Profits Optimization Reasearch of Dual-Channel Supply Chain Oriented to Manufacturers Online Customization and Traditional Retail

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Abstract

Under the background of "Internet +", increasing manufacturers sell standard products through retail channels and sell customized products in electronic channel. The competition about dual-channel supply, relationship between production cost and delivery time and the influences of online market acceptance, product customization attribute value, price and delivery time on online customization and traditional retail markets are considered, based on the decision variables of the price of custom and standard products and the guaranteed delivery time, the Stackelberg models are constructed respectively for the manufacturer-led and retail-led supply chain under decentralized system and the overall profits maximization of the supply chain is modeled under centralized system, the existence and uniqueness of the optimal solutions is proved by the optimization theory. The optimal decisions, market demands and enterprises profits under different systems are compared through numerical examples, the relation between the sensitivity coefficients and the optimal enterprises profits are obtained through the parameters sensitivity analysis. The idea of model construction and relevant conclusions are of reference and significance for manufacturing enterprise management practices.

Keywords: *Online customization, dual-channel supply chain, decentralized system, centralized system, game theory, profits optimization, manufacturers*

I. Introduction

With the rapid development of e-commerce and information technology, more and more manufacturers adopt the dual-channel strategy (i.e. traditional retail channels and e-direct channels) to sell products to consumers. For example, Dell, HP, IBM, apple, Nike, Estee Lauder and Uniqlo all have adopted this strategy. If the two channels sell the same products, the division of labor and positioning of enterprises are unclear, which will lead to the conflict between manufacturers and retailers in order to compete for the common target customers, thus reducing market share and corporate profits. Gilbert and other surveys [1] found that 66% of enterprises believe that channel conflict is the biggest obstacle to the development of B2C business. In order to take advantage of dual channels and reduce or avoid channel conflicts, some manufacturers sell standard products in traditional channels and customized products in electronic channels through retailers. Customers can choose the style, color, size, pattern and personalized mark of products through electronic channels. For example, as an international brand of sportswear, Nike's standard products are only sold in physical retail stores, while its NIKEiD brand is launched online. Consumers can choose and buy customized shoes with their names printed through electronic channels [2].Adidas, a Nike competitor, also launched the "miadidas" project, which allows customers to submit their personalized needs on their official website or through social networking sites [3].The research of Xiao et al.[2] and Batarfia et al.[4] shows that compared with traditional channels, e-direct channels are more effective, and customization is an important value-added service of direct channels, which can better meet customers' heterogeneous needs for product attributes. By selling standard products in traditional retail channels and customized products online, the capacity utilization rate of manufacturers can be improved, market share can be increased and the competitiveness of enterprises can be enhanced.

For the sales of standard products under two channels, most studies mainly consider price, service competition and channel coordination. Without considering the price or service level competition in channel coordination, Fruchter and Tapiero [5] use the dynamic hierarchical game theory to study the price decision of dual channel supply chain. The research shows that manufacturers can charge the same price for the two channels and the heterogeneity of customers affects the price of electronic channel and the profit of supply chain. Yao and Liu [6], Yue and Liu [7]

study the demand diffusion between the two channels, and analyze the adverse impact of online channels on retailers. Chen et al. [8]found that the manufacturer's optimal channel strategy depends on the channel environment.

Yan and Pei [9] believe that improving retail service level can reduce channel competition and improve supply chain performance. Similarly, the research of Dan et al. [10] shows that the retailer's service level directly affects the overall profit of the supply chain and the price strategy of the members of the supply chain. Zhang Xuelong et al. [11] studied the price and service level system of vertical dual channel supply chain, respectively established the demand model and profit model under the disturbance of price substitution coefficient, service level substitution coefficient, price substitution coefficient and service level substitution coefficient at the same time, and obtained the optimal profit under different output, price and service level.

In view of the price and production system of dual channel supply chain under demand or output disturbance, Huang et al. [12, 13] constructed a game model under decentralized and centralized system, and found that the optimal production plan has certain robustness under demand disturbance, and only when the market scale changes beyond a certain threshold, the production and price plan can be adjusted. In order to study the impact of delivery time on the dual channel supply chain, Hua et al. [14] studied the optimal price problem under decentralized and centralized system basing on the consideration of delivery time, and found that the customer's acceptance of online channels had a great impact on the supply chain performance. Zhu Yuwei et al. [15] put forward a pricing and demand competition strategy considering the time sensitivity of consumers, established a pricing demand model of supply chain, and analyzed the impact of the predicted value of the time sensitivity coefficient of consumers on the revenue of dual channel supply chain.

As for the coordination problem of dual channel supply chain for standard products, Chen Shuzhen and Xiong Zhongkai et al. [16] built an optimization model under the conditions of promotion-price sensitive demand and promotion compensation incentive, analyzed and compared the optimal promotion investment, promotion compensation investment and pricing strategy under centralized and decentralized system. Zhang Xuelong and Wang junjin [17] introduced two variables, price sensitivity coefficient and competition coefficient of dual channel, and respectively established three models under centralized system, decentralized system and coordination strategy. The results have shown that two-part pricing, wholesale price contracts and Shapley value method allocation contracts and other strategies can achieve supply chain coordination. Danbin and Wang Yao et al.[18] established a utility model that comprehensively considered different functional attributes of heterogeneous products, different preferences of consumers and the impact of service efforts, and proposed two-part tariff coordination strategy. In view of the substitutability of the same product in different channels and the randomness of demand in dual channel supply chain, Dan bin and Xu Guang ye [19] studied the inventory coordination problem and established the revenue sharing contract coordination model. Cao [20] analyzed the price and production optimal system of dual channel supply chain with or without demand interruption, and proposed revenue sharing contract. In order to discuss the coordination problem of dual channel supply chain of manufacturers with uneconomical characteristics of production scale, Wang Xianjia and Zhou Yaping [21] proposed the concept of coordination degree, gave the market price and overall profit under the centralized system, and put forward the wholesale price contract and revenue sharing contract under the decentralized system.

According to the above research on profits optimization and coordination strategy of dual channel supply chain, the product type considered is homogenized standard product. For the price, delivery time strategy and channel coordination of customized products provided by online channels while selling standard products in traditional channels, the main research results are as follows: Shao Xiaofeng [22] studied the coordination problem between price of customized products with uncertain demand and price sensitivity and stock of standard products, proposed a repurchase contract based on revenue sharing. On this basis, the coordination between product pricing and delivery time is further studied, and a commission contract is proposed. For mass customization strategy, Shao [23] discusses the conditions that manufacturing enterprises should meet to provide customization services. The results show that the expected profit of the supply chain system can be increased by reducing the average cost of the standard products when mass customization is introduced into the centralized system. Fornasiero [24] and others created a supply chain configuration model based on discrete event simulation for mass customization, analyzed the interdependence between supply chain participants and the consistency between coordination mode and system strategy. Xia and rajagopalan [25] studies the standardization and customization system problems including consumer heterogeneity, product diversification, customer delivery time and price of two competing enterprises. The research shows that increasing variety diversity or reducing delivery time can increase market share and edge profit. For the diversification of standard products and customized products, price system and inventory strategy under dual channels, Xiao et al.[2] and Liu Yongmei et al.[3] found that when the reserved price of retail channels

is low enough, the unit wholesale price and the retail price of standard products sold through retail channels will increase. Li et al. [26] considered the degree of consumers' preference for online channels and the assumption of consumers' sensitivity to product differentiation, constructed relevant models, and concluded: if online channels provide customized products, the price of standard products does not need to decline, the profits of supply chain members are improved due to the alleviation of vertical competition and the increase of market share. Batarfia [4] expressed the demand as a linear function of the price, delivery time and the degree of customization product differentiation of the two kinds of products, constructed the cost optimization model, and obtained the marginal profit and production batch decision of the enterprise.

