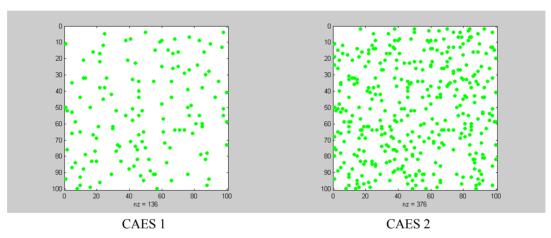
From figure 10, online banking arrives at saturation at CAES 16. Cell phone in America and China almost go to saturation at CAES 26. But internet is far away from saturation at CAES 26. The results show the market potential of four products. It seems there will be great opportunity in the internet market.
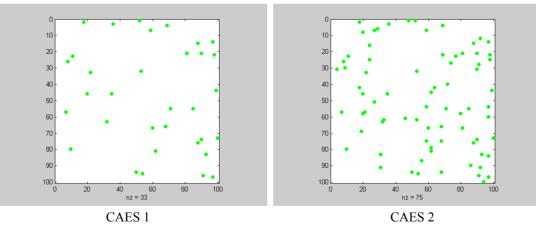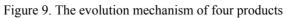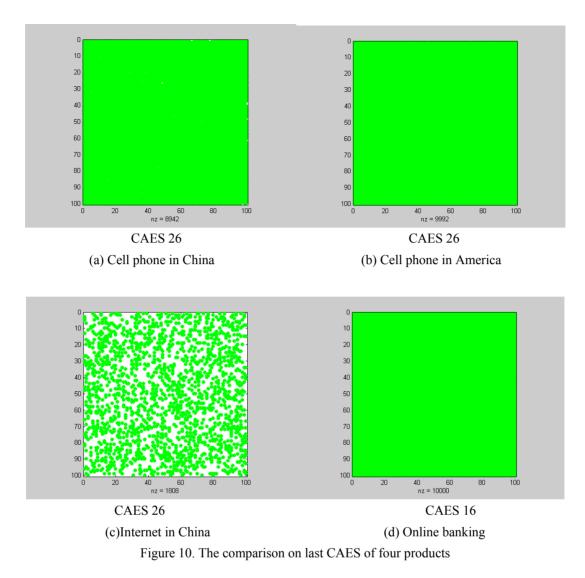

CAES 1   CAES 2

(a) Cell phone in China

CAES 1 CAES 2

(b) Internet in China

CAES 1 CAES 2

(c) Online banking

CAES 1 CAES 2

(d) Cell phone in America

Figure 9. The evolution mechanism of four products

CAES 26 CAES 26

(a) Cell phone in China (b) Cell phone in America

CAES 26 CAES 16

(c)Internet in China (d) Online banking

Figure 10. The comparison on last CAES of four products

There is another interesting phenomenon. The case of landline does not work because of the negative coefficient. What happen? There might be something. We watch the figure of real cumulative sales on landline (Figure 11). The cumulative sales curve keep going down after the max value. This is a problem. It is the return phenomenon in durables area or it also can be called customer attrition in services area. Customer attrition, which is the phenomenon that a customer terminates the relationship with the services provider, is a main difference between durables and services (Libai et al., 2009).
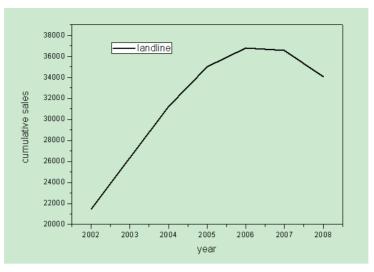
Figure 11. Cumulative sales curve for landline in China

A key is when a customer returns durables or terminates relationship with the provider. In generally, there is the existence of time limit for durables return. The durables will not be returned if over the time limit. But for services, usually, there exist two situations. Firstly, services with service contract could be terminated after the deadline of the contract. Secondly, the services without service contract could be terminated at any time after using. Bass paid more attention on the durables and did not consider the return phenomenon which is more ubiquity in the services. There should be other product with similar phenomenon in market diffusion. Here, we proved the concept of customer attrition is a considerable influence on new service growth process proposed by Libai et al. (2009). Therefore, service cross market growth should consider customer attrition in the market competition. We leave this option for a future research.

5. Discussion and Limitations

We demonstrated the ability of the cellular automata method to serve as an analysis tool both in real data and in the condition of unavailable data. The results show that the method is promising, while it successfully examined the effect of external and internal learning on new product diffusion and analyzed cross market growth of products in the condition of unavailable data.

Our study has several limitations. In this paper, we only use one evolution rule based on one famous assumption. The cases presented are limited to a few cases in services area.

A key concern is the heterogeneity effect on individual-level, especially in services purchase behavior diffusion. Goldenberg et al. (2001a) found the diffusion process loses its bell shape, causing known aggregate models to lose their fit and predictive power, when the individual parameters are below certain critical values. Owing to the differences between durables and services mainly exist in the specific characteristics of services i.e., their intangibility, co-production with customers, simultaneity, heterogeneity and perishability (Fitzsimmons & Fitzsimmons, 2000) that seems higher risk than durables which could strongly affect on consumer purchase decision, the existence of unique individual level dynamic diffusion should be shown in the services purchase behavior diffusion. Cellular automata can provide a much broader framework of diffusion phenomenon than the diffusion process. Under the complex marketing environment, the complexity of diffusion phenomenon needs more complex cellular automata evolution rules and computer systems. Clearly，cellular automata models are capable to shed more light on this aspect in future research.

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