Evolutionary Game Analysis of Supply and Demand under Customization Model

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Abstract. This paper uses evolutionary game theory to analyze the supply and demand game and the diffusion of customization products in social networks (taking small world networks and scale-free networks as examples). It finds out that buyers and sellers concurrently choose customized products or ordinary products is a stable evolution strategy. The diffusion of customized products and ordinary products in small world networks or scale-free networks can reach a stable state. In these two types networks, the centrality of nodes has a significant positive impact on buyers' decision to choose customized products. Strengthen new work externality is beneficial to the diffusion of customized products.

Keywords: Customization, Supply and Demand, Evolutionary Game, Network Externality.

1. Introduction

Supply-side reform is hot in China in currently. The customization model is regarded as an important means of supply-side reform. Mass customization can improve the quality and efficiency of the supply system to meet the rising consumer demand better. Compared with the traditional model, this model can bring the following benefits to consumers :(1) consumers can obtain products with fresh and clear personal characteristics that better match their preferences (color, size, pattern, style, etc.), so that their personality can be fully expressed; (2) consumers can obtain pleasure or a sense of achievement by participating in the design and manufacture of products[1]. In this business model, sellers face two strategies: offering customized products to consumers and offering ordinary products. So, how should sellers choose or arrange for these two products? How will customized products and ordinary products spread among consumers? At present, few researches analyze this question from the perspective of evolutionary game. The existing research on personalized customization mode mainly focuses on the business model of personalized customization[2,3], the method of personalized customization[4,5], and the influencing factors of customers' purchase intention under the personalized mode [6,7].Based on evolutionary game theory and social network simulation experiments, this paper explores the evolution of supply and demand under personalized customization mode, and provides theoretical support and practical suggestions for the supply-side reform in related fields.

2. Game of Supply and Demand Evolution

This section discusses the game of supply and demand evolution. There are two types of players in the market: the seller of the product and the buyer. This article assumes that the seller either offers a customized product or an ordinary product, rather than both. In other words, the seller has to make a choice between these two products. A buyer also chooses only one product, either a customized product or an ordinary product. Common products cost is assumed as 0. The game situation between the buyer and the seller is shown in Table 1.

In Table 1, b represents the seller's revenue from selling common products, a_1 represents the additional revenue from selling personalized products, and c represents the additional cost of producing personalized products, $b + a_1 - c > 0$. d represents the buyer's return on the ordinary product, and a_2 represents the additional utility of the personalized product. The ratio of sellers and buyers choosing personalized products at the initial moment is x and y, $x \in [0,1]$, and $y \in [0,1]$, respectively.

Table 1. Return matrix of supply and demand game

		buyers	
		Personalized products (y)	Common products (1-y)
The seller	Personalized products (x)	b+a_1-c, d+a_2	-c,0
	Common product (1 – x)	0, 0	b, d

According to the revenue matrix, the expected revenue of personalized products (U_{s1}) and ordinary products (U_{s2}) provided by the seller are as follows:

$$U_{s1} = (a_1+b-c)*y-c*(1-y); U_{s2} = (1-y)*b$$

The average seller's return is: $Us = x * Us1 + (1-x) * Us2$.

According to the replication dynamic equation, the change rate of personalized products selected by the seller is:

$$\begin{aligned} \frac{dx}{dt} &= x(U_{s1} - \overline{U_s}) \\ &= x * \big(xc(1-y) - y(1-x)(a_1+b-c)\big) - \big(c + b(x-1)\big)(1-y) \end{aligned} \quad (1)$$

Similarly, the expected return of buyers for personalized products (U_{b1}) and ordinary products (U_{b2}) is as follows:

$$U_{b1} = (d + a_2) * x; U_{s2} = d * (1-x)$$

The average return of buyers is:

$$U_b = y * U_{b1} + (1-y) * U_{b2}$$

The speed of change for the buyer to choose to provide personalized products is

$$\frac{dy}{dx} = y(U_{b1} - \overline{U_b}) = y\big(d(x-1)(1-y) + x(a_2+d) - xy(a_2+d)\big) \quad (2)$$

By setting equations (1) and (2) equal to 0, we can obtain five equilibrium points for solving the system :(0,0), (0,1), (1,1), $E(x^*, y^*)$. Where $x^* = d/(a_2 + 2d), y^* = (b + c)/(a_1 + 2b), x^* \in (0,1)$, $y^* \in (0,1)$.