It can be seen from the above that there are many related literatures and rich research results on the optimization of dual channel supply chain and contract coordination of online and offline sales of standard products, but there are few related literatures on the research of sales of standard products in traditional retail channels and customized products in online channels. Existing literature mainly considers the impact of mass customization strategies, product diversification, and delivery time factors on the price strategies and channel structure of the two types of products, but does not comprehensively consider the price and delivery time of standard products and customized products under the dual channel supply chain, and does not compare and analyze the impact of different game models on the channel structure and the profits of enterprises. In this paper, aiming at on online customization and traditional retail dual channel supply chain, comprehensively considering the influence of two kinds of product price, delivery time of customized product, custom attribute value on dual channel demand and the relationship between production cost and completion time, the Stackelberg game model dominated by manufacturer and retailer is constructed under decentralized system, and the vertical game model is constructed under centralized system. After that, we get the optimal pricing, the guaranteed delivery time of customized products and the profit of each enterprise, and further analyze the influence of each sensitivity coefficient on the profit of the enterprise. The consideration of the influencing factors of dual channel demand, the construction and derivation of the model are innovative, and the relevant conclusions can be used for reference by the relevant departments.

II. Model assumption and parameter setting

(1)　　This paper studies the profits optimization of a dual channel supply chain composed of a manufacturer and a retailer, and The channel structure is shown in Figure 1 [2, 4]. After the demand forecast, the manufacturer carries out mass production, first of all, it needs to produce core components. On the one hand, the core components are added with basic features and then converted into standard products. The standard products are sold to the retailer at the wholesale price ω and then the retailer sells them at the retail price p_r, on the other hand, the customer places an order to the manufacturer through the online direct sales channel to purchase customized products, after a certain period of time, the manufacturer adds customized features to the core components and then converts them into customized products, which are sold at a price of p_d. Manufacturers provide templates for customized products, and customers can choose several customization features, that is, the price of customized products is the same [2, 3].
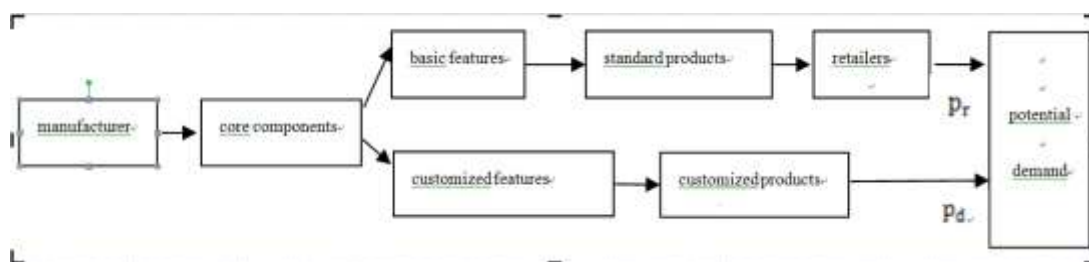

Fig.1: Dual channel supply chain structure for online customization and traditional retail

(2) Both manufacturers and retailers are risk neutral and completely rational, that is, they make decisions according to the principle of maximizing expected profits. Manufacturers and retailers can be the same or different stakeholders. When they are the same stakeholders, there is no trading relationship between them, and they make centralized decision through cooperation. When they are different stakeholders, they compete with each other in

transaction, price and delivery time. Both of them may be the leaders of the supply chain. The system process is a complete information dynamic game (i.e. Stackelberg game).

(3) Standard products can be obtained immediately, but can not meet the multi-attribute requirements of customers. Customized products can well meet the personalized needs of consumers, but there is delivery delay time, thus affecting the utility of consumers [15, 22], and that is to say, the longer the delivery time, the fewer customers will buy customized products, and some customers who originally intended to buy customized products will turn to buy standard products, making the standardized demand the largest.

(4) In addition to the influence of price and delivery time, the demand of online channel customization products is also affected by the acceptance of online customization channels and the custom attribute value of products. The acceptance of online customization channels refers to the degree of consumers' preference for online customization [2, 26], and the custom attribute value of products refers to the value generated due to the personalized characteristics of customized products [4]. When there is channel competition, the greater the consumer's preference for online customization is, the greater the custom attribute value is, and the greater the customized demand is, the smaller the standardized demand is.

The production capacity of the enterprise is higher than the market demand, so there is no penalty cost for late delivery or out of stock, and the inventory cost is not considered. From the above description, considering the channel competition between manufacturers and retailers, with reference to most of the literature[2-4,11,15-22], the demand functions of online direct sales with customized products and traditional retail with standard products are set as the following linear expression:

$$D_d = \theta a - \alpha_d p_d + \gamma p_r - \beta_d t_d + \mu_d \kappa_d \tag{1}$$

$$D_r = (1-\theta) a - \alpha_r p_r + \gamma p_d + \beta_r t_d - \mu_r \kappa_d \tag{2}$$

Among the formulas, $\kappa_d = \sum_{i=1}^{I} \lambda_i w_i$.

In the above formula, D_d represents the customized demand through online channels, and D_r represents the standardized demand through traditional retail. a is a constant and $a > 0$, representing the potential demand of the two channels. p_d stands for customized product price, p_r stands for standard product price, t_d stands for guaranteed delivery date, and κ_d stands for custom attribute value of customized product. θ indicates the consumer's acceptance of online customization channels, i.e. the proportion of demand for customized products when p_r and p_d are zero [3, 4], and $0 < \theta < 1$. $1 - \theta$ indicates the demand proportion of standard products when p_r and p_d are zero. α_d and α_r are the sensitivity coefficients of p_d and p_r to the demand of the two channels, which represent the number of decrease or increase of D_d or D_r when p_d or p_r rises or falls by one unit, and $\alpha_d > 0$, $\alpha_r > 0$. γ indicates the cross price sensitivity coefficient between different channels, and not only describes the level of mutual substitution caused by different sales prices between channels but also the competition intensity between different channels, and $0 < \gamma < \alpha_d$, $0 < \gamma < \alpha_r$. Its significance is that the impact of cross price on demand is smaller than that of the channel's own sales price so as to ensure the downward inclination of demand curve[4, 11, 16, 21]. β_d and β_r are respectively the sensitivity coefficients of t_d to D_d and D_r, indicating that when t_d increases by one unit within a certain range, the reduction quantity of customized demand is β_d, among which β_r will be converted into standardized demand, i.e. , β_r among β_d customers who are unwilling to buy customized products due to the extended delivery period will switch to standard products

(assuming that one customer buys one product) and vice versa. Referring to the hypothesis of G. Hua [14], there are: $0 < \beta_r < \beta_d$, and $\beta_d - \beta_r$ represents the loss demand of dual channel when t_d extends one unit within a certain range.

