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The product demand model driven by consumer's information perception and quality perception

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HIGHLIGHTS

- Multi-layer network to study the influence of consumer's information perception and consumer's quality perception on market demand.
- Consumer's information perception has a greater impact on market demand.
- A two-layer model of consumer information perception communication and consumer quality perception communication is constructed.
- The active state of the node is changed at a certain probability, thereby changing the information perception, quality perception and market demand of the multi-layer network.

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ABSTRACT

This paper uses the multi-layer network to study the influence of consumer's information perception and consumer's quality perception on market demand. In the network society, consumer's information perception have a greater impact on market demand, mainly because the consumer's information perception and the consumer's quality perception are easier to know than before, which in turn affects their market demand. This paper constructs a two-tier model of consumer's information perception communication and consumer's quality perception dissemination. The upper is the consumer's information perception layer and the lower is the consumer's quality perception layer. At the same time, individuals will also have their own behavioral habits, if they change their active state with a certain probability, it will change the information capability of multi-layer network, the dissemination of consumer's quality perception, and the market demand (to meet the personalized needs of the market). Finally, the accuracy of the theoretical analysis is verified by the scale-free network simulation.

1. Introduction

The basic economics is to study the relationship between product demand and price. The demand function of products in market economy is not only directly related to price, but also reflected in the correlation of many external information

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factors. The external information representation specifically includes the consumer's awareness of the product, that is, the degree of consumer's understanding of the product quality and whether the company sells the product to perform safe production and other corresponding external attributes. The external information representation also includes the ability of consumers to identify information. Due to the driving force of the Internet economy, the amount of information obtained by consumers is too large, resulting in limited extraction of information value by consumers. In the paper published in 2005, Yi-Cheng Zhang proposed an information economics framework under the constraints of information capability [1]. In addition, we can find that changes in information capabilities in the market can indeed have a certain degree of impact on the market demand for goods. For example, the Net Red economy affects the changes in the market demand curve by changing the consumer information capabilities of consumer market information awareness.

The American anthropologist Clifford Geertz [2] describes the operational mechanism formed by buyers and sellers in the market economy by manipulating product information. George Akerlof's work on the 'Lemons Problem' [3] proposed a simple example to explain the problem of information asymmetry. At the same time, individual differences lead to significant differences in their capability to understand information. For example, gender differences have significant differences in understanding spatial information capability [4]. Cohn J F, Schmidt K studied the improvement of computer skills from the perspective of individual behavioral differences. It can be seen that individual differences have strong differences in the mastery of information learning and other abilities [5]. The difference in understanding this information is also affecting consumer demand. Consumers can find better products if they simply refer to other people's opinions. The selection process of the consumer for the goods has formed a pressure on the average evaluation of the business. This is the ability to synthesize information that will ultimately determine the quality perception for consumer [6]. Lin R J, Tan K H and Geng Y studied whether the demand of Vietnamese consumers for motorcycles provided in the market based on green products, proved that the company provides green products can help the sale of products [7]. These studies show that changes in consumer demand for products are influenced by their level of understanding the product.

Consumers' understanding of products often comes from two aspects, their own experience and social interaction. As the example given in [6], we compare the shops in the residential area and the shops near the train stations or airport. The customers of residential shops are mainly locals, who repeatedly buy goods there. While the customers of the train station store are mainly travelers, who may shop there once. Then the locals usually have a higher level of information than travelers. The locals have higher information capabilities because they have previously purchased related services or the people around them have purchased services. It can be seen that through their own experience or information exchange with people around them, they can change their information capabilities. Generally speaking, the consumption behavior of each consumer is different in social economics [8,9], which is reflected in the fact that some consumers have strong capability to perceive the consumer's quality perception. For example, some consumers can find the discount information of the products at the first time and transmit the relevant information to the consumers who have their own intersections [10]. While the consumers who passively accept relevant information may cause the consumer to accept or reject relevant information due to subjective inconsistency. If the relevant information is accepted, the consumer's consumption behavior will be stimulated and vice versa. Therefore, the difference of consumption behavior is reflected in information capability and consumer's quality perception [11], and the difference of consumption behavior will lead to the market demand for products.

In real life, each consumer has certain differences in the information capability and the quality perception. From the perspective of information abilities, the information that a company releases a new product will first be distributed to the consumers who pay attention to the enterprise in the first time [12]. Secondly, the relevant information will be spread through the consumer's social network. And consumers interested in the product will be a greater possibility to purchase the product. So this part of the consumer has a strong information capability, while the relatively consumers who do not pay attention to the enterprise have poor information capability. From the perspective of the quality perception, the price reduction or discount promotion information of products will be transmitted to the consumers who pay attention to the products in the first time, and spread through the social network, thereby affecting the consumer's consumption behavior [13,14]. Therefore, each consumer has a greater difference in the quality perception. Here we reveal the facts of the consumer information capabilities and the change in the price-performance information perception capabilities. That is, the common spread of product information and quality perception affects the market's demand for products. Therefore, we need to analyze the changes in market demand from the perspective of information dissemination, and at the same time study the common impact mechanism of these two types of information dissemination. In real life, product information and product quality perception information will be transmitted through the network of interpersonal relationships. The use of these two kinds of information in the spread of social networks can truly reflect the impact of different consumers on the market demand after acquiring two types of information. Therefore, this paper uses the method of network science to describe the evolution of these two kinds of information in the market, and then to study the average information capacity of the market and the evolution of market demand.

