An agent-based model for analyzing product penetration for consumer goods

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ABSTRACT

In the marketing literatures there are several theories for describing the behavior of consumers in their decision. Assael distinguished four types of consumers' buying behavior based on the degree of buyer involvement and the degree of differences among brands, 1)Complex buying behavior, 2)Dissonance-Reducing Buyer Behavior, 3)Habitual Buying Behavior, and 4)Variety-Seeking Buying Behavior. According to Assael, the latter two types of behavior can be seen when the degree of buyer involvement is low. In this paper, we try to build a model for analyzing product penetration based on the consumers' buying behavior in low buyer involvement situation. Especially, we will focus on word-of-mouth (WOM) effect in penetration process of new product. Based on the computer simulation, the following results are derived. 1) Without WOM interaction, the penetration of new product happens. It's independent of the ratio of variety-seekers. 2) With WOM, the penetration of new product requires the existence of variety-seeker, however the ratio of variety seeker about 5-10 % are enough to cause stable penetration. 3) Even a little WOM interaction can cause the turbulence of product share transition. In low buyer involvement situation, the rules of consumer agents can be described as a rather simple one. Even though each consumer's rule is simple, the market as a whole can be complex because there is an interaction between consumers.

Keywords: agent-based approach, marketing, consumer behavior, simulation, word-of-mouth interaction

1. INTRODUCTION

In the marketing literatures there are several theories for describing the behavior of consumers in their decision. Assael distinguished four types of consumers' buying behavior based on the degree of buyer involvement and the degree of differences among brands, 1)Complex buying behavior, 2)Dissonance-Reducing Buyer Behavior, 3)Habitual Buying Behavior, and 4)Variety-Seeking Buying Behavior[1,4].

According to Assael, the latter two types of behavior can be seen when the degree of buyer involvement is low. In this paper, we try to build a model for analyzing product penetration based on the consumers' buying behavior in low buyer involvement situation.

In high involvement situation, consumers make a complex buying decision. In most situation, their decision rules are not uniform. And it often happens, especially in "Dissonance-reducing buying behavior", that consumers do not even aware of their decision rules. Therefore, it's unrealistic assumption that each consumers decision rules can be explicitly described in the models.

In low buyer involvement situation, the rules of consumer agents can be described as a rather simple one. Even though each consumer's rule is simple, the market as a whole can be complex because there is an interaction between consumers. In this kind of complex social systems the agent-based modeling is an effective approach[2,3].

2. MODEL

2.1. Structure

Consumer goods markets can be seen as a two-level system as is depicted in Figure 1.

In the higher level there is a marketer trying to merchandise their goods. In the lower level there are a lot of consumers who have to decide what to buy among a lot of product choice. When the marketer launch their new product, they can affect consumers' decision through various communication channels, such as advertising and promotion. Most of this communication can be regarded as a broadcasting style, that is,

consumers are treated as anonymous agents by the marketer, especially in consumer goods market with low buyer involvement.

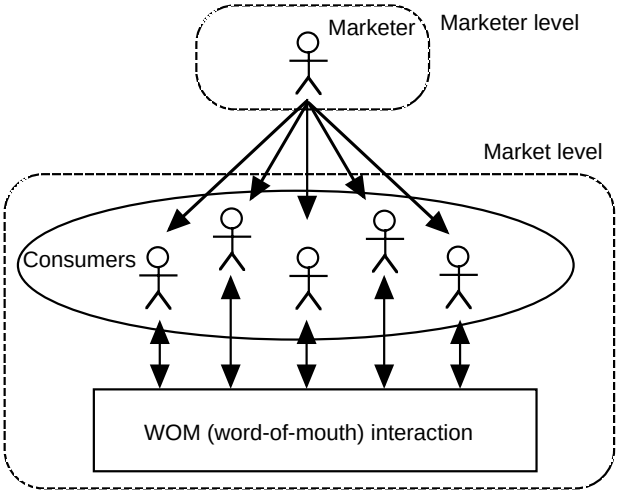


Figure 1. Two-level structure model of consumer markets

On the other hand, consumers can communicate with each other in peer to peer style. They interchange product information and utilize them in the product selection. Therefore, there is a direct interaction among the consumer agents. These word-of-mouth (WOM) communication can affect their buying behavior in a great extent.