When customers purchase customized products through online channels, the guaranteed delivery time is an important factor affecting customers' decisions [24]. Combined with practice, it is assumed that for customized products, the manufacturer has the fastest delivery time and the highest production cost. If the manufacturer delivers within the fastest delivery time, the delivery time does not affect the customized demand, but the production cost reaches the maximum. Within a certain range, with the extension of production time or delivery time, the production cost will continue to decline, but there is a lower cost limit. Accordingly, the time and cost parameters related to online customization are described as follows: t represents the total time from the time when the customer places an order to the time when the customized product is delivered to the customer. t_0 is the fastest delivery time for the manufacturer to produce customized products, which is a constant. t_d refers to the extended production time on the basis of t_0 for the purpose of reducing production cost, which is a decision variable. From the above definition, we know that $t = t_0 + t_d$. Since the size of t depends on the length of t_d, t_d is assumed to be the guaranteed delivery time. c_h represents the production cost of the customized product completed by the manufacturer in t_0, which is a constant. c_l represents the lowest production cost of the customized product, which is a constant. t_l refers to the upper limit of delivery time extended by the manufacturer on the basis of t_0 in order to reduce costs, and $t_l = \left\lfloor \dfrac{c_h - c_l}{\eta_t} \right\rfloor$, where $\lfloor X \rfloor$ refers to the maximum integer less than or equal to X. When $t_d \geq t_l$, the production cost of customized products is no longer reduced. c_d refers to the actual production cost of the customized product completed by the manufacturer, assuming that c_d and t_d have a linear relationship, and

$$c_d = \begin{cases} c_h - \eta_t t_d, 0 \leq t_d < t_l \\ c_l, t_d \geq t_l \end{cases}$$

, where η_t refers to the rate of change of production cost, that is, when t_d increases or decreases by one unit, the production cost decreases or increases η_t.

Another factor influencing consumers to purchase customized products through online channels is the differentiation level of customized products [27]. The parameters of customization product differentiation level are set as follows: κ_d represents custom attribute value of the customized product, which is used to measure the differentiation level of the customized product. λ_i represents the value of the i-th customization feature of customized products, I represents the total number of customization features, and $\lambda_i > 0$, where $1 \leq i \leq I$. w_i represents the weight of the i-th customization feature, reflecting the differences of customers' preferences for different customization features, which can be determined by fuzzy comprehensive evaluation and analytic hierarchy process (AHP), and $0 < w_i < 1$. According to the above parameter settings, there is: $\kappa_d = \sum\limits_{i=1}^{I} \lambda_i w_i$.

μ_d and μ_r represent the sensitivity coefficient of κ_d with respect to D_d and D_r in turn, i.e. when κ_d increases by one unit, the increase in customized demand is μ_d, and some of them come from customers who originally intended to purchase standard products, so the demand for standard products will decrease, and the decrease is μ_r. Refer to relevant literature [4,25-26], assume that $0 < \mu_r < \mu_d$.

The other parameters are described as follows: ω refers to the wholesale price of standard products, which is a constant. c_0 is the unit processing cost of the retailer, which is a constant. Among the above parameters, a, κ_d (including λ_i, I and w_i in κ_d's expression), ω, c_h, c_l, c_0, etc., and they all are exogenous variables. The impact of their changes on relevant systems and profits is not discussed in parameter sensitivity analysis. Let π_d denote the profit of the manufacturer under the decentralized system, π_r denote the profit of the retailer under the decentralized system, π denote the overall profit of the supply chain under the centralized system. In order to make the profits of enterprises in various channels positive, there are some settings: $p_d > c_d \geq c_l$, $\omega > c_0$, $p_r > \omega + c_r$. According to the above parameter settings, π_d, π_r and π are expressed as follows:

$$\pi_d = \left(p_d - c_d \right) D_d + \left(\omega - c_0 \right) D_r \tag{3}$$

$$\pi_r = \left(p_r - \omega - c_r \right) D_r \tag{4}$$

$$\pi = \left(p_d - c_d \right) D_d + \left(p_r - c_0 - c_r \right) D_r \tag{5}$$

According to the above assumptions, the research problems are as follows: considering the competition between online customization and traditional retail channels, taking customized product price, guaranteed delivery time and standard product retail price as decision variables, and based on the change relationship between production cost and guaranteed delivery time, three problems are solved in stages: (1) Under the decentralized system, Steinberg game model is constructed with the dominant position of manufacturer and retailer respectively, and the influence of the different dominant and subordinate positions on the price system of manufacturer, retailer, channel demand and optimal profit is analyzed. (2) Under the centralized system, a vertical game model with three decision variables is constructed, and compared with various kinds of system and enterprise profit under the system. (3) Through the example and parameter sensitivity analysis, this paper describes the influence of sensitivity coefficient on the optimal decision, channel demand and profit under the decentralized and centralized system of each enterprise, and obtains relevant conclusions.

III. Model construction and analysis

3.1 Analysis of the optimal decision of each enterprise based on Steinberg game under decentralized system

If the online customization channels and the traditional retail channels compete with each other, the profit of the manufacturer can be divided into two parts: the profit obtained by selling customized products through the online channel and the profit obtained by selling standard products through the traditional retailer. For retailers, there are only profits from selling standard products. Based on Steinberg game model, if the manufacturer is dominant and the retailer is subordinate under decentralized decision, the game process is analyzed as follows: firstly, the retailer determines its response function according to the customized product price and the guaranteed delivery time, then the manufacturer makes the customized product price decision according to the retailer's response function and the guaranteed delivery time, and gets the profit function with the guaranteed delivery time as the decision variable, and the manufacturer determines the optimal guaranteed delivery time and then determines the customized product price after getting the profit function. Finally, the retailer obtains the optimal price decision of the standard product according to the response function. According to the above analysis, the model is established as follows:

$$\begin{cases} \max_{p_d,t_d} \pi_d = (p_d - c_d)(\theta a - \alpha_d p_d + \gamma p_r - \beta_d t_d + \mu_d \kappa_d) + (\omega - c_0)((1-\theta)a - \alpha_r p_r + \gamma p_d + \beta_r t_d - \mu_r \kappa_d) \\ s.t. \pi_r = (p_r - \omega - c_r)((1-\theta)a - \alpha_r p_r + \gamma p_d + \beta_r t_d - \mu_r \kappa_d) \\ \quad p_r \end{cases}$$

(6)

Proposition 1: if the online customization channels and the traditional retail channels compete with each other, the manufacturer takes the dominant position and the retailer takes the subordinate position. For the optimal guaranteed delivery time t_d^{1*}, the optimal decision of the manufacturer is p_d^{1*} and the retailer is p_r^{1*} ,they are as follows:

$$p_d^{1*} = \frac{\gamma z_2 - \beta_d + \gamma z_1 \eta_t - \alpha_d \eta_t}{2(\alpha_d - \gamma z_1)} t_d^{1*} + \frac{\theta a + \gamma z_3 + \mu_d \kappa_d + \alpha_d c_h + (\omega - c_0)(\gamma - \alpha_r z_1) - \gamma z_1 c_h}{2(\alpha_d - \gamma z_1)}$$

(7)

$$p_r^{1*} = z_1 p_d^{1*} + z_2 t_d^{1*} + z_3$$

(8)

Among them $t_d^{1*} = \{t_d | \max \pi_d(t_d), t_d \in [0, t_l]\}$.

$$z_1 = \frac{\gamma}{2\alpha_r}, \quad z_2 = \frac{\beta_r}{2\alpha_r}, \quad z_3 = \frac{(1-\theta)a + (\omega + c_r)\alpha_r - \mu_r \kappa_d}{2\alpha_r}.$$

Prove: firstly, the first and second derivative of π_r with respect to p_r are obtained:

$$\frac{d\pi_r}{dp_r} = -2\alpha_r p_r + \gamma p_d + \beta_r t_d + (1-\theta)a + (\omega + c_r)\alpha_r - \mu_r \kappa_d$$