For the dynamic evolution of a system described by differential equations, the stability of its equilibrium point can be determined by the characteristics of the jacobian matrix[8]. The jacobian matrix of the system can be obtained by taking the partial derivatives of equations (1) and (2) with respect to x and y respectively:

$$J = \begin{bmatrix} (c\text{-}2xb+1)(y-1) + (y\text{-}2xy)(a_1+b-c), & x(a_1+b-b(x-1)-x(a_1+b)) \\ y(a_2+d-d(y-1)-y(a_2+d)), & (x\text{-}2xy)(a_2+d)-d(x-1) \end{bmatrix}$$

By using the determinant of jacobian matrix and the positive and negative traces to judge the stability of the five equilibrium points, the results are shown in Table 2:

Table 2. Stability of equilibrium points

Break-even point	Sign of det(J)	Sign of tr(J)	conclusion
A(0,0)	+	—	stable(ESS)
B(0,1)	+	+	unstable
C(1,0)	+	+	unstable
D(1,1)	+	—	stable(ESS)
E(x^*,y^*)	—	0	saddle point

As can be seen in Table 2, there are two stable evolution strategies in the game of supply and demand under the personalized customization mode: both the buyer and the seller choose customized products (1,1) or both choose ordinary products (0,0). The evolution path of the whole supply and demand game is shown in Figure 1.

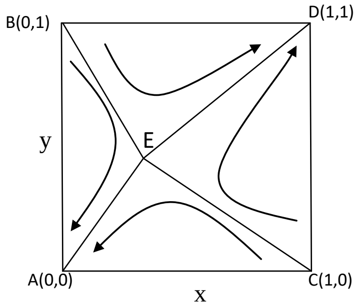

Figure 1. Evolution path of supply and demand game

In Figure 1, E is the saddle point, namely the threshold point of the whole system, whose coordinates are $x^* = d/(a_2 + 2d)$, $y^* = (b + c)/(a_1 + 2b)$. If the proportion of buyers choosing personalized products at the initial moment is greater than x^*, that is, when $x > d/(a_2 + 2d)$, $U_{b1} - U_{b2} = x(a_2 + 2d) - d > 0$,it means, at this time buyers will choose personalized products for a better return by buying personalized products rather than ordinary products. Conversely, when $x < d/(a_2 + 2d)$, $U_{b1} - U_{b2} < 0$, buyers will buy ordinary products. Similarly, when the initial proportion of sellers choosing to provide personalized products at the initial moment is bigger than $y*$, sellers tends to sell personalized products because of greater benefits, and vice versa. Therefore, the polyline BEC in Figure 1 is the borderline of the whole system. When the initial state of supply and demand of personalized products falls into the ABEC region, the system will eventually evolve to the point $A(0,0)$.If the initial state falls into the BECD region, the system will eventually evolve to point $D(1,1)$.For personalized sellers, trying to increase the proportion of customers who initially choose personalized products in the market will help them eventually gain a larger market share.

3. Evolutionary Games on Social Networks

3.1 Game Model

Recent years, social networking tools such as WeChat and MicroBlog have became important channels for product promotion. There are network externalities in social networks where consumers refer to their friends' purchases when deciding to buy a product[9].Therefore, the strategy of a member node in the network can be regarded as the result of the interactive game between the member and their friends. Combined with the specific situation of the personalized mode, we propose the return matrix as shown in Table 3. Returns in the matrix Value represents the benefit of node member i under the corresponding policy combination.

Table 3. Game return matrix of network node members

		Node member j	
		Personalized products	Common products
Node member i	Personalized products	$s + e + a + \theta i \triangle ci$	s
	Common products	$s - e$	s

In this paper, node i in the network should consider the choice of personalized products and common products of all his friends, that is, to game with all his friends according to the return matrix shown in Table 3. In different periods, node i can choose different strategies based on the purchase of its friends, that is, different product types are selected at different stages to meet social needs[10].

