Hindawi
Mathematical Problems in Engineering
Volume 2022, Article ID 5605883, 10 pages
https://doi.org/10.1155/2022/5605883

Research Article

Dual-Channel Pricing of Online Retail Based on Evolutionary Game Theory and Coevolutionary Algorithm

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Received 18 January 2022; Revised 14 February 2022; Accepted 5 April 2022; Published 28 April 2022

Academic Editor: Gengxin Sun

For the offline market entry strategy and product pricing of online retailers in the retailer competitive supply chain structure, a supply chain game model composed of a single manufacturer, a single traditional retailer, and a single online retailer is constructed and an improved coevolutionary game algorithm (ICGA) is proposed to solve the model. In addition, a dynamic optimization model based on dissatisfaction is established to dynamically adjust the coevolutionary game algorithm. The research shows that when online retailers open offline channels, with the increase of offline market share of online retailers, the profits of traditional retailers decrease and manufacturers increase, while the profits of online retailers increase first and then decrease; there is a maximum point. The profits of online retailers, manufacturers, and supply chains will be optimized due to the opening of offline channels. When the offline market share of online retailers is lower than a specific threshold, the new offline channels of online retailers will also make the profits of traditional retailers greater. At this time, the profits of all members of the supply chain will be optimized. Finally, the final optimization stability strategy can make the offline retail and online retail achieve the best operation state, and the overall theoretical rate of supply chain has been significantly improved, which proves the effectiveness and superiority of the proposed model and algorithm.

1. Introduction

Along with e-commerce development, product sales have gradually changed from a single channel to dual-channel sales model, which inevitably leads to service and price competition among channels [1]. This paper will study the price game of dual-channel supply chain based on service quality and delay decision, explore the impact of decision variables on system stability, analyse the impact of system stability on the evolution trend of price game, and realize the effective control of unstable system [2].

Service competition between manufacturers and retailers and price competition between dual channels are the main competition modes; the equilibrium strategy of competition between manufacturers and retailers is an important content of research [3]. In particular, under the influence of different disturbances and multiple demands, retailers service competition and service cost sharing mechanism are more studied [4]. In the price competition between manufacturers and retailers, retailers pay more attention to fairness. It will consider the impact of fairness on service level and product retail price in decision-making. In addition, the optimal service and pricing strategies in the form of noncooperative game are different, which is determined by the decision-making objectives [5]. Even if the game form is the same, the difference of influencing factors in the game process will lead to different equilibrium strategies, such as different consumer loyalty to products or channels, different types of products sold in two channels (homogeneous products or complementary products), and different risk aversion behaviours of manufacturers and retailers; these will have an impact on the price and service. In addition, manufacturers and retailers take profit as target in the process of noncooperative game, but the different Bo status will also affect the pricing and service strategy. Different decision sequences not only affect the pricing and service strategy, but also affect the evolutionary behaviour, bullwhip effect, and coordination mechanism of the system [6]. The existing research results on service and pricing lay the foundation for the construction and analysis of this model [7].

On the one hand, it is about the research on online and offline channel selection strategies from the perspective of manufacturers, and part of the literature studies the influencing factors of manufacturers' new online sales channels. Literature [8] found that manufacturers' opening online channels will exacerbate their conflict with dual channel retailers. At this time, manufacturers should encourage retailers to sell products through revenue sharing contracts. Literature [9] considered online channels and studied the pricing strategy. At the same time, some scholars have studied retail model of online retailers [10]. Literature [11] put forward the concept of Omni channel retailer sales model and analysed the impact of Omni channel strategy on product demand, channel strategy, and member profit. Literature [12] studied the impact of consumers' channel migration behavior on retailers' revenue through the channel strategy of "online purchase and offline pick-up." Literature [13] research showed that when there are great differences in products from different channels, retail enterprises can increase their own income by choosing the coexistence of online and offline sales. Literature [14] discussed the impact of channel operating costs and customer behavior on retailer channel selection and found that dual channel is the best choice only when the operating costs of different channels are not different. Literature [15] studied the equilibrium pricing decisions of retail enterprises in three cases: pure offline physical stores, pure online stores, and dual channel sales. Literature [16] discussed the impact of opening network channels in traditional physical stores on the operation cost of online and offline channels through an e-commerce for men's clothing. Literature [17] discussed the impact of offline experience stores on consumer behavior and retailer profits. It is found that opening offline experience stores will aggravate the inventory risk of offline channels.

In fact, many factors such as channel cost, compensation mode, and coordination mechanism affect the choice of channels by both upstream and downstream sides of the supply chain. Literature [18] established game models with manufacturers as the main body and e-commerce distributors as the main body and found that manufacturers' choice of distribution channels is mainly affected by the cost of distribution channels. Literature [19] found that retailers need to give manufacturers a certain compensation cost in order to solve the dual marginal effect of dual channels and realize the coordination. Literature [20] proposed that the coordination mode of price compensation or cost sharing between manufacturers and retailers is conducive to supply chain optimization. Literature [21] found that the income distribution mechanism of network channels is the key factor to coordinate channels. Literature [22] established a game model according to the demand function of dual channels and found that manufacturers can achieve channel coordination by adjusting pricing, but this coordination way will damage the interests of manufacturers. Literature [23] established a dual channel supply chain revenue model with retailers as the main body and found that the uncertainty of demand will affect channel pricing. Literature [24] established the demand function related to price and demand, compared the optimal pricing problem under the manufacturer Stackelberg game and the manufacturer retailer Bertrand game, and found that the manufacturer in the Bertrand game decision-making mode has the highest price. Literature [25–31] mainly constructed a closed-loop supply chain network equilibrium model based on the dynamic competition of retail enterprises and studied the behavior and equilibrium conditions of manufacturers, retailers, and demand market. It is hoped that the construction of dynamic competitive supply chain network equilibrium model of retail enterprises can provide theoretical reference for the management and operation of retail enterprises in market competition. The main contributions of this paper are summarized as follows: (1) the offline market entry strategy and product pricing of online retailers in the competitive supply chain structure of retailers are studied, and a supply chain game model composed of a single manufacturer, a single traditional retailer, and a single online retailer is established; (2) to solve the above problems, an improved coevolutionary game algorithm (ICGA) is proposed, and a dynamic optimization submodel based on dissatisfaction is established to dynamically adjust the coevolutionary game algorithm; (3) this paper uses evolutionary game and coevolutionary algorithm to solve the disadvantages of the original pricing model and improve the overall profit margin.