(9)

$$\frac{d^2(\pi_r)}{d(p_r)^2} = -2\alpha_r$$

(10)

Obviously, $\frac{d^2(\pi_r)}{d(p_r)^2} < 0$ .That is, π_r has a maximum value at the extreme point. Let equation (9) be equal to zero, then get equation (8), and substitute equation (8) into the expression of π_d in equation (6), the result is as follows:

$$\pi_d = (p_d - c_h + \eta_t t_d)((\gamma z_1 - \alpha_d)p_d + (\gamma z_2 - \beta_d)t_d + \theta a + \gamma z_3 + \mu_d \kappa_d) + (\omega - c_0)$$
$$((\gamma - \alpha_r z_1)p_d + (\beta_r - \alpha_r z_2)t_d + (1-\theta)a - \alpha_r z_3 - \mu_r \kappa_d)$$

(11)

For formula (11), the first and second derivative respected to p_d are as follows:

$$\frac{d\pi_d}{dp_d} = -2(\alpha_d - \gamma z_1)p_d + (\gamma z_2 - \beta_d + \gamma z_1 \eta_t - \alpha_d \eta_t)t_d + (\theta a + \gamma z_3 + \mu_d \kappa_d + \alpha_d c_h + (\omega - c_0)(\gamma - \alpha_r z_1) - \gamma z_1 c_h)$$

(12)

$$\frac{d^2(\pi_d)}{d(p_d)^2} = -2(\alpha_d - \gamma z_1) = -\frac{2\alpha_d \alpha_r - (\gamma)^2}{\alpha_r}$$

(13)

Because $0 < \gamma < \alpha_d$ and $0 < \gamma < \alpha_r$, there is $\dfrac{d(\pi_r)^2}{d(p_r)^2} < 0$. Therefore, for a specific value of t_d, π_d has a maximum value about p_d. Let equation (12) be equal to zero, and get equation (7). It can be seen from equation (7) and equation (8) that if equation (7) and equation (8) are substituted into equation (6), the expression of π_d with respect to t_d can be obtained, but the expression is extremely complex. Considering that t_d is a positive integer in the interval $[0, t_l]$, and there are limited values of t_d, therefore In order to simplify the derivation of the formula, we can analyze the relationship between π_d and t_d in the case analysis, and then infer that there must be a certain value of t_d, which makes π_d reach the maximum. It is assumed that when $t_d = t_d^{1*}$ (t_d^{1*} can be determined by numerical analysis), π_d is the maximum value. Thus Proposition 1 is proved.

According to Proposition 1, if online customization channels and traditional retail channels compete with each other, when the manufacturer is dominant under decentralized system, the manufacturer must first determine the guaranteed delivery time based on its profit maximization, then determine the customized product price, and then the retailer determine its standard product price. If the retailer is dominant under decentralized system and the manufacturer is subordinate, the retailer must first determine the guaranteed delivery time of customized products, then the retailer determines the retail price of standard products, and then the manufacturer determines the price of customized products. In order to compare and analyze the influence of different game order on the price decision and profit of each enterprise, it is assumed that the guaranteed delivery time is determined based on the retailer's profit maximization (otherwise, the retailer's dominant position cannot be reflected). Based on Steinberg's game theory, the game process is analyzed as follows: firstly, the manufacturer obtains the response function of customized product price, then the retailer determines the functional relationship between the standard product price and the guaranteed delivery time according to the response function of the manufacturer, and the retailer obtains the optimal guaranteed delivery time based on the profit maximization, then determines the standard product price, after that the manufacturer determines the customized product price according to its response function. According to the above analysis and equations (1) to (4), the model is established as follows:

$$\begin{cases} \max_{p_r, t_d} \pi_r = (p_r - \omega - c_r)\left((1-\theta)a - \alpha_r p_r + \gamma p_d + \beta_r t_d - \mu_r \kappa_d\right) \\ s.t. \pi_d = (p_d - c_d)(\theta a - \alpha_d p_d + \gamma p_r - \beta_d t_d + \mu_d \kappa_d) + (\omega - c_0)\left((1-\theta)a - \alpha_r p_r + \gamma p_d + \beta_r t_d - \mu_r \kappa_d\right) \\ \quad p_d \end{cases}$$

(14)

Proposition 2: if the online customization channels and the traditional retail channels compete with each other and the retailer takes the dominant position and the manufacturer takes the subordinate position, for the optimal guaranteed delivery time t_d^{2*}, the optimal decision p_r^{2*} of the retailer and the optimal decision p_d^{2*} of the manufacturer are obtained as follows:

$$p_r^{2*} = \frac{\gamma x_2 + \beta_r}{2(\alpha_r - \gamma x_1)} t_d^{2*} + \frac{(1-\theta)a + \gamma x_3 - \mu_r \kappa_d - (\omega + c_r)(\gamma x_1 - \alpha_r)}{2(\alpha_r - \gamma x_1)}$$

(15)

$$p_d^{2*} = x_1 p_r^{2*} + x_2 t_d^{2*} + x_3$$

(16)

Among them $t_d^{2*} = \left\{ t_d \,\middle|\, \max \pi_r(t_d), t_d \in [0, t_l] \right\}$,

$$x_1 = \frac{\gamma}{2\alpha_d}, \quad x_2 = -\frac{\beta_d + \alpha_d \eta_t}{2\alpha_d}, \quad x_3 = \frac{\theta a + \alpha_d c_h + \mu_d \kappa_d + \gamma(\omega - c_0)}{2\alpha_d}$$

Prove: firstly, the first and second derivative of π_d with respect to p_d in formula (14) are obtained:

$$\frac{d\pi_d}{dp_d} = -2\alpha_d p_d + \gamma p_r - (\beta_d + \alpha_d \eta_t) t_d + \theta a + \alpha_d c_h + \mu_d \kappa_d + \gamma(\omega - c_0)$$

(17)

$$\frac{d^2(\pi_d)}{d(p_d)^2} = -2\alpha_d$$

(18)

Obviously, $\dfrac{d^2(\pi_d)}{d(p_d)^2} < 0$, and that is to say π_d has a unique maximum value at the extreme point. Let equation

(17) be equal to zero to get equation (16). Substituting equation (16) into the expression of equation (14) about π_r, the result is:

$$\pi_r = (p_r - \omega - c_r)\big((1-\theta)a - \alpha_r p_r + \gamma(x_1 p_r + x_2 t_d + x_3) + \beta_r t_d - \mu_r \kappa_d\big)$$

(19)

For equation (19), the first and second derivative with respect to p_r are as follows:

$$\frac{d\pi_r}{dp_r} = -2(\alpha_r - \gamma x_1)p_r + (\gamma x_2 + \beta_r)t_d + (1-\theta)a + \gamma x_3 - \mu_r \kappa_d - (\omega + c_r)(\gamma x_1 - \alpha_r)$$

(20)

$$\frac{d^2(\pi_r)}{d(p_r)^2} = -2(\alpha_r - \gamma x_1) = -\frac{2\alpha_d \alpha_r - (\gamma)^2}{\alpha_d}$$

(21)

Obviously there is $\dfrac{d^2(\pi_r)}{d(p_r)^2} < 0$, so for a specific value of t_d , π_r has a maximum value at the extreme point.