Therefore, the decision of consumer agents depends on the following two factors.

1. Information provided by a marketer, such as advertising, sales promotion.
2. Information provided by WOM interaction.

In this paper, we will focus on WOM effect in penetration process of new product. As was stated in the introductory section, we also focus on the situation where consumers' buying decision is rather simple. Therefore, we will put the following assumption.

1. Information of initially existing product provided by a marketer is invariant over time. Information of new product is introduced into a market in a given fixed time.
2. Consumer agents are heterogeneous in their buying behavior. We introduce two types of consumer agents, habitual buyers and variety-seekers. That is, we partially adopt Assael's typology of consumers. These two are types for low buyer involvement situation.

The purpose of this paper is to introduce the basic model to analyze new product penetration with WOM interaction among consumers based on minimum assumptions described above.

2.2. Implementation

We are interested in the model's behavior when we run the model with a large amount of agents with simple rules. We use the following symbols.

$n \times n$: the size of rectangular cells
G : the number of initial products
N : the number of consumer agents
V : the ratio (percent) of variety-seekers in population
M : the mean of product choice TTL (time-to-live)
S : the standard deviation of product choice TTL
W : the propability of WOM influence

The meaning of each symbols will be explained below.

Information source of G distinct products are scattered around in a array of $n \times n$ rectangular cells. Each cell is a unit square. N consumer agents move around randomly in the array. They are seeking the product information. There are two types of consumer agents. One is "Variety-seeker", and the other is "Habitual buyer".

Assume a consumer agent eventually runs into a product information on some cell. He or she makes his/her mind to buy the product if he/she has not decided what to buy yet. However, if he/she has already decided what to buy, his/her behavior differs depending on the type. Variety-seeker agent switches his choice to the new ones. Habitual-buyer, however, does not change their choice, and keeps his choice to the current brand.

We will describe the simulation setting formally.

1. Consumer agents

$$i \in \{1, 2, \ldots, N\}$$

Let assume the set of agents can be partitioned into two sets,

$$\{1, 2, \ldots, M\}, \{M+1, \ldots, N\}$$

where $\{1, 2, \ldots, M\}$ be the set of variety-seekers agents, and {M+1,…,N} be that of habitual buyers. V percent of N agents are variety-seekers and the rest are habitual-buyers. That is,

$$\frac{M}{N} = V(\%)$$

The behavior rule of these two type consumers will be described below. Initially, N agents are scattered randomly in the array of $n \times n$ rectangular cells.

2. Products

We will denote the set of products

$$\{1, 2, \ldots, G, G+1\}.$$

$G+1$ denotes the new product which are introduced into market afterward. Initially, the product information source of $\{1, 2, \ldots, G\}$ are also scattered

randomly in the array of $n \times n$ rectangular cells. $G+1$ is also placed randomly in the array. Their positions are invariant through each simulation run.

3. $xy-$ coordinate of agents

$$(x_i(t), y_i(t))$$

denotes the $xy-$ coordinate of Agent i in $n \times n$ rectangular array at time t. t is a discrete time variable, and we assume $t = 0,1,2,\ldots$. $x_i(t)$ denotes the value of a real valued time function x_i at time t. Each agent moves around in $n \times n$ rectangular array, therefore,

$$x_i(t), y_i(t) \in [0, n]$$

where $[0, n]$ is a closed interval in the real line.

4. Product decision

Agent i's product selection is denoted by

$$p_i(t).$$

Hence, for any i and any t,

$$p_i(t) \in \{1, 2, \ldots, G, G+1, None\}$$

where *None* denotes Agent i does not decide what to buy at time t.