This paper considers the impact of channel cost distribution and income distribution on channel selection behaviour, establishes model of manufacturers and retailers that more comprehensively reflects the actual situation, and analyses the impact of various influencing factors on the channel selection behaviour. On this basis, under the dual channel strategy, this paper analyses the impact of arrival payment time. This research is helpful for supply chain members to reasonably choose dual channels and formulate the optimal price strategy under dual channels.

2. Problem Formulations and Dual-Channel Supply Chain Model

2.1. Structure of Online Retailer's Dual-Channel Supply Chain. This paper considers establishing a two-stage supply chain model composed of a manufacturer and a retailer. The manufacturer is responsible for product R&D and manufacturing. The retailer can buy products from the manufacturer and sell them in the market through distributors or directly buy products and sell them in the market through the manufacturer's network channels. However, because the manufacturer or retailer will have a certain impact on the distributor after choosing the network channel, the distributor must be compensated accordingly. Through the above description, we can lead to the problem studied in this paper: how manufacturers and retailers choose the most suitable sales channel and set the price of products. The following basic assumptions are put forward.

Aiming at the enterprise practice of e-commerce enterprises opening offline physical stores and considering the factors of product price competition of traditional retailers in the market, this paper constructs a supply chain game model. The specific structure is shown in Figure 1.

Hypothesis 1. The manufacturer's probability of adopting dual channel strategy is p, and the probability of adopting traditional channel strategy is $1-p$. The probability of retailers adopting dual channel strategy is q, and the probability of adopting traditional channel strategy is $1-q$.

Hypothesis 2. M is the income of manufacturers and retailers after selecting network channels. Where the manufacturer's income is αM, if $0<\alpha\leq 1$, the retailer's income is $(1-\alpha)M$. M_M and M_R are the profits of manufacturers and retailers in traditional channels, respectively.

Hypothesis 3. C is the compensation cost to the distributor after the manufacturer or retailer selects the network channel. If both manufacturers and retailers choose dual channels for sales and purchase, the compensation cost to distributors needs to be divided through negotiation. If the compensation cost paid by the manufacturer is sufficient and $0<\beta\leq 1$, the compensation cost paid by the retailer is $(1-\beta)C$. It needs to bear all the compensation costs to the distributor, that is, $\beta = 1$; conversely, $\beta = 0$.

When manufacturers bring new products to the market, they use the novelty seeking psychology of some consumers to set a high price to meet the demand level of the public. This is the so-called skimming pricing strategy, which is a smart pricing strategy. Because various consumers have different incomes and different consumption psychology, they have different needs for products, especially for new products. Consumers with innovative psychology are always willing to try new products first, making full use of the psychological characteristics of consumers. In this paper, the online retailers and offline retailers will adopt the two-tier retail pricing model. In addition, fully consider the offline retail behavior of online retailers.

2.2. Design of the Supply Chain Pricing Model. In addition, in order to simplify the analysis process, it is assumed that the cross price elasticity coefficient is equal $(f_t = f_d = f_r = f)$ and the manufacturer's production cost per unit product is 0. Therefore, the demand function of each channel in the two cases can be obtained. When online retailers open offline physical stores, the demand of each channel is

$$\begin{aligned} D_{t2} &= (1-\alpha)(1-\beta) - P_{t2} + f_d P_{d2} + f_r P_r, \\ D_{d2} &= \alpha - P_{d2} + f_t P_{t2} + f_r P_r, \\ D_r &= (1-\alpha)\beta - P_r + f_t P_{t2} + f_d P_{d2}. \end{aligned} \tag{1}$$

The manufacturer first determines the wholesale price of products provided to traditional retailers and online retailers. The profit functions of the three are

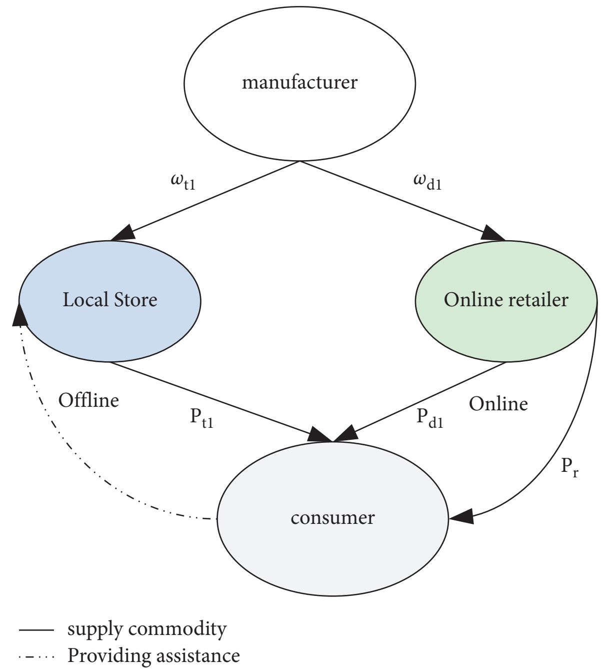

Figure 1: The structure diagram of online retailer's dual-channel supply chain.