Let equation (20) be equal to zero, and equation (15) is obtained. Since t_d is a positive integer in the interval $[0, t_l]$, and there are limited values of t_d , the changing relationship between π_r and t_d can be obtained in the case analysis, and then it is deduced that there must be a certain value of t_d , which makes π_r reach the maximum. Suppose that when $t_d = t_d^{2*}$, π_r reaches the maximum value. Thus Proposition 2 is proved.

3.2 Analysis of the optimal decision of each enterprise based on the vertical game under the centralized system

For online customization and traditional retail channels, if the manufacturer and retailer become the same interest subject, then each enterprise realizes the optimal price and guaranteed delivery time decision with the goal of maximizing the overall profit. The system process is as follows: the supply chain first obtains the functional relationship between customized product price, standard product price and guaranteed delivery time, and then get the function relation between the whole profit function and the guaranteed delivery time, then make the guaranteed delivery time, and finally determine the price of customized products and standard products. According to the above analysis and formula (1) to formula (5), the vertical game model is established as follows:

$$\max_{p_d, t_d, p_r} \pi = (p_d - c_d)(\theta a - \alpha_d p_d + \gamma p_r - \beta_d t_d + \mu_d \kappa_d) + (p_r - c_0 - c_r)\big((1-\theta)a - \alpha_r p_r + \gamma p_d + \beta_r t_d - \mu_r \kappa_d\big)$$

(22)

Proposition 3: if the manufacturer and the retailer become the same interest subject, in order to maximize the

overall profit of the supply chain under the centralized system, for the optimal guaranteed delivery time t_d^{3*} , the optimal system of the manufacturer p_d^{3*} and the optimal system of the retailer p_r^{3*} are as follows:

$$p_d^{3*} = \frac{(m_2 + m_1 n_2) t_d^{3*} + m_3 + m_1 n_3}{1 - m_1 n_1}$$

(23)

$$p_r^{3*} = \frac{(n_2 + n_1 m_2) t_d^{3*} + n_3 + n_1 m_3}{1 - m_1 n_1}$$

(24)

Among them $t_d^{3*} = \left\{ t_d \middle| \max \pi(t_d), t_d \in [0, t_l] \right\}$,

$$m_1 = \frac{\gamma}{\alpha_d}, \quad m_2 = -\frac{\beta_d + \alpha_d \eta_t}{2\alpha_d}, \quad m_3 = \frac{\theta a + \alpha_d c_h + \mu_d \kappa_d - \gamma(c_0 + c_r)}{2\alpha_d},$$

$$n_1 = \frac{\gamma}{\alpha_r}, \quad n_2 = \frac{\beta_r + \gamma \eta_t}{2\alpha_r}, \quad n_3 = \frac{(1-\theta)a - \mu_r \kappa_d - \gamma c_h + \alpha_r(c_0 + c_r)}{2\alpha_r},$$

Prove: the first and second derivative or partial derivative of $\square \pi$ with respect to p_d and p_r are:

$$\frac{d\pi}{dp_d} = -2\alpha_d p_d + 2\gamma p_r - (\beta_d + \alpha_d \eta_t) t_d + \theta a + \alpha_d c_h + \mu_d \kappa_d - \gamma(c_0 + c_r)$$

(25)

$$\frac{d\pi}{dp_r} = -2\alpha_r p_r + 2\gamma p_d + (\beta_r + \gamma \eta_t) t_d + (1-\theta)a - \mu_r \kappa_d - \gamma c_h + \alpha_r(c_0 + c_r)$$

(26)

$$\frac{d(\pi)^2}{d(p_d)^2} = -2\alpha_d \quad , \qquad \frac{d(\pi)^2}{d(p_r)^2} = -2\alpha_r \quad , \qquad \frac{d(\pi)^2}{dp_d dp_r} = \frac{d(\pi)^2}{dp_r dp_d} = 2\gamma$$

(27)

The determinant corresponding to the Hesse matrix of π with respect to p_d and p_r is expressed as follows:

$$HESSE = \begin{vmatrix} -2\alpha_d & 2\gamma \\ 2\gamma & -2\alpha_r \end{vmatrix} = 4\left(\alpha_d \alpha_r - (\gamma)^2\right) > 0$$

(28)

Since the first-order determinant is less than zero and the second-order determinant is greater than zero, then π has a unique maximum value at the extreme point. Let equation (25) and equation (26) be equal to zero, and use Cramer's rule to get equations (23) and (24).

Since t_d is a positive integer in the interval $[0, t_l]$, and there are limited values of t_d , the changing relationship between π and t_d can be obtained in the case analysis, and then it is deduced that there must be a certain value of t_d , which makes π reach the maximum.

Suppose that when $t_d = t_d^{3*}$, π reaches the maximum. Thus Proposition 3 is proved. The value of each parameter should make the optimal decision, profit and dual channel demand of each enterprise greater than zero to make sure that Proposition 1 to Proposition 3 have practical significance. From Proposition 1 to Proposition 3, it can be

seen that under different system situations, the optimal price decision and profit of each enterprise have a changing relationship with the guaranteed delivery time of customized products. Because the optimal guaranteed delivery time may be different under different game situations, it is impossible to directly compare the optimal decision and profit of each enterprise under each proposition, but it can be compared, discussed and analyzed through examples.

IV. Numerical examples and sensitivity analysis of parameters

4.1 Case study

A clothing manufacturer produces a certain brand of clothing, sells standard products through traditional retail channels and customized products through electronic channels, with cloth as the core component, and completes standard products and customized products on the basis of cloth. Customized products are simplified into three heterogeneous attributes, namely style, size, pattern and logo mark. The heterogeneous attribute value weight is determined by scoring method and analytic hierarchy process (limited to space, this paper does not discuss the determination method in detail). The relevant parameters are assigned as follows: $a = 12000$, $\theta = 0.4$, $\alpha_d = 15$, $\alpha_r = 25$, $\gamma = 2$, $\omega = 180$, $c_0 = 120$, $c_r = 30$, $t_0 = 12$, $c_h = 240$, $c_l = 180$, $\eta_t = 5$, $\beta_d = 40$, $\beta_r = 20$, $\mu_d = 100$, $\mu_r = 60$, $\lambda_1 = 12$, $w_1 = 0.4$, $\lambda_2 = 10$, $w_2 = 0.4$, $\lambda_3 = 6$, $w_3 = 0.2$, $\kappa_d = \sum_{i=1}^{I} \lambda_i w_i = 10$.

According to Proposition 1 to Proposition 3, use Matlab to calculate and draw, and get Table 1 and Figure 2 to Figure 3.