5. Inertia of product choice

We assume that Habitual buyers keep their choice in a certain period of time (product choice TTL: time-to-live). TTL of product choice is denoted by

$$ttl_i(t)$$

This ttl_i is set on the buying decision, and its initial value varies depending on each purchase. Therefore, ttl_i is set on the buying decision randomly by the value along the normal distribution of given mean M and standard deviation S.

We can summarize the rule for consumer agents as follows. Each consumer agent follows these steps in each simulation time t.

Step 0 If $ttl_i(t)$ of Agent i is not 0, set it to $ttl_i(t)-1$. Otherwise, set this agent's choice $p_i(t)$ to *None*. That is, if $ttl_i(t) \neq 0$, then

$$ttl_i(t) = ttl_i(t) - 1,$$

else ($ttl_i(t) = 0$),

$$p_i(t) = None.$$

Step 1 Checks if there any other consumer agents in the cell where this agent resides with the probability W. If there are some, go to Step 2, otherwise Step 3.

Step 2 Choose one consumer as a WOM partner randomly which is in the same cell. Let the partner be Agent $j(\neq i)$.

1. If Agent i has no choice and Agent j (the partner) has his brand (i.e., he's already made his mind what to buy), then Agent i's choice becomes the same one as the partner's. That is, if $p_i(t) = None$,

$$p_i(t) = p_j(t)$$

and in this case, TTL of Agent i is reset by the value along the normal distribution of given mean M and standard deviation S.

$$ttl_i(t) = l$$

where $l \sim N(M, S^2)$.

2. If agent i has his choice and agent j (the partner) has not, then the partner's choice becomes the same one as agent i's. That is, if $p_j(t) = None$,

$$p_j(t) = p_i(t)$$

and in this case,

$$ttl_j(t) = l$$

where $l \sim N(M, S^2)$.

Step 3 Check if there are any products in the cell where this agent resides. It there are some, go to Step 4, otherwise Step 5.

Step 4 Choose one product as a target product randomly which is in the same cell. Let the target product be k.

1. If Agent i has no choice or the agent is a variety-seeker, then the agent makes his mind to buy the product.

2. Otherwise, Agent i is a habitual buyer and has already made a decision on what to buy. Therefore, this agent does not change his decision.

That is, these two rules can be described as

$$p_i(t) = \begin{cases} k & \text{if } p_i(t) = None \text{ or } 1 \le i \le M \\ p_i(t) & \text{o.w.} \end{cases}$$

Step 5 Move forward unit distance with headed to randomly selected direction. That is, the direction from $(x_i(t), y_i(t))$ to $(x_i(t+1), y_i(t+1))$ is randomly determined, and

$$\sqrt{[x_i(t+1) - x_i(t)]^2 + [y_i(t+1) - y_i(t)]^2} = 1.$$

Step 6 Increment time

$$t = t + 1$$

and repeat from Step 0.

3. SIMULATION

3.1. General settings

We coded the rules above into a simulation program and tried runs with the parameter settings shown bellow. V and W were taken as control parameters.

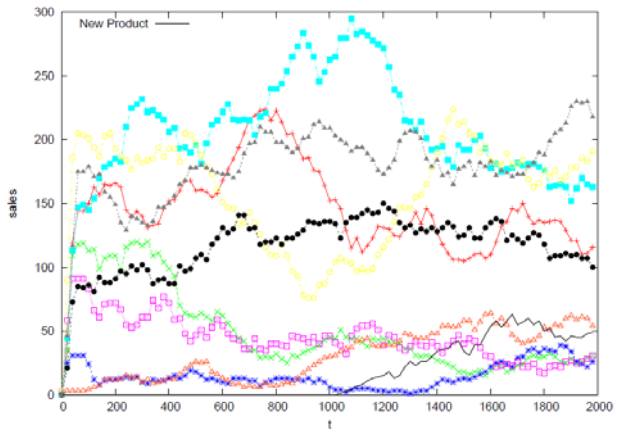
1. The degree of influence in WOM interaction ($W \in [0,1]$)
2. The ratio (percent) of variety-seeker agents in whole population ($V \in [0,100]$)

We ran the simulation to 1,000 steps with initial nine products ($G = 9$), and introduced the tenth product into a randomly selected cell, and observe the penetration process of new product until 2,000 steps.