Table 1: The system parameter table.

Parameter	Content
f	Cross price elasticity coefficient
α	Acceptance of network channels
ω_{ti}	Retailer wholesale price
P_{ti}	Retailer channel retail price
P_r	Retail price of offline store
D_{di}	Online channel demand
Π_{ti}	Retailer profit
Π_{mi}	Manufacturer profit
c	Production costs
β	Proportion of online retailers
ω_{di}	Wholesale price of online retailers
P_{di}	Online channel retail price
D_{di}	Retailer channel demand
D_r	Offline channel demand
Π_{di}	Online retailer profit
Π_{si}	Overall profit of supply chain

$$\begin{cases} \Pi_{t2} = (P_{t2} - \omega_{t2})D_{t2}, \\ \Pi_{d2} = (P_{d2} - \omega_{d2})D_{d2} + (P_r - \omega_{d2})D_r, \\ \Pi_{m2} = (\omega_{t2} - c)D_{t2} + (\omega_{d2} - c)(D_{d2} + D_r). \end{cases} \tag{2}$$

Symbols and descriptions involved in the model are shown in Table 1.

3. Research on Improved Coevolutionary Game Algorithm (ICGA)

3.1. Research on Cooperative Progress Algorithm. Because coevolution algorithm emphasizes the evolution and cooperation among multiple populations, it can be regarded as the

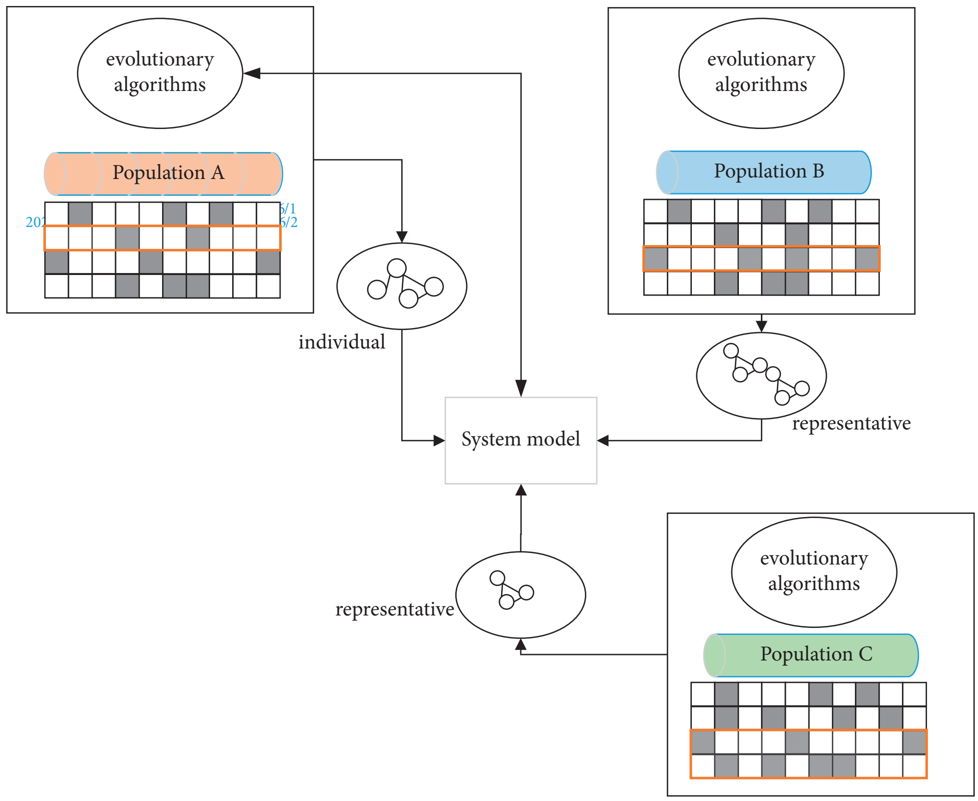

Figure 2: Framework figure of coevolution algorithm.

process of dynamic selection decision-making and interaction among different populations, which is the research content of game theory. The dynamic mechanism of population evolution and the coordination mode between populations that coevolution algorithm needs to build can be built by game theory, especially the theory of evolutionary game. The coevolution algorithm decomposes the complex system into a series of interacting subsystems. Each subsystem corresponds to a population in the ecosystem. The evolution process of these populations is isolated from each other; that is, individuals only cross operate with other individuals in the population, and all species interact through a common system model and complete the overall evolution of the ecosystem.

Figure 2 illustrates the coevolutionary algorithm of three species. Each species evolves independently in its own population through the evolutionary algorithm and cooperates with each other by selecting the method representing the common system model. For species, when evaluating individual fitness, its contribution to the whole system problem needs to be calculated. Therefore, the calculation results are selected from species and species to get the total results. The evolutionary process among species is the same. Through their own evolution and cooperation, the fitness of the whole system has been continuously improved. Of course, the evolutionary algorithms used by each species in the figure can be more flexible, and even different evolutionary algorithms can be used.