We make s the basic return that consumers get when they buy a common product. When both nodes i and j choose common products, the revenue of node i is $s+e_1$, where e_1 is the network externality strength of common products[11].When the node j chooses personalized product and node i chooses common product, the different choices of the two nodes will bring some negative effects to node i, that is, the negative effect of network externalities[12] .Therefore, in this case, the return s-e of node i, where e is the network externality strength of personalized products. When node i chooses personalized products and its friend node j chooses ordinary products, the revenue of node i is $s-e_1+a$, and a represents the additional revenue brought by personalized products to the buyer. When both nodes i and j choose personalized products, the revenue of node i is $s + e + a + \theta_i \triangle c_i$, where c_i represents the customer integration capability of node i. Customer integration capacity is a unique concept in the mode of personalized customization, which refers to the skills that customers need to cooperate with the seller smoothly and effectively to meet their own needs in the value-added process of product customization [13]. $\theta_i \triangle c_i$ represents an improvement in the ability to interact with nodes j that also chooses personalized products,$\triangle c_i = \text{Max}\,\{0, c_j - c_i\}$. θ_i represents the absorption capacity of node i, and $\theta_i \in [0,1]$.

Whether node i adjusts the strategy depends on the comparison of the total return under the two strategies. The condition for node i to select the customized product is:

$$\sum_{j\in\Omega i} U_{ij}^{a} - \sum_{k\in\Omega i} U_{ik}^{b} > 0 \tag{3}$$

In the formula (3), Ω_i represents the set of friends of node i, U_{ij}^{a} represents the game revenue between node I and node j when they selected personalized product, U_{ij}^{b} represents the return of the game between node i and node k while selecting the common product, U_{ij}^{a}, $U_{ij}^{b} \in \{U_{i1}, U_{i2}, U_{i3}, U_{i4}\}$. If formula (3) does not hold, then node i adjusts its strategy and selects ordinary products.

At different times, because buyers choose different strategies, two products occupy different market shares, there are different diffusion cases. The diffusion rate of the two products is calculated by the following formula:

Diffusion rate of personalized products = number of buyers choosing personalized products/total number of buyers in the network *100%;

Diffusion rate of common products = number of buyers choosing common products/total number of buyers in the network *100%.

3.2 Simulation Experiment

In recent years, researchers have found that social network is neither regular network nor completely random network through theoretical or empirical studies on a large number of social networks, but belonging to small world networks or scale-free networks with large average clustering coefficient and small characteristic path length [14]. Therefore, based on the small world network and scale-free network, this section analyzes the diffusion of customized products and common products on social networks. The diffusion of the two products is based on the game rules described in section 3.1the Simulation Program is Written Using Matlab Software.

Let's set the number N of nodes in both networks to 1000. For the initialization of small world network, set the number of friends of each node as 3, and the probability of disconnection and reconnection is 40%. For scale free networks, set the initial number of nodes to 3, adding 3 nodes each time. Let $s = 0.5, a = 0.2$, c_i and θ_i be generated randomly. The network externality strength e of personalized products is set as 0.1 and $e1 = 0.6e$.The initial ratio of buyers using both strategies is set at 1:1, that is, 50% of buyers choose personalized products and 50% of buyers choose ordinary products. The simulation program runs for 10 periods. The diffusion of the two products is shown in Figure 2 and Figure 3.