Figure 2 shows a typical simulation output. Ten plot lines represent transition of sales of the ten products in every 20 steps, including the new product introduced into market at time 1000. "Sales" of each product means the number of consumers who decided to buy the product at that time. Therefore, the sales $s_k(t)$ of product k at the time t is defined as follows.

$$s_k(t) = |\{i : p_i(t) = k\}|$$

We are plotting sales in every 20 steps because of the visibility.



n=43, G=9, N=1000, V=10, M=100, S=10, W=0.5

Figure 2. A simulation example

Initially nine products were introduced in the market. At $t = 1000$ the new product was introduced, and the share of the new product (drawn with a bold line) increased until the end of the simulation run ($t = 2000$). In this simulation run, the new product obtained Rank 6 in sales at the end of the simulation. This output indicates that the change of share ranking in product sales can be rather mild in a certain parameter setting. However, as is shown below, in other simulation runs we can see quick change, or the turbulence in sales ranking.

3.2. Simulation results

We tried the simulation with the following three different setting of the parameter of WOM influence W.

1. Without WOM influence ($W = 0$)
2. With WOM influence of probability 1/2 ($W = 0.5$)
3. With deterministic WOM influence ($W = 1.0$)

For each W setting we tried the simulation with changing the control parameter V, the ratio of variety-seekers in whole population.

We will show four settings of the parameter V, $V = 0, 5, 10, 20$, for each W. Therefore, we will present 12 combinations of control parameter setting. For each 12 combination, we generated 10 simulation outputs. We will show some typical outputs from those simulation runs. The share rankings of the new product at the end of ten simulation run in the same parameter setting were used to obtain the maximum, the average and the minimum value of share ranking.

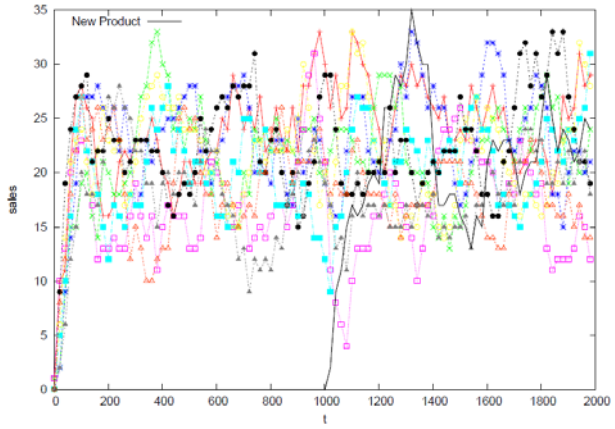
1. Without WOM influence

Figure 3 shows a selected simulation output from 10 iterations with the parameter setting $W = 0$ and $V = 0$. In Figure 3-(a) sales of all ten products are plotted in every 20 steps. In Figure 3-(b) sales of selected products and new one are plotted so that the transition of new product sales is more visible. Products whose shares was Rank 1 (top rank) and 10 (bottom rank) at the end was selected here. We will present two graphs for each simulation output with the same scheme hereafter. However, the selection of products may varies depending on the rank of the new product at the end of simulation.

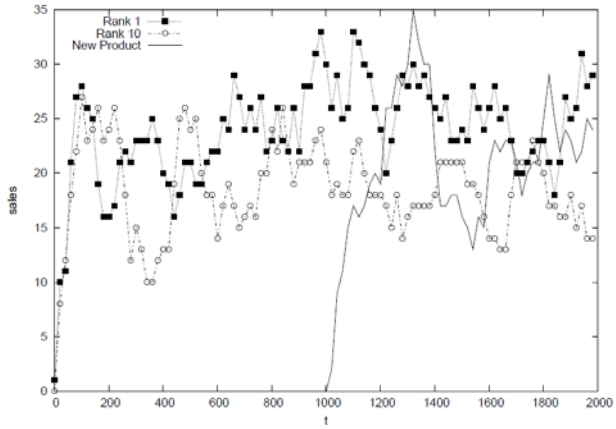
Because there is no diffusion of product information via WOM, a large number of consumers stay undecided what to buy in each time. This results in the smaller amount of sales of all products if you compare them to those in Figure 2. However, the relative share of the new product grows rapidly after the launch, and it succeeded in penetrating into the market. In this simulation run, the new product obtained Rank 5 in sales among ten products and its share was 10.5%.