In a multi-layer network, nodes at different levels represent the same individual, and the forms of network connections at different levels are different [15,16]. They are mainly divided into virtual network layer and physical contact layer. The virtual network layer includes virtual social networks such as WeChat and Weibo. The physical contact level includes practical contactable networks such as daily life and work. Buldyrev et al. [15] pointed out the importance of multi-layer network analysis through concurrency failures in the power grid. In terms of multi-layer networks, Clara et al. [17] first analyzed the impact of information transmission on disease transmission through the UAU–SIS multi-layer network model,

and used the micro-Markov chain method to theoretically calculate the steady state of the disease transmission system. On this basis, Clara et al. [17] studied the influence of mass media on information dissemination and obtained a better multi-layer network model. The research of the multi-layer network show that different attributes of the same node in the network will form different network structures. This makes different things spread differently in the network, and its evolution has an important impact on the entire network. In a competitive market, the increased understanding of the product by consumers will improve the demand of the corresponding products in the market, and the improvement of the consumer's quality perception capability will also affect their market demand.

Therefore, this paper uses product information dissemination and the quality perception dissemination to establish individual information capability and quality perception systems in multi-layer networks, and then establish a market product demand model. In this model, the improvement of consumer's information perception makes it easier to understand the quality information of the products. In addition, individuals in a multi-layer network have an active state, and nodes with different active states have different levels of understanding of consumer's quality perception and their own information cognition capability. Then, on this basis, the paper analyzes the sensitivity of consumer's information perception and consumer's quality perception to market demand changes. Finally, this paper verifies the model and theoretical analysis through computer simulation. And then discusses the changes of consumer demand system under different conditions.

2. Market demand under the information capability framework

In the market, consumers have certain information capability, which can perceive the service quality of products. When consumers have infinite information capability, they can fully perceive all information about products. When the consumer's information capability is insufficient, the information of the product cannot be felt at all. On the one hand, the information capability of consumers comes from their own consumption experience. On the other hand, the consumers information capability comes from the product information and services provided by producers to the society. For example, Apple can increase consumer awareness of Apple's mobile phone by expanding its advertising coverage, and then discover more potential consumers and generate more demand. Therefore, we can see that consumers' information capability depends on two aspects, that is their own cognition and product quality information provided by producers, both of which will affect the market demand.

The quality of the products mentioned here cannot be measured by money alone. For example, the emergence of Apple's mobile phone has changed consumer perceptions of product quality, resulting in lower prices for other brands of mobile phones, but the quality of these brands has not changed before and after. Therefore, in the research process of this paper, product quality (Q) and product price (P) are treated as independent variables. Before or during the appearance of high-quality products, some consumers will buy higher-priced and lower-quality products. The correlation between quality and price can often be handled through market transactions, and this correlation depends on the market information capability of consumers.

The focus of this paper is on the overall market demand $q(Q, p, \varepsilon)$. The total demand in the market comes from N consumers. The information capability of these consumers are different, but there is an average information capability, which we call it the average information capacity of the market. Then the total market demand can be expressed as:

$$q(Q, p, \varepsilon) = \sum_{i=1}^{N} q_i(Q, p, \varepsilon) \tag{1}$$

Because of the fact that potential buyers can decide to purchase a certain type of product or to abandon the purchase of a certain type of product, each product can be considered to be replaced. Assuming that the total demand of the market in which N potential consumers purchase the product is 1(we think that the total demand of the market is 1). When the total market demand is 0.3, it means that 30% of consumers in the market are willing to buy the product. The quality, price and information capability of the products concerned in this article are expressed as a percentage of unspecified units. Therefore, the quantity purchased (q) is linearly proportional to the "probability" of the consumer purchasing the product.

It can be found that the quality of products here has been given a new role, but consumers often have weaker sensitivity to the quality of products. When sellers in the market create corresponding opaque information, consumers will be slow to respond to quality-driven consumer behavior. This relationship is described in the [11] article as follows:

$$q(Q, \varepsilon) = A(Q - AQ_0)/(1 - AQ_0) \tag{2}$$

where A is confidence factor. Note that q(Qmax, ε) = A for any ε. In proposing the above formula, we try to keep the functions simple and whenever possible, linear functions are preferred. The choice of parameters seems to be somewhat contrived, this is because the formula is a special example of the full expression q(Q, p, ε).

3. Market demand model driven by quality perception and information perception

3.1. Model assumptions

It is considered that the information perception and the quality perception is a multi-layered communication network. The network individuals in different communication levels are the same individual, and the connections between individuals in different levels of networks have different characteristics. In other words, because the same person's perception of the product information and the product quality are different, different levels of networks are constructed to describe the propagation of different information.