3.2. The Improved Coevolutionary Game Algorithm. This paper proposes a coevolutionary game algorithm to solve the model. In the coevolutionary game algorithm, retailers and offline physical stores as game participants generate two populations, which are recorded as P1 and P2 in the initial population, respectively. There are a certain number of individuals in each population. Individuals record the decision vector and the population to which they belong. P1 and P2 take u1 and u2 as benefit objectives, respectively. The population game structure is shown in Figure 3.

In evolutionary game, each individual is randomly selected from the group and plays the repeated game. It is assumed that each individual participating in the game has only limited rationality. When two individuals in the group meet, they play for the same resource. Let two individuals $x \in P_i$ and $x\prime \in P_j$ meet and play the game in the benefit maximization game problem. The payment function obtained by x is as follows:

$$\text{payoff}(x)\begin{cases} \dfrac{u_i(x) - u_{i\min}}{u_{i\max} - u_{i\min}}, & i = j, \\ \\ \dfrac{\left(u_i(x) - u_j(x')\right) - \left(u_{i\min} - u_{j\max}\right)}{\left(u_{i\max} - u_{j\min}\right) - \left(u_{i\min} - u_{j\max}\right)}, & i \neq j. \end{cases} \quad (3)$$

$u_{i\min}$ represents the smallest value in the population $u_i(x)$; $u_{i\max}$ represents the largest value in the population $u_i(x)$.

Let the number of variables of the problem to be optimized be N1, and divide the N1 variables into n modes:

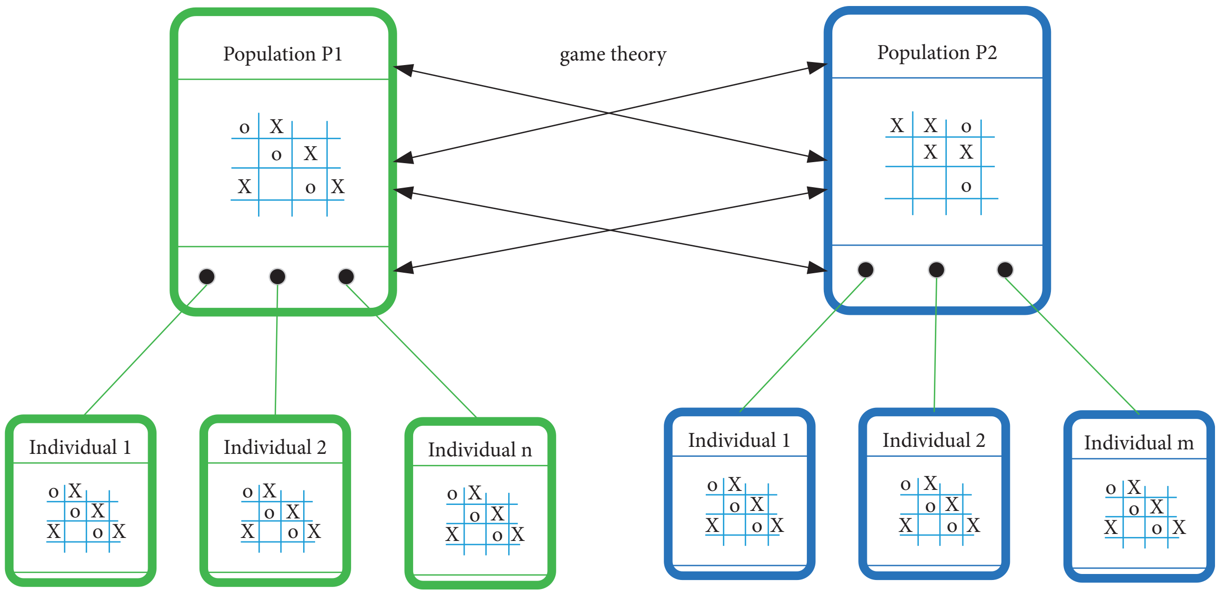

Figure 3: Structure of the ICGA pricing model.

$$M_i = \{x_1^i, x_2^i, \ldots, x_r^i\},$$
$$x_j^i \quad j = 1, 2, 3, \ldots, r. \tag{4}$$

Then, generate the initial population corresponding to each pattern in the following way; that is, create a random real number matrix of $m \times r$, where m is the number of individuals in the population and r is the number of variables contained in the pattern. Because each mode corresponds to the partial solutions of the problem to be optimized, these partial solutions need to be combined into the complete solution of the original problem. Firstly, an individual is randomly selected from the population corresponding to each model, and then the selected individuals are paired to form a complete solution, which is regarded as the individual of the random matching set. A random matching set is generated in this way. Furthermore, calculate the individual fitness of each random matching set, and then select the best individual as the elite strategy.

Information transfer mode is a neighbor migration mode. Note that the ith random matching set RC_i is used to transfer information as S_i. The set of information it receives is G_i. There is the following information transfer formula:

$$S_i = \{m_1^i, m_2^i, \ldots, m_M^i\}$$
$$G_i = S_i \cup S_{i+1}. \tag{5}$$

It is worth noting that before the evolutionary game begins, the game status between network retailers and physical stores changes flexibly and finally gets the best scheduling decision.

The implementation flow of ICGA is shown in Figure 4.