As is shown in Figure 3, the sales of each product are

fluctuating to a large extent. This is because the decision of product choice is made by the encounter to the product information by accident through the random walk on the rectangular cells. If we make the consumers more habitual, that is, if we set the product choice TTL M longer, the sales becomes smoother. However, the growth of new product sales certainly happens.



(a) Sales of all products

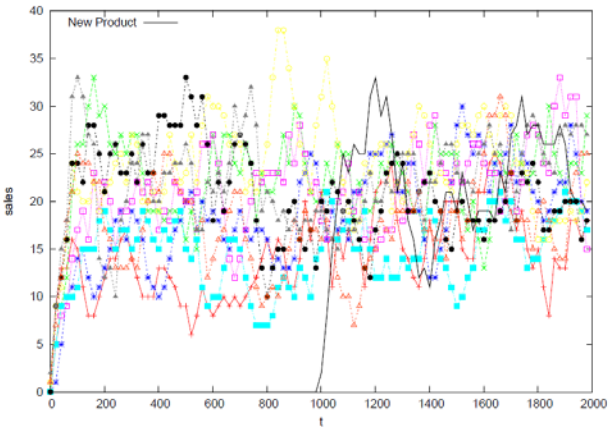


(b) Sales of selected products and new product

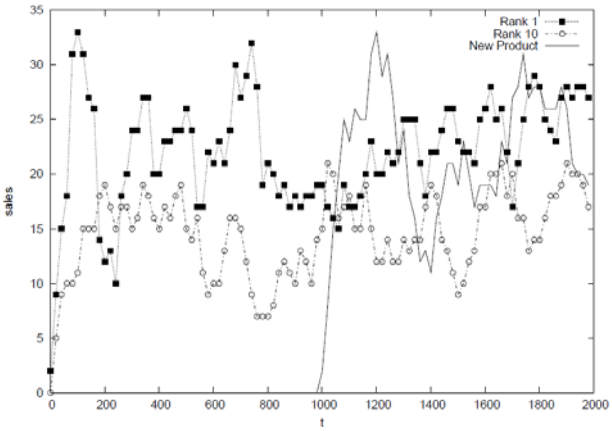
n=43, G=9, N=1000, V=0, M=100, S=10, W=0

Figure 3. Simulation result ($W = 0$, $V = 0$)

Figure 4 shows one of the simulation result with the setting $W = 0$ and $V = 20$. In this simulation, the new product obtained Rank 7 at the end of simulation and its share was 9.0%. However, after the launch of new product, it acquired Rank 1 share in the market. As is shown there, the ratio of variety-seekers does not affect on the sales transition. The penetration of new product is independent of the existence of variety-seekers.



(a) Sales of all products



(b) Sales of selected products and new product

n=43, G=9, N=1000, V=20, M=100, S=10, W=0

Figure 4. Simulation result ($W = 0$, $V = 20$)

Figure 5 shows the change of the maximum, the average and the minimum rank of new product at the end of simulation ($t = 2000$) in ten simulation runs along with increasing V. When $V = 0$, the maximum (highest) rank in 10 simulation runs was 2, and the minimum (lowest) was 10. It also indicates that the average was around 6. As is shown in the figure the rank of new product varies from the top to the bottom throughout the all setting of V. However, the difference in rank does not mean much difference in share as is shown in Figure 3 and 4. Therefore, V does not affect on the penetration of the new product.