Hypothesis 1. The upper is the information capability layer, indicating that the individual can obtain the relevant information of the products. The spreading of information capability satisfy the unaware–aware–unaware (UAU) process. Aware (A) individuals can improve their information capability and the understanding of the products by acquiring information of the products. Unaware (U) individuals do not have any information about the products and the information capability is not improved. The dissemination mode of the products information capability communication layer is: the unaware individuals can communicate with the aware individuals to get information with the probability λ, while the aware individuals can forget the information with the probability δ.

Hypothesis 2. The lower is the quality information layer, which indicates that the individual can obtain the quality information of the products. The spreading of the quality information satisfy the Susceptible–Infected–Susceptible (SIS) model. The susceptible individual N is sensitive to the quality information. And the learning individual Y is knowing the quality information. The dissemination mode of the quality information layer is: the susceptible individual N can convert into the learning individual Y with the probability β. While the learning individual Y can be return to the susceptible individual N with the probability μ.

Hypothesis 3. Individuals in a multi-layer network have the characteristics of tending to avoid disadvantages, that is each individual has certain sensitivity to information. However, the individuals behavior status we simplified as the active state and the inactive state. The superscript sign m stands for the active state and n stands for the inactive state. The active individuals can get all links with their neighbors, while the inactive individuals can only get connections by their active neighbors. Individuals change their status between active and inactive with the probability α and $1-\alpha$, respectively. And the susceptible individuals S^n in the inactive state can only be infected by the active individual I^m.

3.2. Propagation model

According to these assumptions, we use the Greek letter ϕ to represent the information capability to enhance the stimulation of individuals. The information capability propagation probability λ and the quality perception propagation probability β can be changed by increasing the stimulation of individuals. In this process, the probability that individuals with improved information capability perceives consumer's quality perception is $\beta^{\mathrm{A}} = \beta$. While the probability that individuals with unimproved information capability perceives consumer's quality perception is $\beta^{\mathrm{U}} = (1-\phi)\cdot\beta^{\mathrm{A}}$. The information capacity increase stimulus ϕ has a range of values [0, 1]. When $\phi = 1$, it means that the individual has the maximum information capability. And when $\phi = 0$, it means that the individual has the minimum information capability, that is it does not affect the individual's identification of quality products.

The reaction process of multiplex networks model can be schematically represented by

Behavior state change

$$UY^n \xrightarrow{\alpha} UY^m, AN^n \xrightarrow{\alpha} AN^m, AY^n \xrightarrow{\alpha} AY^m$$

$$UN^m \xrightarrow{1-\alpha} UY^n, AN^m \xrightarrow{1-\alpha} AN^n, AY^m \xrightarrow{1-\alpha} AY^n$$

Active spreading

$$UN^m + AN \xrightarrow{\lambda} AN^m + AN$$

$$UN^m + AY \xrightarrow{\lambda} AN^m + AN$$

$$UN^m + AY \xrightarrow{\beta^U} UN^m + AY \xrightarrow{1} AY^m + AY$$

$$AN^m + AY \xrightarrow{\beta^A} AY^m + AY$$

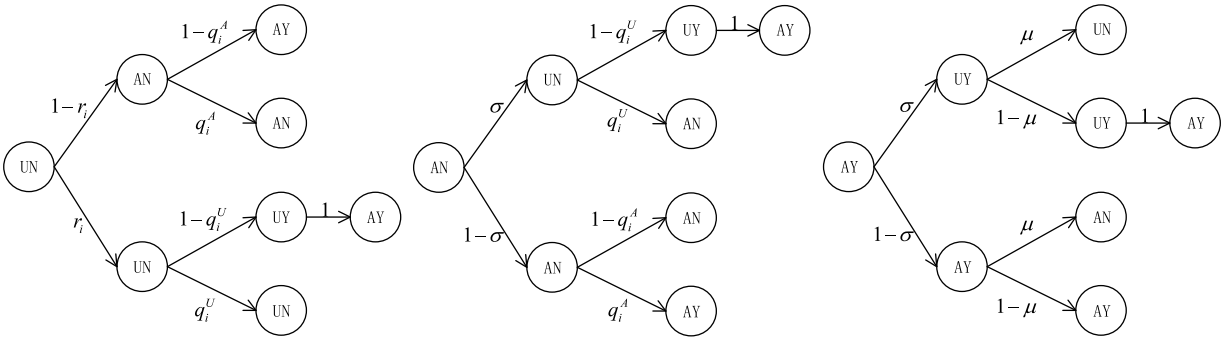

Fig. 1. Transition probability trees.