The implementation flow of ICGA can be expressed as follows: (1) for the optimization problem, the variables of the problem are divided into several patterns, and then the population of each pattern is initialized; (2) in the first iteration, the individual fitness is not calculated, and the genetic operation is not performed. The random matching set is directly generated from the initial population of each pattern, and each pattern corresponds to a random matching set; (3) calculate the fitness, and form the elite strategy set according to the calculated fitness value; (4) if the accuracy of the fitness value of the optimal individual in the elite strategy set meets the convergence requirements or has reached the maximum evolutionary algebra, the solution of the problem is output; (5) the information is transferred between the random matching sets, and the reference set corresponding to each pattern is generated. At the same time, the elite strategy set is decomposed according to the pattern, and the decomposed individuals are transmitted back to the population corresponding to each pattern to generate a new population. Then, the fitness value of the individuals in the new population is calculated by the reference set and genetic operation is carried out.

4. Simulation Results and Performance Analysis

In the experimental part, this paper analyses the reliability and superiority of the algorithm from three angles. (1) Analyse the characteristics of the two channel models under different parameters. Verify the advantages of the dual channel model. (2) Verify the effects of different population distribution probabilities on the results of evolutionary game. (3) Compared with CGA algorithm, the advantages of ICGA algorithm are verified.

4.1. Analysis on the Impact of Offline Stores. Assuming that the parameter f in the model is 0.3 $\alpha = 0.2$, that is, when consumers are in a specific network channel preference, this paper discusses the proportion of offline market when online retailers open offline physical stores β so as to provide a reference for the offline channel expansion of online retailers and product pricing in the new channel structure. As shown

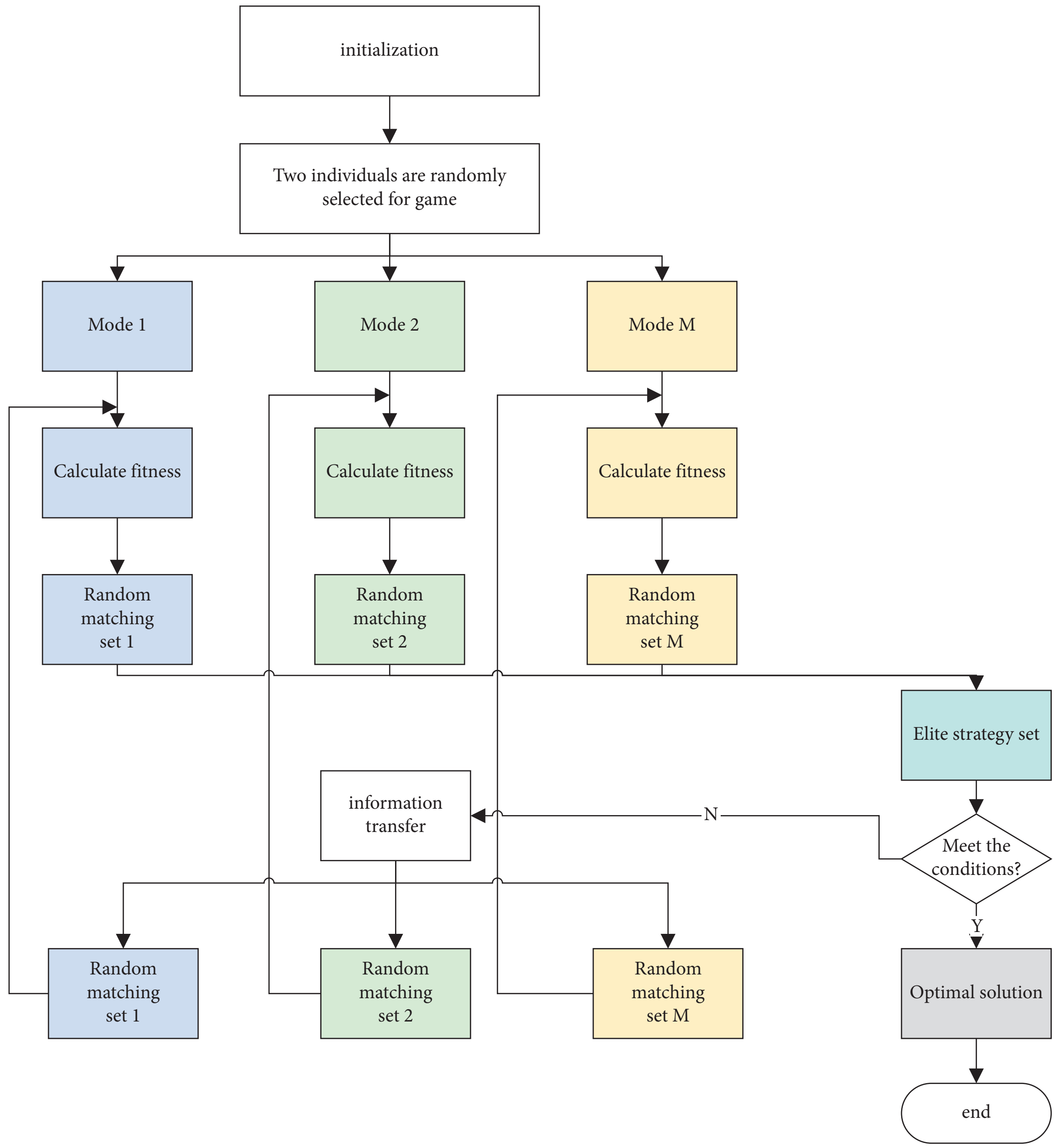

Figure 4: Implementation flow of ICGA.

in Figure 5(a), the wholesale price in the two channel structures has the following relationship. (1) Traditional channel wholesale price: when the offline market share of online retailers is relatively low, the wholesale price of traditional channel products when online retailers open offline physical stores is greater than that when online retailers do not open offline physical stores. When the offline market share of online retailers is relatively high, the new offline physical stores of online retailers will cause the wholesale price of traditional channels to be lower than the benchmark. (2) Wholesale price of online channel: when online retailers open offline physical stores, the wholesale price of online channel products is greater than that when online retailers do not open offline physical stores. With the increase of offline market share of online retailers, the gap between online channel wholesale prices in the two channel structures will continue to expand. Therefore, manufacturers should make wholesale price decisions, according to the actual market share of retailers, in order to coordinate the channel conflict between retailers.