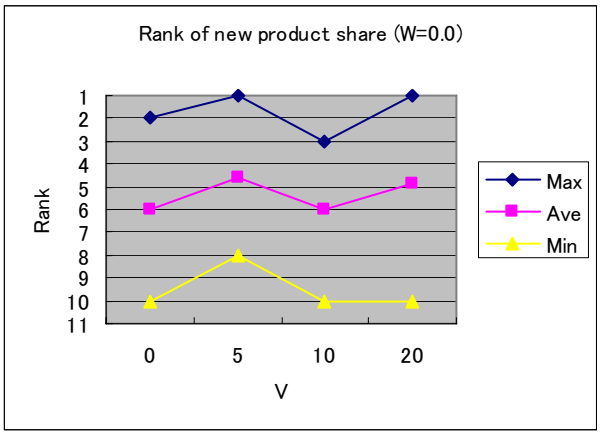
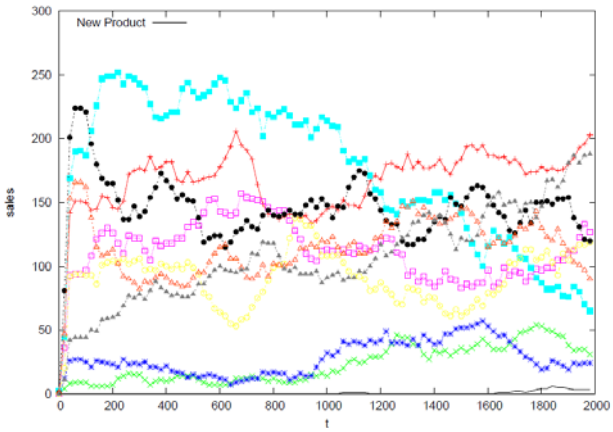


Figure 5. Rank of new product sales ($W = 0$)

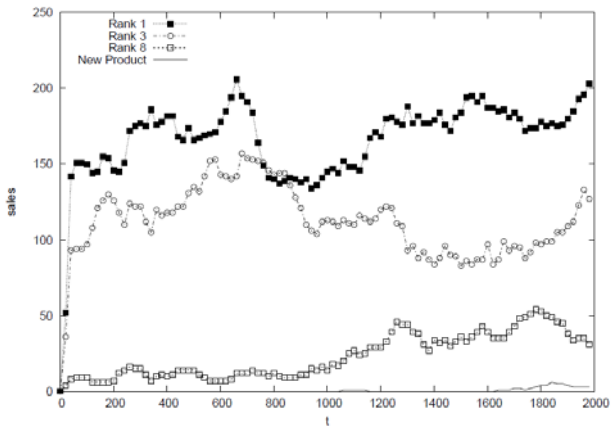
2. With WOM influence of probability 1/2

Figure 6 shows one of the simulation result with the setting $W = 0.5$ and $V = 0$. With WOM influence, the quick fluctuation of sales can not be seen. The new product can not obtain sales in this setting. The sales of new product ended in Rank 10 (the bottom) and its share was 0.31%. This shows the penetration of new product is unlikely to happen.

Figure 7 shows one of the simulation result with the setting $W = 0.5$ and $V = 10$. In this setting the new product earned Rank 4 sales at the end of simulation, and its share was 9.8%. This shows that the penetration of new product happens with the existence of variety-seekers if there is a WOM influence.