Inactive spreading

$$UN^n + AN^m \xrightarrow{\lambda} AN^n + AN^m$$

$$UN^n + AY^m \xrightarrow{\lambda} AN^n + AY^m$$

$$UN^n + AY^m \xrightarrow{\beta^U} UY^n + AY^m \xrightarrow{1} AY^n + AY^m$$

$$AN^n + AY^m \xrightarrow{\beta^A} AY^n + AY^m$$

Recoveries

$$AN \xrightarrow{\sigma} UN, AY \xrightarrow{\mu} AN$$

3.3. Mean-field approach analysis

According to these assumptions, there are three primary states: unaware susceptible(UN), aware susceptible(AN), aware informed(AY). And six sub-states: three active UN^m, AN^m, AY^m, three inactive UN^n, AY^n, AY^n. Without considering the dynamic changes of the edges between individuals in a multi-layer network, in order to give a mean-field analysis, all nodes in the multiplex networks need to be classified into different classes according to its degree [5,13,17]. The $N(k, l)$ represent the number of nodes with degree k in information capability layer and degree l in quality information layer. Then the number of three primary states at time t are represented as $UN(k, l, t)$, $AN(k, l, t)$, $AY(k, l, t)$, and $\rho^{UN}(k, l, t)$, $\rho^{AN}(k, l, t)$, $\rho^{AY}(k, l, t)$ as their density respectively, for example $\rho^{UN}(k, l, t) = {}^{UN(k,l,t)}/_{N(k,l)}$. Obviously, we have the equations that $\rho^{UN}(k, l, t) + \rho^{AN}(k, l, t) + \rho^{AY}(k, l, t) = 1$. Given that the number of individuals connected to node i with good information capability is g ($g \leq k$) and the number of individuals who have access to high quality products is h ($h \leq l$) at time t. During time Δt, for individual i there are: the probabilities of node i to stay in good information capability state is $(1 - \lambda\Delta t)^g$, stay in good information capability state but not identifying high quality products is $\left(1 - \beta^A \Delta t\right)^h$, stay in low information capability state and low quality perception state is $\left(1 - \beta^U \Delta t\right)^h$.

The probabilities that node i has g ($g \leq k$) good information capability neighbors and h ($h \leq l$) good quality information neighbors at time t are

$$N_i^A(g, h, t) = C_k^g \theta_1(k, l, t)^g [1 - \theta_1(k, l, t)]^{k-g} \tag{3}$$

$$N_i^N(g, h, t) = C_l^h \theta_2(k, l, t)^h [1 - \theta_2(k, l, t)]^{l-h} \tag{4}$$

where $\theta_1(k, l, t) = \sum_{k'} P\left(k'|k\right)\left[\rho^{AS}\left(k', l, t\right) + \rho^{AI}\left(k', l, t\right)\right]$ represents the approximate probability of a given link of node i with degree (k, l) to connected to an individual with superior information capability at time t, and $P\left(k'|k\right)$ is the degree–degree correlations function in the product information capability communication layer. $\theta_2(k, l, t) = \sum_{l'} P\left(l'|l\right)\rho^{AI}\left(k, l', t\right)$ represents the approximate probability of a given link of node i with degree (k, l) to connected to an individuals who have informed about quality products information at time t. $P\left(l'|l\right)$ is the degree correlations distribution function of the quality information dissemination layer.

The probabilities for the individual i who does not have good information capability not being informed denoted by r_i. The probabilities for the individual i who has good information capability not getting the quality products denoted by q_i^A. The probabilities for the uninformed individual i not being affected with an informed individual denoted by q_i^U. And then we can get the probability trees, see Fig. 1, to reveal the possible states and their transitions.

Then, the transition probabilities of active node, for all possible values of g and h are:

$$r_i^m = \sum_{g=0}^{k} C_k^g \left(1-\lambda\Delta t\right)^g \theta_1\left(k,l,t\right)^g \left[1-\theta_1\left(k,l,t\right)\right]^{k-g} \tag{5}$$

$$q_i^{A,m} = \sum_{h=0}^{l} C_l^h \left(1-\beta^A\Delta t\right)^h \theta_2\left(k,l,t\right)^h \left[1-\theta_2\left(k,l,t\right)\right]^{l-h} \tag{6}$$

$$q_i^{U,m} = \sum_{h=0}^{l} C_l^h \left(1-\beta^U\Delta t\right)^h \theta_2\left(k,l,t\right)^h \left[1-\theta_2\left(k,l,t\right)\right]^{l-h} \tag{7}$$

Because inactive individuals are only affected by active individuals, the transition probabilities of inactive node are:

$$r_i^n = \sum_{g=0}^{k} C_k^g \left(1-\lambda\Delta t\right)^g \left[\alpha\theta_1\left(k,l,t\right)\right]^g \left[1-\alpha\theta_1\left(k,l,t\right)\right]^{k-g} \tag{8}$$

$$q_i^{A,n} = \sum_{h=0}^{l} C_l^h \left(1-\beta^A\Delta t\right)^h \left[\alpha\theta_2\left(k,l,t\right)\right]^h \left[1-\alpha\theta_2\left(k,l,t\right)\right]^{l-h} \tag{9}$$

$$q_i^{U,n} = \sum_{h=0}^{l} C_l^h \left(1-\beta^U\Delta t\right)^h \left[\alpha\theta_2\left(k,l,t\right)\right]^h \left[1-\alpha\theta_2\left(k,l,t\right)\right]^{l-h} \tag{10}$$