As in Figure 5(b), the retail price in the two channel structures has the following relationship: (1) Traditional channel retail price: the zero selling price of traditional retailers when online retailers open offline physical stores is greater than that when online retailers do not open offline physical stores. When the offline market share of online retailers is relatively high, the zero price of traditional retailers is less than the benchmark when online retailers open offline physical stores. (2) Online channel retail price: when online retailers open offline physical stores, the online retail

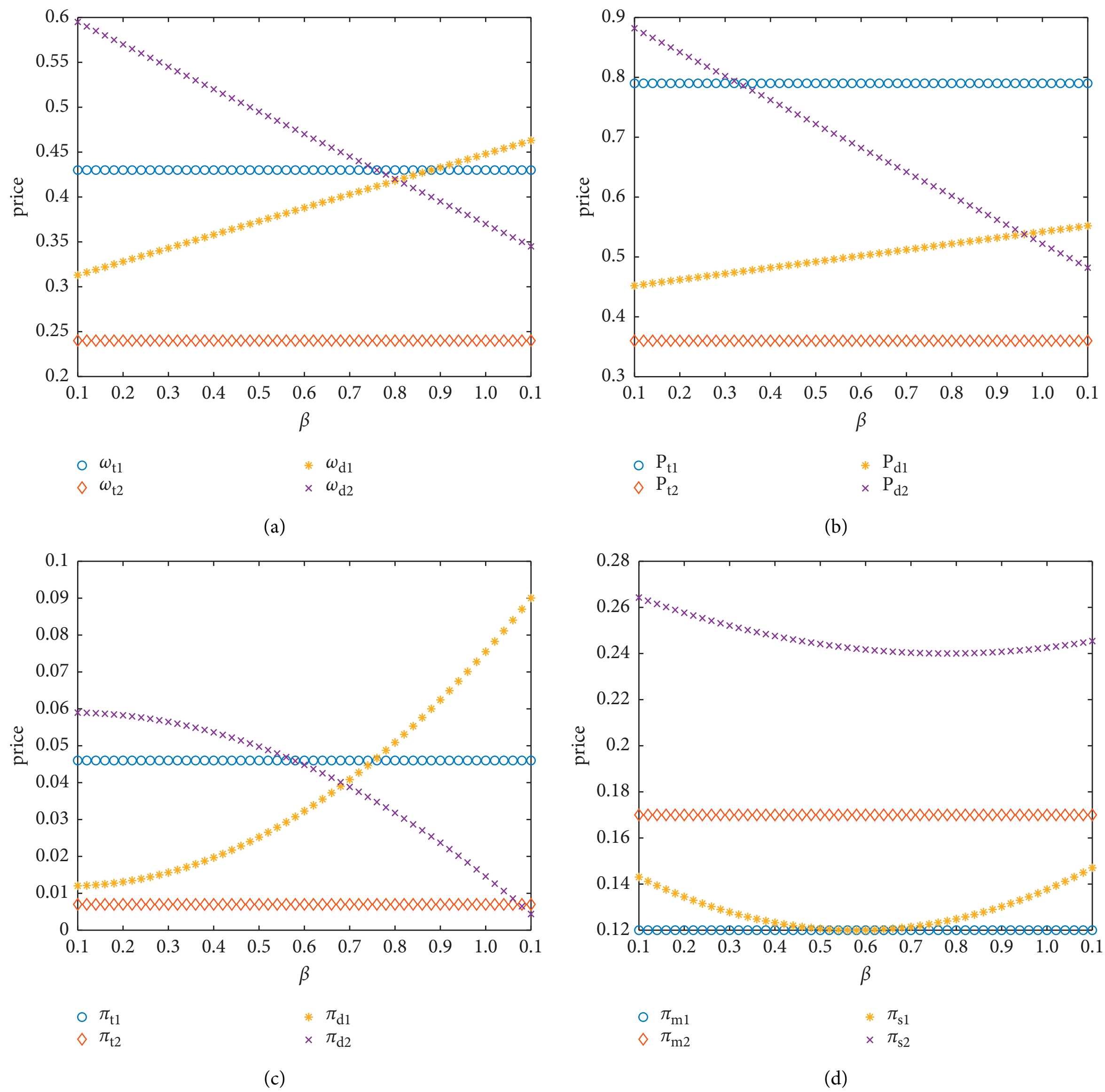

Figure 5: Comparison results of two modes. (a) Wholesale price under two modes. (b) Retail price under two modes. (c) Retail profit under two modes. (d) Manufacturer and supply chain profit.

price is greater than that when they do not open offline physical stores. With the increase of offline market share of online retailers, the gap in the two channel structures will continue to increase. Therefore, when online retailers select offline channels, they should not only consider the fixed cost of physical stores, the degree of channel competition, and consumers' network preference, but also consider how to coordinate the price competition between their own channels.

