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Analysis of Optimal Variables of Return Freight Insurance Decision for Each Part of Supply Chain Based On Stackelberg Game

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ABSTRACT

Based on the theory of demand and profit function, this paper studies the effects of different return freight insurance policies on manufacturers (sellers), platform optimal price, and optimal wholesale price under the distribution model. By constructing a mathematical model under Steinkelberg game, this paper analyzes the model without freight insurance and the model with freight insurance borne by different parts of the supply chain to explore the changes of the optimal variables of each party. The results show that: with the increase of the residual value of returned goods, the optimal retail price and the optimal return volume will increase, while the optimal wholesale price and the optimal demand will decrease. Under the model of freight insurance shared by the platform and the manufacturer, with the increase of freight insurance shared by the manufacturer and the platform, the optimal selling price increases, the optimal demand and the optimal return volume decrease, and when the cost of freight insurance borne by the manufacturer exceeds half, the wholesale price increases. Under the model of buyer bearing freight insurance, when consumers have high price sensitivity, the higher the cost of consumer bearing freight insurance, the lower the maximum selling price.

KEYWORDS

Game theory; Free freight insurance model; Model decision made by seller

1. INTRODUCTION

With the development of e-commerce business, more and more consumers shop online. From the data point of view, the scale of China's online shopping users continues to expand, according to the data disclosed by the China Internet Network Information Center, the scale of China's online shopping users has reached 676 million in 2020. Not only that, the transaction volume has also reached new highs, according to the 2021 China E-commerce Development Report, China's e-commerce transaction volume reached 44.8 trillion yuan in 2020.

The e-commerce platform links a large number of suppliers and consumers, reduces transaction costs, and gives birth to some new business models, which greatly promotes economic development. However, the opacity of information on the Internet has also brought some new problems. The separation of payment and delivery processes has resulted in a decline in product adaptation rates, reduced consumers' willingness to pay and increased processing costs for online retailers. To this end, some e-commerce platforms have introduced the return freight insurance mechanism to reduce the negative impact of opaque information, taking the platform's overall refund rate disclosed by Jingdong as an example, after the launch of return freight insurance in 2017, the overall refund rate has been significantly reduced, which is reflected in the double 11 period of the year, when sales increased by more than 50%, the refund rate is only 0.86%. It was down 0.41% from October of the same year.

However, under the self-operated model (the freight insurance is launched and operated by the platform), the platform prices the freight insurance too high, leading to an increase in the return rate, while the pricing is too low, leading to conflicts such as inability to make profits and unable to make ends meet. Under the non-self-operated model, it is unable to handle operational decision-making problems such as profit distribution with third-party insurance companies.

This paper will use the game theory model (to provide decision-making) to solve the following problems: (1) whether the platform should provide freight insurance model (to establish a profit model without freight insurance); (2) Under what conditions should the e-commerce platform introduce the return freight insurance mechanism (the game between the seller and the platform, and the model under the condition of no freight insurance is compared); (3) Introduce buyers to explore how the buyers bear the return freight insurance will affect the game equilibrium (including platform profits, retailer profits, etc.).

2. LITERATURE REVIEW

Based on Steinkelberg's game theory, Tao Yuting et al. established a game model according to the game relations between ports and ships and between ships, and studied the problem of energy coordination. On this basis, the power generation and total electricity demand supplied by the ship's self-generated motor are adjusted by the reference shore power price provided by the port. Or through the reverse feedback to adjust the price of shore power, external purchase of electricity, and so on, and finally reach the game equilibrium. Results A two-way auction quotation strategy based on Bayesian game is proposed to maximize the efficiency of energy use between the parties [1], which is similar to the parties' game of the e-commerce supply chain. Ships can be likened to whether the buyer chooses freight insurance, and the energy management center is the combination of the e-commerce platform and the seller. Because the energy management center will buy external power when the power generation is insufficient, it can be regarded as a two-party game, so the model has the value of analog reasoning. Zhang Chao, Zhang Xinxin et al. studied the power market, analyzed the steel enterprises in Game One, studied the optimal method of their power pricing, established the game model of steel enterprises, fossil fuel power generation enterprises and local governments, and compared the three pricing schemes of fixed price, fixed premium and variable premium. The results show that there are great differences in the research and analysis objects under the three pricing strategies, and the fixed-price strategy has the lowest risk [2]. Xie Puliang et al. studied the game between the government and relevant enterprises with carbon quota as the decision-making variable under the carbon quota trading policy. This paper analyzes the relationship between optimal decision making and equilibrium profit of road and railway enterprises in low-carbon environment by constructing game models of government and highway enterprises, decentralized decision making and centralized decision making, and designs the coordination mechanism of revenue sharing contract and profit redistribution to realize the coordination of the logistics service supply chain of public and railway intermodal transport [3]. It can be seen that Stackelberg game is used in both papers to analyze the strategic interaction between different decision makers. In the context of e-commerce return freight insurance, this model can be used to analyze the relationship between e-commerce, consumers and logistics companies. By building a model of leaders and followers, we can explore in more depth how to adjust return policies to optimize profits while maintaining the balance of interests of all parties. At the same time, both emphasize the impact of cost, environmental factors and policy on the choice of strategy. In the field of e-commerce, the decision of return freight insurance is also affected by multiple factors such as product category, return rate, logistics cost and so on. The article can analyze how these parameters affect the cost-effectiveness of the return policy, and then discuss how to set more effective insurance and price strategies. Similar to the research on ship and energy management center, Liang Xiaoshuo introduced a price-dominated game mechanism to coordinate the balance of interests of different subjects, and analyzed the leaders and followers of industrial parks [5].