From Eqs. (5)–(10) we can get the transition probabilities of three primary states are, see Fig. 1:

$$r_i = \alpha r_i^m + \left(1-\alpha\right) r_i^n = \alpha\left[1-\lambda\Delta t\theta_1\left(k,l,t\right)\right]^k + \left(1-\alpha\right)\left[1-\alpha\lambda\Delta t\theta_1\left(k,l,t\right)\right]^k \tag{11}$$

$$q_i^A = \alpha q_i^{A,m} + \left(1-\alpha\right) q_i^{A,n} = \alpha\left[1-\beta^A\Delta t\theta_2\left(k,l,t\right)\right]^l + \left(1-\alpha\right)\left[1-\alpha\beta^A\Delta t\theta_2\left(k,l,t\right)\right]^l \tag{12}$$

$$q_i^U = \alpha q_i^{U,m} + \left(1-\alpha\right) q_i^{U,n} = \alpha\left[1-\beta^U\Delta t\theta_2\left(k,l,t\right)\right]^l + \left(1-\alpha\right)\left[1-\alpha\beta^U\Delta t\theta_2\left(k,l,t\right)\right]^l \tag{13}$$

Hence, the rate of change in three primary states during $[t, t+\Delta t]$ are

$$\begin{aligned} UN\left(k,l,t+\Delta t\right) &= UN\left(k,l,t\right) - UN\left(k,l,t\right)\left(1-r_i\right) - UN\left(k,l,t\right)\left(1-q_i^U\right) + \sigma\Delta t AY\left(k,l,t\right) \\ &= UN\left(k,l,t\right) - \alpha UN\left(k,l,t\right)\left\{1-\left[1-\lambda\Delta t\theta_1\left(k,l,t\right)\right]^k\right\} \\ &\quad - \left(1-\alpha\right) UN\left(k,l,t\right)\left\{1-\left[1-\alpha\lambda\Delta t\theta_1\left(k,l,t\right)\right]^k\right\} \\ &\quad - \alpha UN\left(k,l,t\right)\left\{1-\left[1-\beta^U\Delta t\theta_2\left(k,l,t\right)\right]^l\right\} - \left(1-\alpha\right) UN\left(k,l,t\right)\left\{1-\left[1-\alpha\beta^U\Delta t\theta_2\left(k,l,t\right)\right]^l\right\} \\ &\quad + \sigma\Delta t AN\left(k,l,t\right) \end{aligned} \tag{14}$$

$$q(Q_1,\varepsilon_0,t+\Delta t) = \frac{1}{1+\varepsilon_0}(Q_1 - \frac{1}{1+\varepsilon_0}Q_0)/(1-\frac{1}{1+\varepsilon_0}Q_0)\frac{UN\left(k,l,t+\Delta t\right)}{N\left(k,l\right)} \tag{15}$$

$$\begin{aligned} AN\left(k,l,t+\Delta t\right) &= AN\left(k,l,t\right) + UN\left(k,l,t\right)\left(1-r_i\right) - AN\left(k,l,t\right)\left(1-q_i^A\right) - \sigma\Delta t AN\left(k,l,t\right) + \mu\Delta t AY\left(k,l,t\right) \\ &= AN\left(k,l,t\right) + \alpha UN\left(k,l,t\right)\left\{1-\left[1-\lambda\Delta t\theta_1\left(k,l,t\right)\right]^k\right\} \\ &\quad + \left(1-\alpha\right) UN\left(k,l,t\right)\left\{1-\left[1-\alpha\lambda\Delta t\theta_1\left(k,l,t\right)\right]^k\right\} \\ &\quad - \alpha AN\left(k,l,t\right)\left\{1-\left[1-\beta^A\Delta t\theta_2\left(k,l,t\right)\right]^l\right\} - \left(1-\alpha\right) AN\left(k,l,t\right)\left\{1-\left[1-\alpha\beta^A\Delta t\theta_2\left(k,l,t\right)\right]^l\right\} \\ &\quad - \sigma\Delta t AN\left(k,l,t\right) + \mu\Delta t AY\left(k,l,t\right) \end{aligned} \tag{16}$$

$$q(Q_1,\varepsilon_1,t+\Delta t) = \frac{1}{1+\varepsilon_1}(Q_1 - \frac{1}{1+\varepsilon_1}Q_0)/(1-\frac{1}{1+\varepsilon_1}Q_0)\frac{AN\left(k,l,t+\Delta t\right)}{N\left(k,l\right)} \tag{17}$$

$$\begin{aligned} AY\left(k,l,t+\Delta t\right) &= AY\left(k,l,t\right) + UN\left(k,l,t\right)\left(1-q_i^U\right) + AN\left(k,l,t\right)\left(1-q_i^A\right) - \mu\Delta t AY\left(k,l,t\right) \\ &= AY\left(k,l,t\right) + \alpha UN\left(k,l,t\right)\left\{1-\left[1-\beta^U\Delta t\theta_2\left(k,l,t\right)\right]^l\right\} \\ &\quad + \left(1-\alpha\right) UN\left(k,l,t\right)\left\{1-\left[1-\alpha\beta^U\Delta t\theta_2\left(k,l,t\right)\right]^l\right\} \\ &\quad + \alpha AN\left(k,l,t\right)\left\{1-\left[1-\beta^A\Delta t\theta_2\left(k,l,t\right)\right]^l\right\} + \left(1-\alpha\right) AN\left(k,l,t\right)\left\{1-\left[1-\alpha\beta^A\Delta t\theta_2\left(k,l,t\right)\right]^l\right\} \\ &\quad - \mu\Delta t AY\left(k,l,t\right) \end{aligned} \tag{18}$$

$$q(Q_2, \varepsilon_1, t+\Delta t) = \frac{1}{1+\varepsilon_1}(Q_2 - \frac{1}{1+\varepsilon_1}Q_0)/(1-\frac{1}{1+\varepsilon_1}Q_0)\frac{AY(k,l,t+\Delta t)}{N(k,l)} \tag{19}$$