Figure 5(c) shows that there is the following relationship between retailer profits in the two channel structures: (1) Traditional retailer profits: intuitively, the new offline channels of online retailers are bound to reduce the profits of traditional retailers, but an interesting phenomenon is found according to the analysis of an example. The addition of offline physical stores by online retailers can make the profits of traditional retailers greater than the benchmark situation, and their profits will be improved. However, when the offline market share is higher than the critical threshold, online retailers opening offline physical stores will lead to continuous damage to the revenue of traditional retailers until it is less than the benchmark. (2) Profit of online retailers: the strategy of adding offline physical stores is bound to increase the total market share of online retailers. With the increase of offline market share, the profit of online retailers is greater than the benchmark situation, and its revenue is improved. It can be seen from Figure 5(d) that there is the following relationship between manufacturers and supply chain profits in the two channel structures. (1) Manufacturers' profits: when online retailers open offline physical stores, manufacturers' profits are greater than when online retailers do not open offline physical stores, and manufacturers' profits are optimized. At the same time, when online retailers open offline physical stores, the increase of offline market share of online retailers will reduce the manufacturer's profits first and then increase. The second strategy is that the manufacturer will abandon the original traditional retailer distribution channel and choose to cooperate with the online retailer with dual channel sales mode to distribute goods. (2) Profit of whole supply chain: when online retailers open offline physical stores, the profit will be greater than the benchmark situation. However, when online retailers open offline physical stores, the increase of the proportion of offline market occupied by online retailers will lead to the decrease and then increase of the profit of the supply chain.

4.2. Effects of Different Population Distribution Probabilities on the Results of Evolutionary Game. Without considering the dynamic impact of maximum dissatisfaction on population distribution probability, the above system optimization results are obtained by artificially selecting different initial population distribution probabilities and performing evolutionary games, respectively, as shown in Figure 6.

The abscissa in Figure 6 represents the distribution probability p1 of the retail population 1, that is, the proportion of the population with u1 as the benefit target in the whole population. The value is from 0 to 1 with an interval of 0.05. As shown in Figure 6, with the increase of p1, the value of retail benefit membership u1 under the final evolutionary stability decision shows an upward trend, while the value of online retail benefit membership u2 shows a downward trend. This is because in ICGA algorithm, when the number of individuals with u1 as the benefit target in the group increases, these individuals are easy to play games with other individuals in the same population in the random game process, which indirectly increases their fitness and makes u1 more advantageous than u2, resulting in the final evolutionary game result biased towards u1.

The above results show that the final evolutionary stability strategy is largely related to the initial population distribution. Therefore, the game status of online retail and offline physical stores can be changed flexibly, and finally the best scheduling decision can be obtained.

4.3. Comparative Simulation. In this paper, the dynamic characteristics of the system will be displayed so as to study the influence of the adjustment speed of decision variables on the system.

Other conditions remain unchanged. When $G2 = 0.005$, $G3 = 0.003$, $G4 = 0.00$ and changes in the interval [0.006, 0.0095], the recovery price changes of manufacturers and retailers are shown in Figure 7. When (0.006, 0.00762), the system is in a stable state. After many games, the two recovery prices are stable at 12.11 and 7.903, respectively. When $G1 = 0.00762$, the system will have the first bifurcation and then gradually fall into chaos after cycle 2 and cycle 4.

The faster the adjustment speed of the system, the more sensitive the enterprise is to the system, and the easier the market is to fall into chaos. However, the adjustment speed will affect the periodic value of the market from order to disorder. Therefore, when competing with retailers, manufacturers should not blindly increase the number of

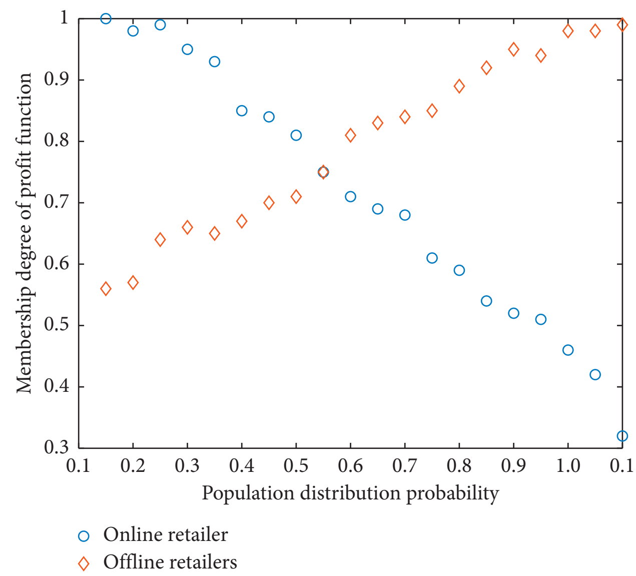

Figure 6: Influence of population distribution probability on the results of optimization strategy.

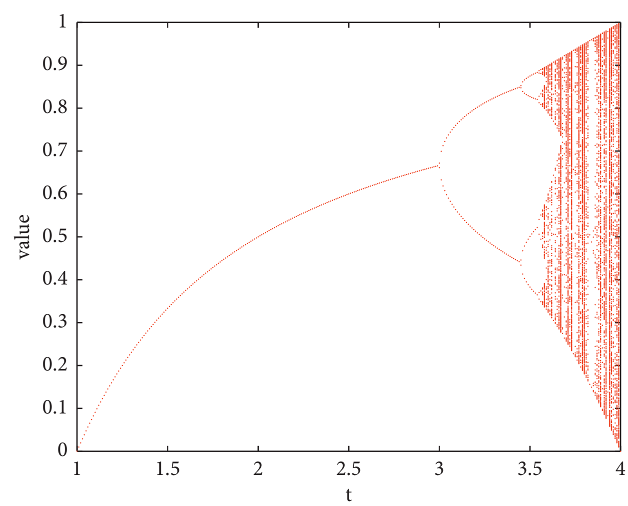

Figure 7: The structure of improved sequential pattern mining algorithm.

recycled products in order to occupy a larger recycling market share and obtain greater recycling profits. Manufacturers should not adjust the wholesale price of new products and recycled products too quickly, but should comprehensively consider the market situation and the reaction of competitors.