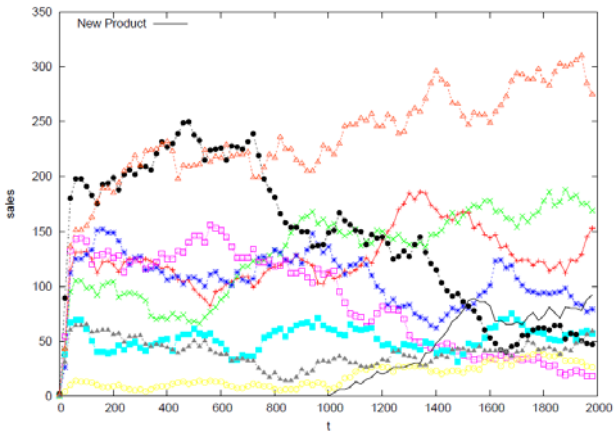
(a) Sales of all products



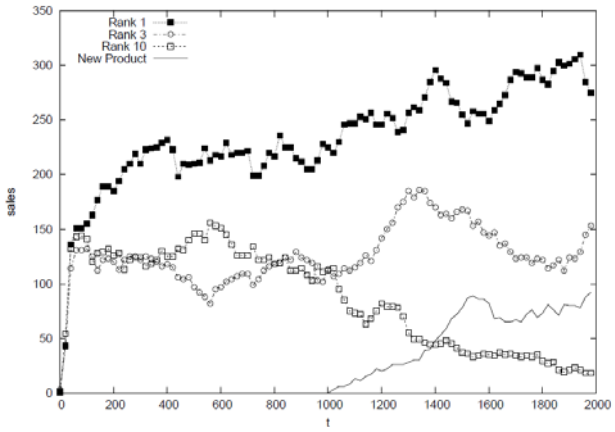
(b) Sales of selected products and new product

n=43, *G*=9, *N*=1000, *V*=0, *M*=100, *S*=10, *W*=0.5

Figure 6. Simulation result ($W = 0.5, V = 0$)



(a) Sales of all product



(b) Sales of selected products and new product

n=43, *G*=9, *N*=1000, *V*=10, *M*=100, *S*=10, *W*=0.5

Figure 7. Simulation result ($W = 0.5, V = 10$)

As is shown in Figure 8, this tendency rises along with the increase of V. With the setting $W = 0.5$ and $V = 10$, the new product earned Rank 10 in the worst case, but its share was 3.0%, and in the best case it earned Rank 4 and its share was 9.8%. With the setting $W = 0.5$ and $V = 20$, the new product earned Rank 10 in the worst case, but its share was more than 3%, and in the best case it earned Rank 4 and its share was more than 10%.

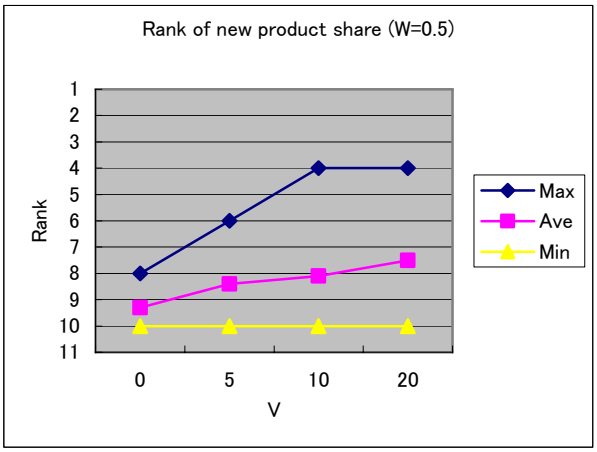
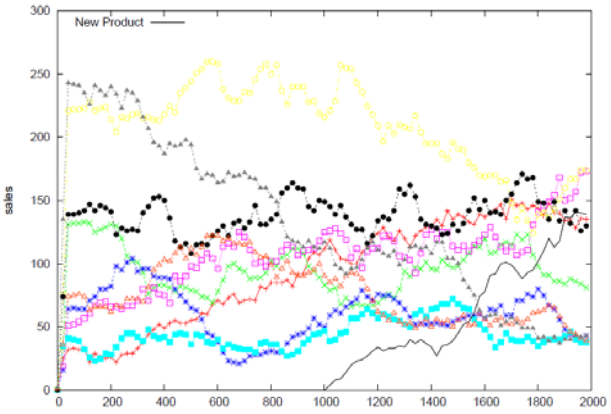


Figure 8. Rank of new product sales ($W = 0.5$)