Eqs. (14)–(17) constitute a nonlinear dynamic system, and $\rho^{AI} \ll 1$ is established when the system is in steady state. According to the mean field approximation theory, the influence of high order terms is not considered. In the limit $\Delta t \to 0$, we obtain:

$$\begin{aligned}\frac{\partial q(Q_1,\varepsilon_0,t)}{dt} &= \frac{1}{1+\varepsilon_0}(Q_1 - \frac{1}{1+\varepsilon_0}Q_0)/(1-\frac{1}{1+\varepsilon_0}Q_0)\left(-\left(2\alpha-\alpha^2\right)\lambda k\rho^{US}(k,l,t)\,\theta_1(k,l,t)\right.\\ &\left.-\left(2\alpha-\alpha^2\right)\beta^U l\rho^{US}(k,l,t)\,\theta_2(k,l,t)+\sigma\rho^{AS}(k,l,t)\right)\end{aligned} \tag{20}$$

$$\begin{aligned}\frac{\partial q(Q_1,\varepsilon_1,t)}{dt} &= \frac{1}{1+\varepsilon_1}(Q_1 - \frac{1}{1+\varepsilon_1}Q_0)/(1-\frac{1}{1+\varepsilon_1}Q_0)\left(\left(2\alpha-\alpha^2\right)\lambda k\rho^{US}(k,l,t)\,\theta_1(k,l,t)\right.\\ &\left.-\left(2\alpha-\alpha^2\right)\beta^A l\rho^{AS}(k,l,t)\,\theta_2(k,l,t)-\sigma\rho^{AS}(k,l,t)+\mu\rho^{AI}(k,l,t)\right)\end{aligned} \tag{21}$$

$$\begin{aligned}\frac{\partial q(Q_2,\varepsilon_1,t)}{dt} &= \frac{1}{1+\varepsilon_1}(Q_2 - \frac{1}{1+\varepsilon_1}Q_0)/(1-\frac{1}{1+\varepsilon_1}Q_0)\left(\left(2\alpha-\alpha^2\right)\beta^U l\rho^{US}(k,l,t)\,\theta_2(k,l,t)\right.\\ &\left.+\left(2\alpha-\alpha^2\right)\beta^A l\rho^{AS}(k,l,t)\,\theta_2(k,l,t)-\mu\rho^{AI}(k,l,t)\right)\end{aligned} \tag{22}$$

3.4. Market demand in a communication environment

According to Fig. 2, we can get the individual *UN* with poor information capability and low quality perception, the individual *AN* with excellent information capability low quality perception, the individual *AY* with excellent information capability and high quality perception. The state change rate of the three overall states at time $[t, t+\Delta t]$, can be obtained as follows:

$$q(Q, \varepsilon, t+\Delta t) = q(Q_1, \varepsilon_0, t+\Delta t) + q(Q_1, \varepsilon_1, t+\Delta t) + q(Q_2, \varepsilon_1, t+\Delta t) \tag{23}$$

According to the mean field approximation theory, the influence of high order terms is not considered. In the limit $\Delta t \to 0$, we obtain:

$$\frac{\partial q(Q,\varepsilon,t)}{dt} = \frac{\partial q(Q_1,\varepsilon_0,t)}{dt} + \frac{\partial q(Q_1,\varepsilon_1,t)}{dt} + \frac{\partial q(Q_2,\varepsilon_1,t)}{dt} \tag{24}$$

In economic behavior, increasing the consumer's early understanding of the product quality will motivate the consumer to purchase the product. For example, the quality of the brand LV package is actually better than most of the similar products on the market. Under this premise, it is important to improve consumers' understanding of the brand LV package. At the same time, LV officially expands the coverage of product advertising to enhance the information capability of consumers. And all of these can increase the sales of LV bags. The consumer's information perception and the high quality perception will gradually change the consumer's product needs when they come to a certain extent. In this process, the needs of the enterprise will change. At this time, the income expression of the enterprise is:

$$G(Q, \varepsilon, t+\Delta t) = q(Q, \varepsilon, t+\Delta t)*(1-Q) \tag{25}$$

4. Numerical simulations

For consumers, the improvement of quality perception and the improvement of consumer's quality perception will have a certain impact on the demand of the market. These two kinds of information perception are different in terms of communication capability, so we need to separately study the impact of these information dissemination on market demand. In the simulation analysis, we fixed the information capability and compared the market demand of different consumer's quality perception. In the same way, we fixed the consumer's quality perception and compared the market demand of different information capability.