Table 1 Optimal decision, channel demand and profit of each enterprise under different systems situations

System type	t_d^*	p_d^*	p_r^*	D_d	D_r	π_d	π_r	$\pi_d + \pi_r$
Decentralized system 1 (producer-led)	5	338	253	1030	1063	190843	45227	236070
Decentralized system 2 (retailer-led)	12	348	256	606	1140	170441	52293	222734
Centralized system	6	341	228	905	1695	——	——	250998
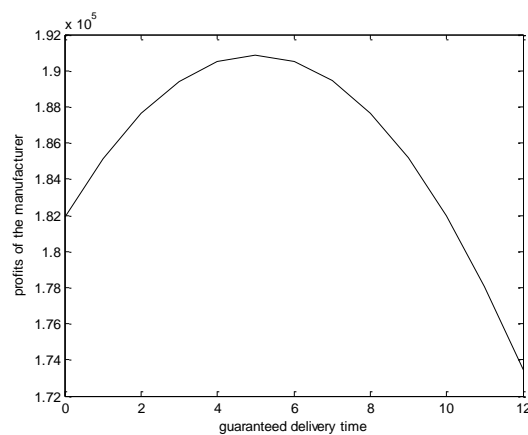
(a) The relationship between the profit of the manufacture and the guaranteed delivery time when the manufacturer dominates
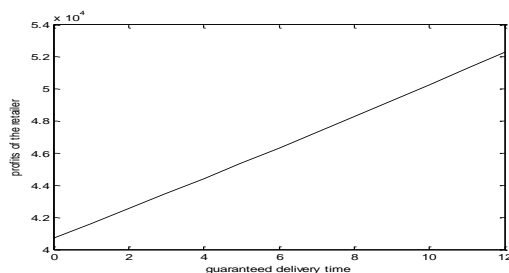
(b)The relationship between the profit of the retailer and the guaranteed delivery time when the retailer dominates

Fig.2: The relationship between the profit of the dominant enterprise and the guaranteed delivery time under the decentralized system
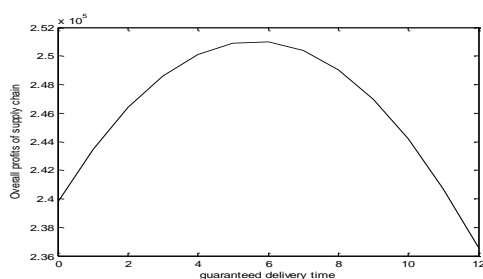

Fig.3: The relationship between the overall profits of supply chain and the guaranteed delivery time under the centralized system

It can be seen from Figure 2 (a) that under decentralized system, when the manufacturer is dominant and the retailer is subordinate, the manufacturer's profit increases first and then decreases with the increase of the guaranteed delivery time, and the manufacturer's profit reaches the maximum when $t_d^{1*} = 5$. According to table 1, the manufacturer's optimal profit value is 190,843 yuan, at this time, the optimal price of customized products is 338 yuan, the optimal retail price of standard products is 253 yuan, the customized demand and standardized demand are 1030, 1063 pieces, and the retailer's profit is 45,227 yuan.

The rule shown in Figure 2 (a) is explained as follows: with the increase of the guaranteed delivery time, according to Proposition 1, the price of online customized products and the manufacturer's unit profit are increasing. Although the demand for online customization is decreasing, the increase of unit profit exceeds the decrease of demand, so the manufacturer's profit is increasing. When the guaranteed delivery time is increased to a certain extent, the increase of unit profit is less than the decrease of demand, so the manufacturer's profit keeps decreasing. When $t_d^{1*} = 5$, the manufacturer's profit reaches the maximum.

It can be seen from Figure 2 (b) that under decentralized system, when the retailer is dominant and the manufacturer is subordinate, the retailer's profit increases approximately linearly with the increase of the guaranteed delivery time, and when $t_d^{2*} = t_l = 12$, the retailer's profit reaches the maximum. According to Table 1, the retailer's optimal profit value is 52,293 yuan. At this time, the standard product's optimal retail price is 256 yuan, the customized product's optimal price is 348 yuan, the traditional retail demand and online customization demand are 1,140 and 606 pieces respectively, and the manufacturer's profit is 170,441 yuan.

The rule shown in Figure 2 (b) is explained as follows: with the increase of the guaranteed delivery time, the retail price of standard products increases slightly according to Proposition 2. Because the standardized demand is linearly related to the guaranteed delivery time, the increase of the guaranteed delivery time makes the increase of the standardized demand exceed the decrease of the standardized demand caused by the increase of the retail price, therefore the standardized demand increases approximately linearly. As the retailer's unit profit increases slightly, the retailer's profit increases approximately linearly. Under the limitation of production cost, the maximum delivery time is 12 days, so when $t_d^{2*} = 12$, the retailer's profit reaches the maximum.

It can be seen from Figure 3 that under the centralized system, with the increase of the guaranteed delivery time, the overall profit of the supply chain increases first and then decreases. , the profit reaches the maximum when $t_d^{3*} = 6$. According to Table 1, the optimal profit of the supply chain is 250,998 yuan. At this time, the optimal price of the manufacturer is 341 yuan, the optimal price of the retailer is 228 yuan, and the customized demand and standardized demand are 905 and 1,695 pieces in turn. The rule shown in Figure 3 is explained as follows: according to Proposition 3, as the guaranteed delivery time increases, the price of customized products and the retail price of standard products increase slightly, which leads to the increasing unit profit of online customization and traditional retail .Because of the linear positive correlation between the standardized demand and the guaranteed delivery time, the standardized demand increases linearly, so the traditional retail profit increases continuously. Because of the linear negative correlation between the demand for online customization and the guaranteed delivery time, the demand for online customization decreases continuously. When t_d is small, with the increase of t_d, the profits of online customization and traditional retail channels are increasing, so the overall profit of the supply chain is increasing, With the further increase of t_d, the profit of online customization channel is decreasing, and the decline degree is larger than the increase degree of the profit the traditional retail channels, which leads to the decrease of the overall profit of the supply chain. When $t_d^{3*} = 6$, the overall profit of the supply chain reaches the maximum.

It can be seen from Table 1 when the guaranteed delivery time has been determined under different systems, the price of online customization product changes slightly, but the retail price of standard product changes a lot, set, and the price is the lowest under centralized system. The online customized demand is highest when manufacturers dominate and lowest when retailers dominate under decentralized systems. The standardized demand is highest under centralized system and lowest when manufacturers dominate under decentralized system. No matter the manufacturer or the retailer, the profit of the enterprise in the dominant position is higher than that in the subordinate position under decentralized system, but the sum of the profit of the enterprises in the decentralized system is smaller than the whole profit of the supply chain in the centralized system. The above conclusion is consistent with the reality, that is, under the decentralized system, the decision made by each enterprise to pursue its own profit maximization is most beneficial to itself, but it may be very unfavorable to the enterprise with which it has a competitive relationship, resulting in channel conflict. Under the centralized system, each enterprise takes the overall profit maximization as the goal, and the decision made is beneficial to the whole, but there are problems of contract coordination or profit distribution.

4.2 Parameter sensitivity analysis

In order to analyze the impact of parameter changes on the overall profits of enterprises and supply chain under the dual channel mode, This paper carries out sensitivity analysis (in the analysis process, only consider the change of a certain parameter within the feasible range, and the value of other parameters is the same as in example 4.1)for $\theta, \alpha_d, \alpha_r, \gamma, \beta_d, \beta_r, \eta_t$ et al.. Although the profit of each enterprise is different when the manufacturer is dominant and the retailer is dominant under decentralized system, no matter who is dominant, the profit of each enterprise has similar change rules when the same parameter changes. Due to space limitation, the following

parameter sensitivity analysis only considers the change rule of the profit of each enterprise and the overall profit of the supply chain with the relevant parameters under decentralized system where the manufacturer is dominant and under centralized system.

When the parameter changes between 0.2 and 0.6 (according to Proposition 1 to Proposition 3, if $\theta < 0.2$, there is $D_d < 0$. if $\theta > 0.6$, there is $D_r < 0$,which will not be discussed),Table 2 (decentralized decision in Table 2 refers to decentralized system led by manufacturer and followed by retailer, the same below).