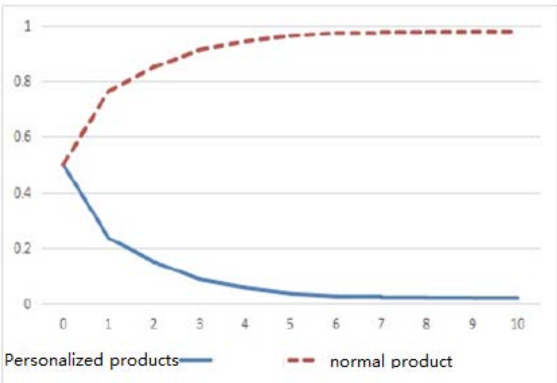

Figure 2. The diffusion of two products in the small world network

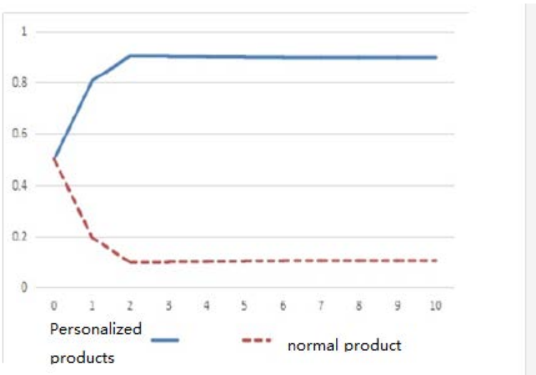

Figure 3. The diffusion of two products in scale-free network

It can be seen from Figure 2 and Figure 3 that after 10 games, the diffusion of the two products in the two networks has reached a basically stable state, but the opposite situation appears in the diffusion. In the small world network, common products become the mainstream choice. In scale free networks, personalized products account for the vast majority of the market.

The feature of scale free network is that the degree distribution of nodes is power-law distribution, that is, a few main nodes are connected with a large number of nodes in the network. Such characteristics make these main nodes have to game with a large number of nodes in the network, thus obtaining more reference information. In such cases, these primary nodes more able to discover the value of personalized products, and thus more likely to choose personalized products. Therefore, we propose:

Corollary: the centrality of nodes in scale-free networks has a significant positive effect on the selection of personalized products by node buyers.

To prove this inference, we construct the following logistic regression model:

$$ln\frac{p}{1-p}=\beta_0+\beta_1\,deg\,r\,ee+\beta_2 c+\beta_3\theta \tag{4}$$

In equation (4), degree represents the center degree of the node, c is the customer integration ability of the node, and θ is the absorption ability of the node. We take the data of game 1 in scale-free network as an example to test. In phase 1, the strategy of choosing personalized products was set as 1, and that of choosing ordinary products was set as 0. The regression sample size was 1000. The regression results are shown in Table 4:

Table 4. Logistic regression results of scale-free network

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	degree	.576	.216	7.108	1	.008	1.779
	c	.040	.287	.020	1	.888	1.041
	θ	.087	.216	.164	1	.686	1.091
	Constant	-.137	.219	.391	1	.532	.872

It can be seen from Table 4 that the significance sig of degree, the independent variable representing the degree of node centrality, is less than 0.01, that is, the degree of node centrality has a significant positive impact on the selection of personalized products by buyers. Other nodes in the scale-free network may be influenced by these core nodes and thus follow the selection of personalized products [10]. The main characteristics of the small world network are high clustering coefficient and low feature path length. The high clustering coefficient means that the local connections of the network are relatively close, which may lead to the loss of core nodes in the whole network, thus leading to the lack of leading and radiation effect. This is why a higher percentage of buyers choose personalized products on scale free networks than on small world networks.

We also performed logistic regression on the diffusion of two products in the small-world network and obtained similar regression results. The results are shown in Table 5. Therefore, whether it is scale free network or small world network, the centrality of nodes will significantly affect buyers' choice of personalized products.

Table 5. Logistic regression results of small world network

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	degree	.263	.079	11.155	1	.001	1.301
	c	-.848	.524	2.621	1	.105	.428
	θ	-.294	.377	.607	1	.436	.745
	Constant	-3.334	.619	29.009	1	.000	.036

The above analysis is based on the situation of the same number of consumers who initially choose personalized products and ordinary products. Figure 4 and Figure 5 show the different proportion of consumers who initially choose two products and the diffusion of personalized products in the two networks. In the Figures, p represents the proportion of consumers who choose personalized products. It can be seen from these two Figures that, regardless of the initial proportion of personalized products, ordinary products will eventually become the mainstream choice in the small-world network, while personalized products will occupy the majority share in the scale-free network.

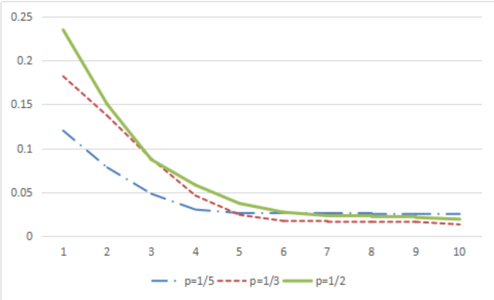

Figure 4. The diffusion of personalized products with different initial proportion in small world network