We use scale-free network generation algorithm to build the multiplex networks. The number of nodes in multiplex networks is 10 000, the information capability layer $m = 6$ and the quality perception layer $m = 3$. Each point in the grid 100*100 of the figure is obtained by averaging 50 numerical simulations.

From Fig. 2 we can find: (1) The improvement of the consumer's quality perception can promote the increase of market demand. (2) Different information capability are different for the market demand change process. When the consumer's quality perception is weak, the market demand for products is less affected. However, when the consumer's quality perception transmission rate is greater than 0.125, the impact of the consumer's quality perception dissemination on market demand starts to make a difference. (3) When the consumer's information capability is at a low level, the higher the consumer's quality perception, the faster the market demand response; (4) The stronger the transmission of information capability among consumers, the weaker the impact of consumer's quality perception dissemination on market demand for sales. That is to say, in today's information explosion society, consumers' information capabilities are generally stronger. Therefore, the role of improving consumer market demand through the dissemination of consumer's quality perception is gradually decreasing.

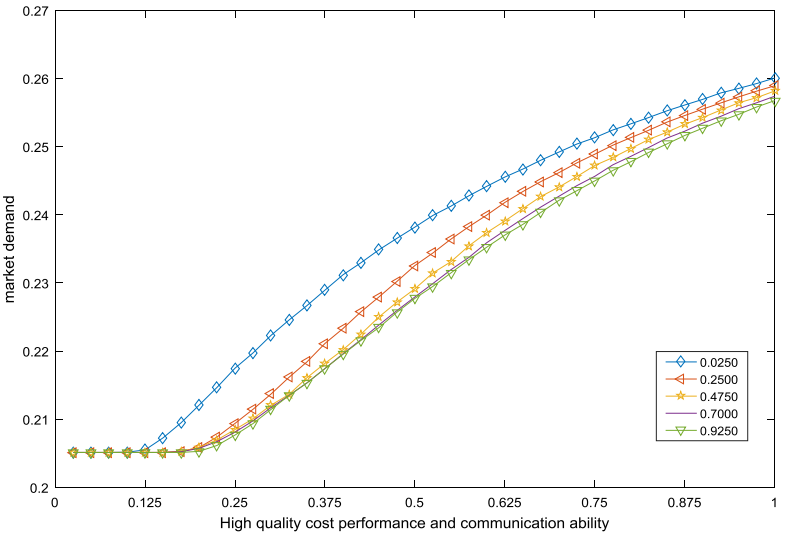

Fig. 2. Under the condition of constant information capability, the market demand changes of different consumer's quality perception. Dynamical parameters: the information capability layer forgotten rate $\delta = 0.4$, the quality perception layer returned rate $\mu = 0.6$, the information capacity increase stimulus rate $\phi = 0.5$, the individual behavior rate $\alpha = 1$.

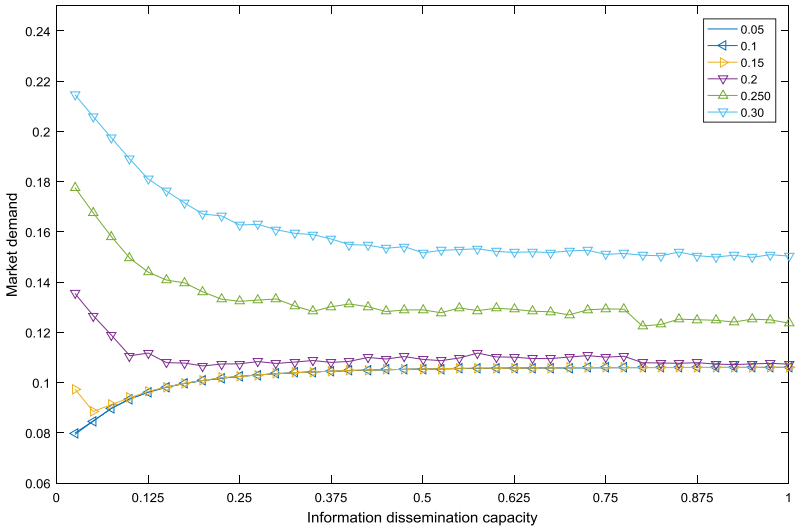

Fig. 3. Under the condition of constant consumer's quality perception, the market demand changes of different information capability. Dynamical parameters: the information capability layer forgotten rate $\delta = 0.4$, the quality perception layer returned rate $\mu = 0.6$, the information capacity increase stimulus rate $\phi = 0.5$, the individual behavior rate $\alpha = 1$.

As can be seen from Fig. 3, when the consumer's quality perception is determined, the influence of different information capability of consumers on market demand is quite different in the consumer market. Mainly reflected in the following three points: (1) When the dissemination efficiency of consumer's quality perception is low, the market demand increases as the information capability transmission rate increases. (2) When the consumer's quality perception is lower than 0.15, the market demand begins to decline first and then rises as the efficiency of information capability increases. (3) When the consumer's quality perception is greater than 0.15, the market demand shows a gradual decline with the increase of the information capability transmission rate. However, the market demand corresponding to the high consumer's quality perception is higher than the low consumer's quality perception.