Table 2 The relationship between the profit of each enterprise and θ under different systems

θ		0.2	0.3	0.4	0.5	0.6
Decentralized system	π_d	130758	137254	190843	291525	——
	π_r	183401	102694	45227	10998	——
	$\pi_d + \pi_r$	314159	239948	236070	302523	——
Centralized system	π	——	257707	250998	315923	452309

It can be seen from Table 2 that when $\theta = 0.2$, centralized system is meaningless, and when $\theta = 0.6$, decentralized system is meaningless. Between 0.3 and 0.5, with the increasing of θ, the overall profit of the supply chain under the centralized system is larger and larger, and the increasing range is larger and larger. The profit of the manufacturer does not increase while the profit of the retailer is declining under the decentralized system, which shows that with the increasing of θ,it is more and more favorable for the manufacturer while more and more unfavorable for the retailer . This is mainly due to that the larger θ is, the more market share online customization channels occupy, and the higher the price of customized products is, the more profit manufacturers earn; the smaller market share traditional retail channels occupy, the lower price standard products is, and the smaller profit retailers obtain.

When α_d (i.e. he price sensitivity coefficient of customized products) varies from 5 to 20, Figure 4 is obtained.
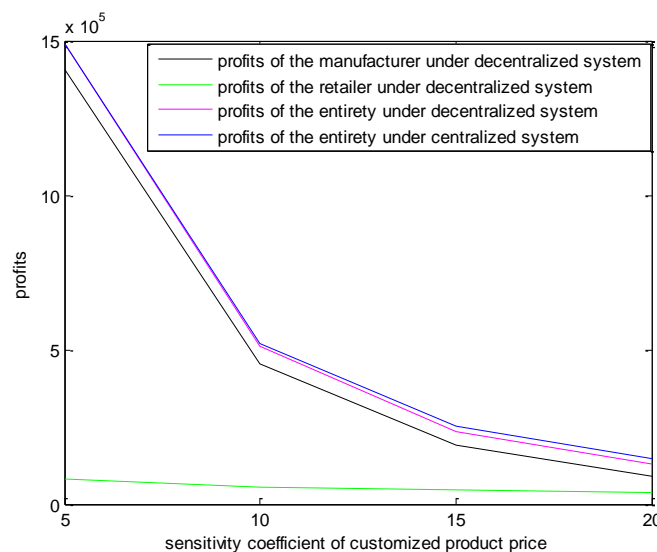

Fig. 4: The change relationship between profit and sensitivity coefficient of customized product price under
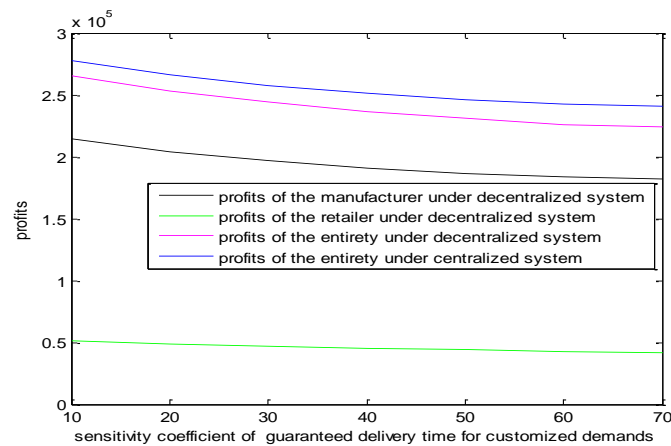
different systems

Fig. 5: The relationship between the profit of each enterprise with respect to the sensitivity coefficient of guaranteed delivery time for customized demands under different systems

It can be seen from Figure 4 that the profit of the manufacturer under the decentralized system and the profit of the whole supply chain under the centralized system keep the similar change rule with the increase of α_d, both of which decrease greatly, while the profit of the retailer decreases slowly.

Figure 5 is obtained when β_d (the sensitivity coefficient of the guaranteed delivery time for customized demands) changes between 20 and 70.

It can be seen from Figure 5 that with the increase of β_d, the change rule of the profit of each enterprise and the overall profit of the supply chain under different systems are similar, and all of them slow down.

When α_r (i.e. the sensitivity coefficient of the standard product price) changes between 5 and 35,Figure 6 is obtained.
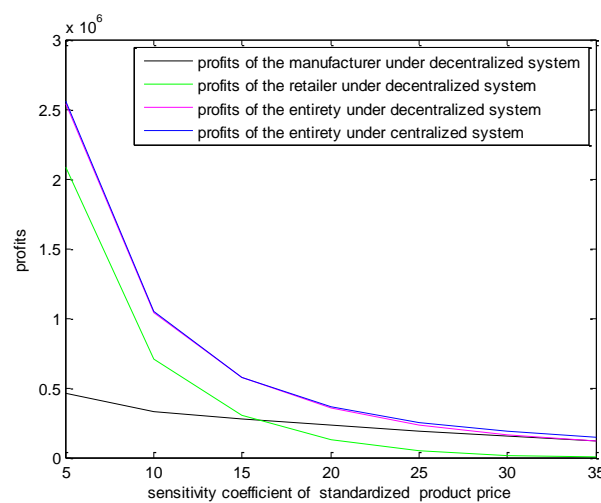

Fig. 6: The relationship between the profit of each enterprise and the sensitivity coefficient of standard product price under different systems

It can be seen from Figure 6 that the profit of enterprises decline continuously under different systems with the increasing of α_r ,and the overall profit of retailers and the overall profit of the supply chain change greatly while the profit of manufactures changes less. When $5 \leq \alpha_r < 15$, the retailer's profit is higher than the manufacturer's; when $15 < \alpha_r \leq 35$,the manufacturer's profit is higher than the retailer's. Figure 7 is obtained when β_r (i.e. the sensitivity coefficient of the guaranteed delivery time for standardized demands) changes between 5 and 35.
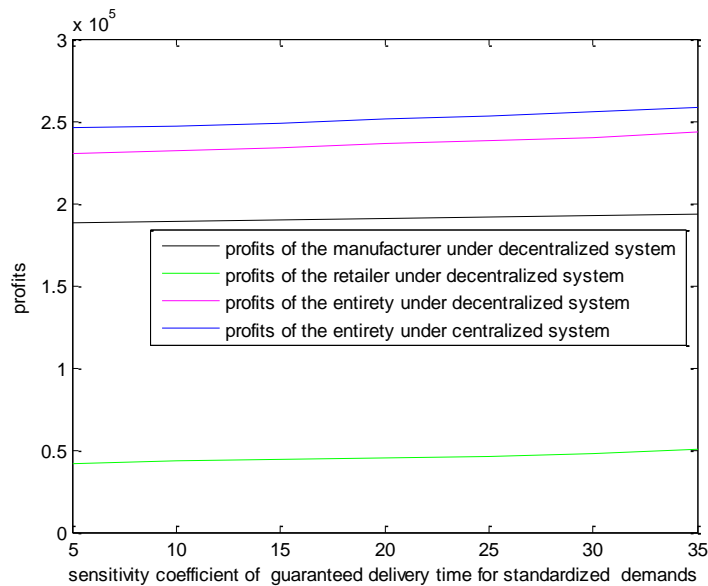

Fig. 7: The change relationship between the profit of each enterprise and the sensitivity coefficient of guaranteed delivery time for standardized demands under different systems