4.4. Comparative Simulation between ICGA and CGA. Considering the influence of the randomness of retail behavior, the distribution probability of each generation of evolutionary population is dynamically adjusted through the dynamic optimization submodel based on maximum dissatisfaction. Figure 8 shows the benefit comparison after dynamic game optimization to achieve the overall optimal operation state and their optimal operation state, respectively.

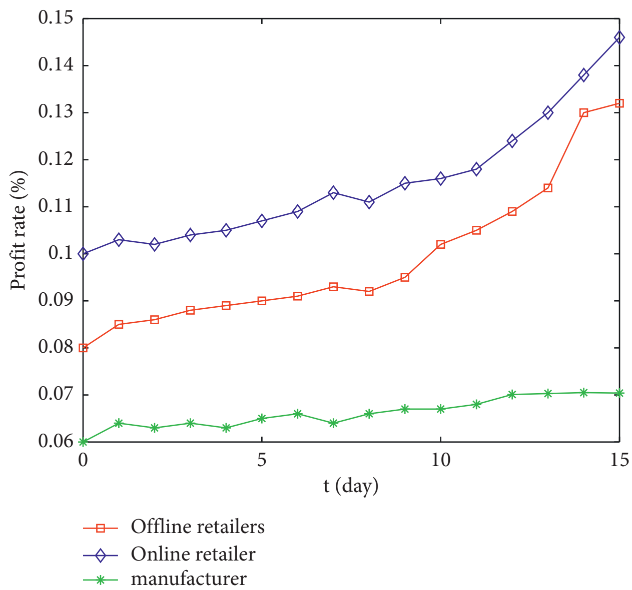

Figure 8: Profit curve of retailers and manufacturers under the ICGA strategy.

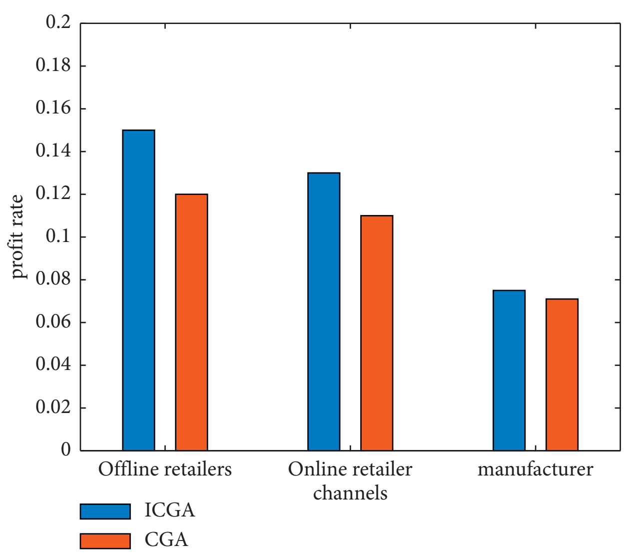

Figure 9: Profit comparison between ICGA and CGA.

Figure 8 shows the curve of profits of offline retail stores, online retail stores, and manufacturers over time. It can be clearly seen that with the passage of time, ICGA algorithm gradually tends to be optimized over time. The profits of offline retail stores, online retail stores, and manufacturers rise rapidly from the beginning and stabilize after reaching a certain peak. At this time, the system tends to be profits peaked. Furthermore, profits are between the first two states, which is a compromise value considering the interests of both sides, so that retailers and manufacturers can achieve a relatively good operation state. In addition, it can be seen from the figure that the profit margin of online retailers is significantly higher than that of offline retailers, mainly due to the labor and rental costs of offline retailers.

In order to better observe the change curve of retailer profit by adopting CGA and ICGA strategies, this paper is compared with [32] under the same conditions. The comparison results are shown in Figure 9.

It can be clearly seen from Figure 9 that adopting the improved CGA strategy for dual channel pricing can significantly improve the profit margin of the product. In particular, the pricing strategy has obvious advantages in improving retailers' profits.

5. Conclusion

This paper integrates the benefits of offline retailers and online retailers, studies their interaction, establishes a benefit model, and subjectively processes the benefit function. An improved coevolutionary game algorithm is proposed to solve the subordinate model. On this basis, considering the influence of randomness, a dynamic optimization submodel based on dissatisfaction is established to dynamically adjust game model. The results show that the proposed method can make offline retailers and online retailers play a game through maximizing their respective benefits and make dynamic optimization adjustment based on dissatisfaction. The final stability strategy can make the offline retailers and online retailers reach the best operation state, ensure the stable operation of retail sales, and maximize the profits of retailers and manufacturers. The simulation results show that the improved CGA strategy can significantly improve the profit margin of products. In particular, the pricing strategy has obvious advantages in improving retailers' profits. However, ICGA algorithm improves the complexity of the algorithm to a certain extent. After considering the supply of multiple online retailers, the coordination and interaction optimization between multiple online retailers and manufacturers is the direction of further research.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The study was supported by Graduate School, Liaoning Technical University.

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