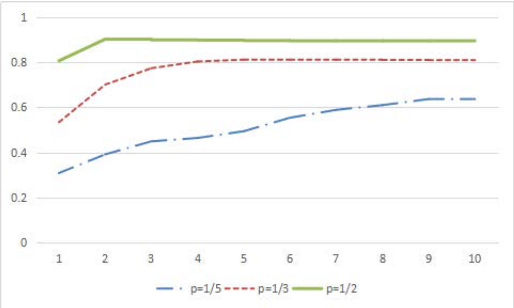

Figure 5. The diffusion of personalized products with different initial proportions in scale free networks

The effect of network externalities is an important reason why buyers get different benefits when they take different combinations of strategies. We then analyze the influence of network externality strength *e* of personalized products on game evolution, taking the diffusion of personalized products in small-world networks and scale-free networks as an example. Let's take 0.1, 0.2 and 0.3 for e, program 10 was run to obtain the diffusion of personalized products in two networks under 3 values of e according to the evolutionary game mechanism proposed above, as shown in Figure 6 and Figure 7.

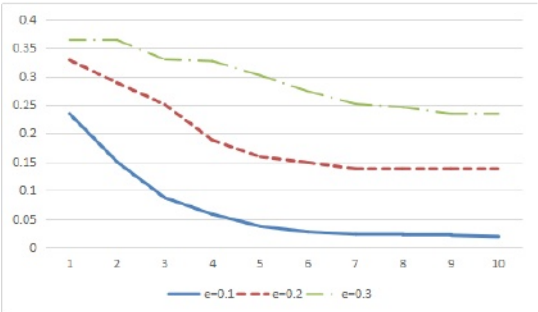

Figure 6. The diffusion of personalized products under different network externalities (small world network)

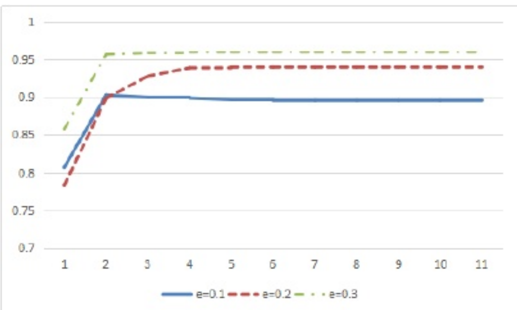

Figure 7. The diffusion of personalized products under different network externalities (scale free network)

As can be seen from Figure 6, in the small-world network, the proportion of buyers choosing personalized products basically increases with the increase of network externality strength *e*. When *e*=0.3, after the system evolution is basically stable, the proportion can be maintained at around 22%. In the scale free network shown in Figure 7, the proportion of buyers choosing personalized products was the highest when *e*=0.3, stabilizing at about 96%. Thus, the increase of network externality intensity is conducive to the diffusion of personalized products.

4. Conclusion

This paper analyzes the game evolution between buyers and sellers under the personalized customization model. Taking the small world network and scale-free network as examples, this paper also analyzes the diffusion of personalized products and ordinary products in social networks. In the personalized customization mode, both the evolutionary game of supply and demand and the diffusion of products in the social network can reach a stable state. Consumers' choice of personalized products is influenced by network type, network node centrality and network externality strength. Different from existing studies that analyze consumers' purchase intention of personalized products based on perceived value, perceived ease of use, perceived risk, perceived interest and other factors[6,7], this paper finds out new factors that influence customers' purchase intention from the perspective of network structure and network effect. Therefore, in theory, the findings of this paper are an important supplement to the research on the influencing factors of consumers' purchase intention of personalized products. Based on the theoretical findings, at the practical level, in order to promote the development of personalized customization model and make it an important means of supply-side reform, at the level of system design, measures should be taken to encourage sellers to conduct personalized customization practice, so as to increase the proportion of sellers providing personalized services. Set the benchmark in the industry, through the promotion of successful cases to provide personalized sellers to bring positive incentives. In terms of marketing, consumers with high degree of node centrality in social networks should become important target groups for personalized customized services. Corresponding strategies should be developed to give play to the demonstration, radiation and driving effect of network central node, and publicity should be increased to improve the strength of network externality. In order to guide consumers to make personalized customization, the difference in quality or value brought by personalized customization mode should be highlighted. These differences can be reflected in the product's utility value, uniqueness value, self-expression value, as well as the interest of customized process and creative achievement.

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