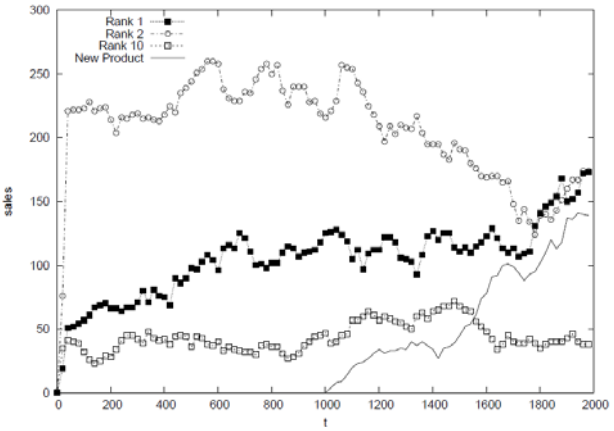
3. With deterministic WOM influence

Figure 9 shows one of the simulation result with the setting $W = 1.0$ and $V = 20$. In this case, the penetration of new product is obvious. Its Rank at the end was 3 and its share was 14.3%.

Figure 10 shows the similar result to that in Figure 8.



(a) Sales of all products



(b) Sales of selected products and new product

n=43, *G*=9, *N*=1000, *V*=20, *M*=100, *S*=10, *W*=1.0

Figure 9. Simulation result ($W = 1.0$, $V = 20$)

4. DISCUSSION AND CONCLUSION

Through the simulation results presented in the previous section, the following results were derived.

1. Without WOM interaction ($W = 0$), the penetration of new product happens. It's independent of the ratio of variety-seekers.
2. With WOM ($W > 0$), the penetration of new product requires the existence of variety-seekers, however, the ratio of variety seeker about 5-10 % is enough to cause stable penetration.

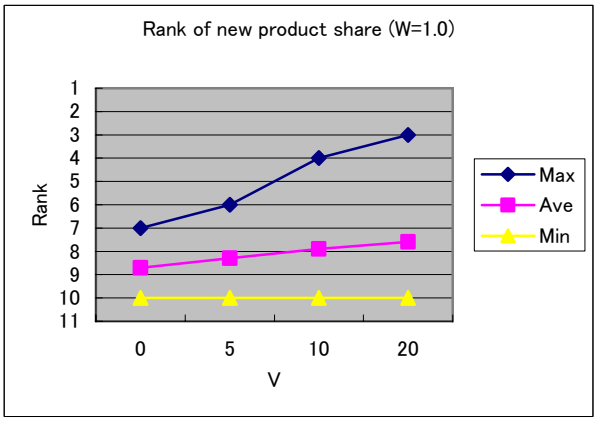


Figure 10. Rank of new product sales ($W = 1.0$)

Without WOM interaction consumers have to seek product information by themselves walking randomly around 43×43 rectangular cells until they encounter one of 9 (or 10 after the new product launch) product information. Hence, the large number of consumers stay undecided what to by at each time. Therefore, many agents free from product choice are in the market. This means that the existence of variety-seekers does not affect the sales distribution.

We tried the simulation with 1000 consumer agents scattered on 43×43 rectangular cells. Therefore, the probability to encounter other consumers is high, and with WOM interaction the product information diffuses rapidly. Hence, it enables consumers in the market to decide what to buy without seeking product information by themselves. Almost all consumers have their selection at each time, and habitual buyers do not change their selection even if they encounter new product information. This is the reason that the existence of variety-seekers is important to realize the penetration of new product in the market with WOM interaction. In launching a new product marketer should consider the way to deliver the new product information to a rather few variety-seekers if he can assume that there is enough WOM interaction among consumers.

Even a little WOM interaction can cause the turbulence of product share transition. In Figure 6, 7 and 9, the major changes of sales ranking happen in a long term, and their changes can not be predictable. Introducing WOM interaction changed the behavior of the model from the stochastic "random walk" fluctuation to a chaotic turbulence.

In consumer's buying decision in low involvement their decision rule can be assumed rather simple, but the existence of inter-agent interaction and variety-seeker can be regarded as a key factor of the complex behavior of the consumer goods market.

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