As shown in Fig. 4, when the consumer's product information capability transmission rate is equal to 0.2, the market demand rate change trend caused by the product quality level of the same product quality information capability is different: (1) When the consumer's quality perception transmission rate is lower than 0.17, there is no difference in market demand for different product quality levels. That is, when the consumer's market perception capability is insufficient, it is not feasible to increase the consumer's demand by improving the consumer's quality perception performance. (2) When

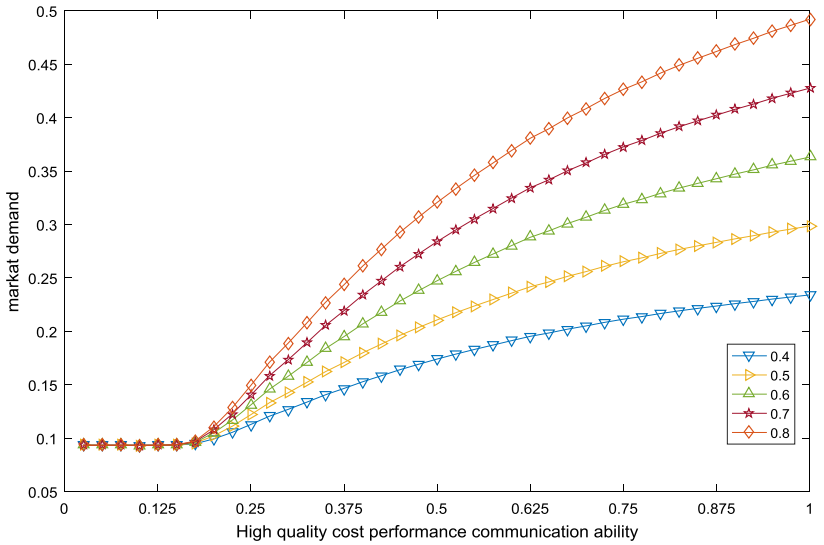

Fig. 4. Under the condition of constant consumer's quality perception, the market demand changes of different quality levels. Dynamical parameters: the information capability layer forgotten rate $\delta = 0.4$, the quality information layer returned rate $\mu = 0.6$, the information capacity increase stimulus rate $\phi = 0.5$, the information capability layer spreading rate $\lambda = 0.4$.

the consumer's quality perception transmission rate in the market is greater than 0.17, the higher the product quality level, the higher the final market demand. That is, when the market high-quality product recognition transmission rate is greater than 0.17, different product quality levels can be selected to enhance the market demand.

5. Conclusion

In order to increase market demand, firstly enterprises need to enable consumers in the market to improve their information capability about products (The quality information of products can be transmitted via the Internet). Under this premise, we will increase the consumer's quality perception and maximize the market demand for our products. The changes in information capability can affect consumer's market behavior, which effectively spread in social networks. That is to say, network communication affects the behavior of different consumers in turn. So companies can take action in order to achieve higher market profits. These market actions require additional investment and can be studied by using relevant theories in network science. For example, research on how to invest can rapidly improve consumer's information perception, and thus increasing market demand.

In addition, by increasing the consumer's quality perception (such as discounts), it can also promote the demand of the market. There are some consumers in the market who are keen to find high quality products (such as seeking discounts on supermarkets, which is quite common in supermarkets in Switzerland). These consumers are also willing to spread the quality information to consumers who have an intersection with themselves. Therefore, it can be said that enterprises can also increase the market demand by providing high quality products. Based on the study of the impact of information capabilities on consumer market demand, this paper analyzes the changes in consumer perception and consumer information capabilities that communicate with surrounding groups. In this paper, we construct a two-layer model through the knowledge of network science, and study the overall evolution of market demand under the joint effect of consumer information perception and quality perception. From the simulation experiment, the following conclusions can be drawn

(1) Consumers' perception of information and quality in social networks have affected market demand to some extent.

(2)Consumer perceptions of information and quality in social networks have a significant impact on market demand. In general, increasing the speed of information dissemination will increase market demand. However, when consumers' quality perception transmission rate is low, market demand is often suppressed.

(3) For the seller, the higher consumer's perceived quality will increase the final demand in the market under this steady state. However, when the market information capability is insufficient, which is to say, when the market information capability transmission rate is less than 0.17, the improvement of the consumer's quality perception performance will not affect the market sales volume. Therefore, in this case, the company does not need to improve the quality of production.

This work is the first article to combine the dissemination of information capabilities with the knowledge of network science. In subsequent studies, other characteristics of information capabilities in social networks can be considered. And the hypothesis can better represent the changing process of consumer information capabilities and then better describe

the market demand. At the same time, it can also be studied from a market activity perspective, such as how companies are advertised on social networks to maximize their promotion at the lowest cost. In addition, it can study the relationship between the interests and inputs of social activities and the changes in consumer information capabilities, and analyze the optimal investment in the entire market. These aspects can be an important direction for future research.

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