It can be seen from Figure 7 that the profit of each enterprise and the overall profits of the supply chain increase slowly under different systems with the increasing of β_r. When η_t (i.e. the change rate of production cost) varies from 0 to 30, Figure 8 is obtained.
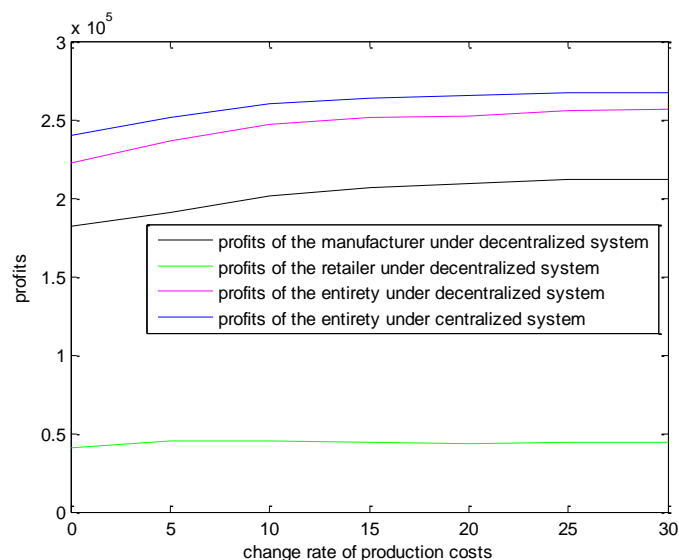

Fig. 8: The change relationship between profits of enterprises and the change rate of production costs under different systems

It can be seen from Figure 8 that the profit of the manufacturer and the overall profit of the supply chain have a slowly rising trend with the continuous increase of η_t, and the retailer's profit has a small change range and no obvious change rule. It shows that the bigger η_t does not related to a better profit for enterprises. When γ (i.e. the sensitivity coefficient of cross price) changes in the range from 0 to 10, Figure 9 is obtained.

It can be seen from Figure 9 that the profit of each enterprise and the overall profit of the supply chain under different systems are increasing and the rate is faster and faster with the continuous increase of γ. It shows that the greater the cross influence between channels is, the more favorable for enterprises.
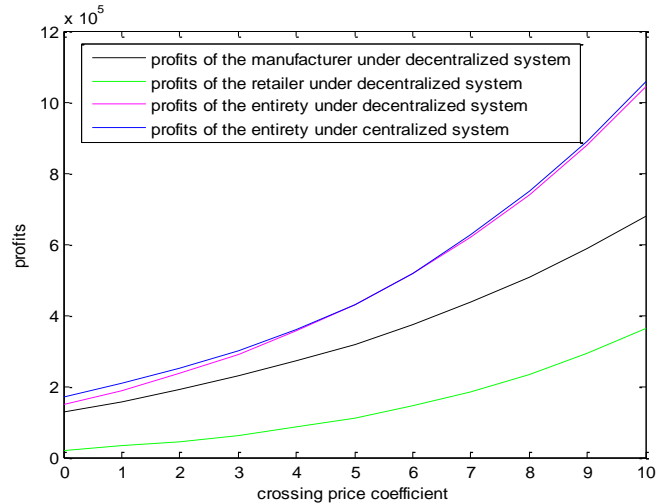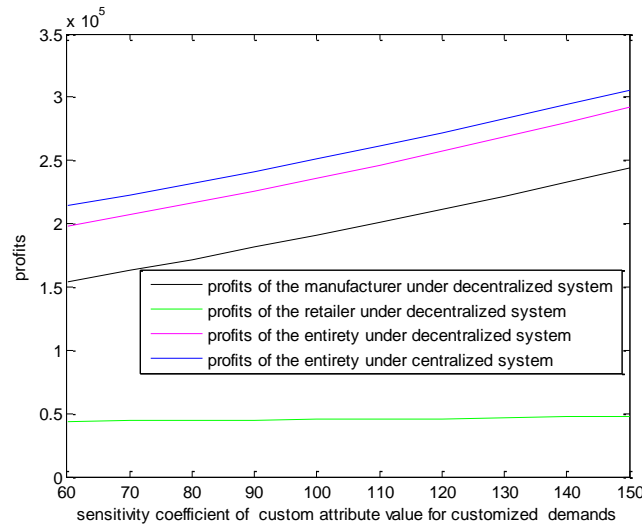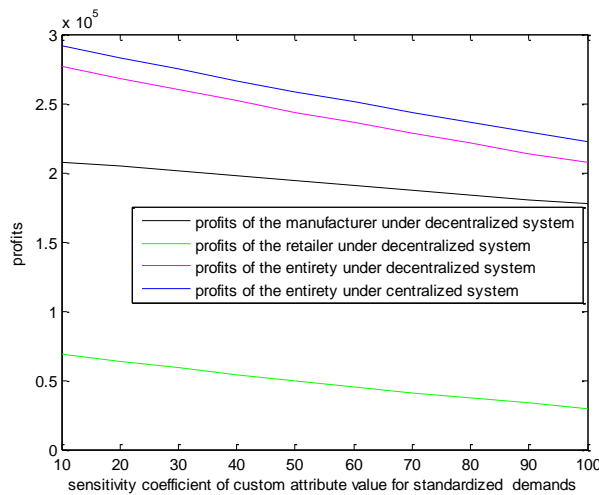

Fig. 9: change relationship between the profit of each enterprise and the crossing price coefficient under different systems

Figure 10 (a) is obtained when μ_d (i.e. the sensitivity coefficient of custom attribute value for customized demands varies equally between 60 and 150). Figure 10 (b) is obtained when μ_r (i.e. the sensitivity coefficient of custom attribute value for standardized demands varies equally between 0 and 100). It can be seen from Figure 10 that the profit of the manufacturer and the whole profit of the supply chain increases approximately linearly under different systems with the increasing of μ_d, while the profit of the retailer almost remains unchanged. The profit of enterprises and the whole profit of the supply chain decreases in a straight line under different systems with the increase of μ_r.

(a) *The relationship between profit of enterprises and* μ_d *under different systems*

(b) *The relationship between profit of enterprises and* μ_r *under different systems*
Fig. 10: The relationship between the profit of enterprises and the sensitivity coefficient of custom attribute value under different systems

V. Conclusion

Considering the interactive influence of price, delivery time, consumer's acceptance of online customization, custom attribute value and other factors on the customized demand through electronic-direct and standardized demand through traditional retail ,taking customized product price, guaranteed delivery time and standard product retail price as decision variables, the Steinberg game model with manufacturer as the dominant position and retailer as the dominant position are respectively constructed under decentralized system, and the supply chain profit maximization model under centralized system is constructed as well. The existence and rationality of the optimal solution under different models are proved and the relevant expressions are obtained.

The model is validated by numerical examples and parameter sensitivity analysis, and relevant conclusions are obtained: under decentralized system, the profit of enterprises in dominant position is higher than that under subordinate position, and the overall profit of dual channels under centralized system is higher than the sum of profits of different channels under decentralized system, and with the increase of guaranteed delivery time, the profit of dominant manufactures and the overall profit of supply chain first increases and then decrease. However,

the dominant retailer's profit has been increasing. With the increase of θ, the more favorable it is for the manufacturer and the more unfavorable it is for the retailer. Within the feasible range, with the continuous increase of parameters such as α_d, β_d, α_r, μ_r and so on, the profit of each enterprise and the whole profit of the supply chain have been declining continuously. With the increase of parameters such as η_t, γ, μ_d and so on, the profit of each enterprise and the whole profit of the supply chain continue to rise, but the rates of the rise or fall of the profits of all enterprises are different, and the change of β_r has little effect on the profits of enterprises. The above conclusions have certain reference significance for production practice. On the basis of this study, considering the randomness of the completion period and the contract coordination strategy of the supply chain under the dual channel mode is the next issue worthy of in-depth consideration and research.

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