At the present stage, the research on return freight insurance is also of great reference value. Shen Siyi uses an innovative return freight insurance pricing model, which combines expected loss pricing and Bayesian network technology, in order to establish a reasonable premium rate for return freight insurance. It summarized several factors affecting consumers' return behavior, collected relevant data by questionnaire survey, performed descriptive statistical analysis on these data, and constructed a premium calculation model based on the expected loss theory, and applied it to estimate the possibility of consumers' return. This study provides an innovative perspective and data support for the pricing of return freight insurance [4].

Fu Wenwen, Zhu Danxia et al. explored the return freight insurance provision strategy of platform sellers in the supply chain composed of sellers, e-commerce platforms and consumers, and particularly considered the impact of market structure. This study analyzes in detail the decision-making process and effects of sellers in providing return freight insurance under different market structures, and reveals how market competitive dynamics and return rates affect strategy choices. The results show that the return rate has a direct impact on whether the seller provides return freight insurance, especially in the competitive environment, the medium return rate encourages the seller to consider the market structure and the behavior of competitors more actively, so as to adjust its own return freight insurance strategy. Through these analyses, the study not only provides empirical guidance for sellers on e-commerce platforms on how to adjust their return freight insurance strategies based on market structure and return rates, but also provides valuable insights into understanding risk management strategies in the competitive dynamics of the e-commerce market. This study highlights the complexity of strategy formulation in the e-commerce environment and its importance for merchants' competitiveness [6]. Junxia He's research focuses on the issue of return freight insurance in an omnichannel retail environment, as well as retailers' competitive and cooperative strategies. This paper first analyzes the competitive strategy of online retailers in the omnichannel environment, especially the decision-making process of return freight insurance in the case of monopoly and duopoly competition. The results show that, in most cases, online retailers can improve their profits by implementing return freight insurance, unless the expected mismatch rate of goods is very low. Strategies for online-to-offline cooperation models are also explored, including commission contract design and service input decisions. He Junxia pointed out that in the case of providing a single channel or cross-channel return service, the cooperation between online and offline channels can achieve a win-win situation through reasonable design of commission contracts and optimization of service investment. He Junxia's research comprehensively considers the omnichannel retail environment, competitive strategy and return freight insurance. It provides theoretical basis and practical suggestions for retailers to make optimal decisions in a complex market environment, especially innovative insights in omnichannel and return policy design [7].

Guo Yan, Xiao Jinrui, Zhang Zhen et al. studied the return freight insurance in online shopping from different perspectives, and discussed its impact on e-commerce platforms and consumer behavior, as well as the development of insurance business. Yan Guo's research focuses on the role of return shipping insurance in promoting consumers' purchase intentions. The research shows that due to the virtuality and information asymmetry of online shopping, there are great risks in the transaction process, which has become a major bottleneck restricting the development of e-commerce platforms. As a tool to reduce the perceived risks and decision-making costs of consumers in online shopping, return freight insurance plays a significant role in increasing consumers' perceived value. Guo Yan's research also pointed out the problems existing in the application of freight insurance and put forward corresponding improvement suggestions [8]. Xiao Jinrui and Zhang Zhen's research focuses on the overall development of return freight insurance and its impact on the business of insurance companies. With the progress of science and technology, online shopping has become a mainstream way of shopping, and return freight insurance has emerged as a new area of insurance business. By analyzing the advantages and existing problems of return freight insurance, this study puts forward suggestions to optimize the insurance business, aiming to help insurance companies better adapt to market demand and improve service efficiency [9].

3. ASSUMPTION AND SYMBOL DESCRIPTION

3.1. Research Assumption

Assumption 1: There is only one e-commerce platform and multiple consumers in the market. This hypothesis helps to construct a "one-to-many" (single seller versus multiple buyers) market scenario, a common model setup in Stackelberg game theory. By simplifying the playing field, we can focus on the strategic impact of e-commerce platforms as market leaders in setting return policies, and how this strategy changes the market structure by influencing consumer choice. This hypothesis excludes the interference of other e-commerce platforms and ensures the clarity and operability of the model.

Assumption 2: If the consumer needs to return the goods after the freight insurance is in effect, the insurance amount provided by the insurance company (insurer) covers the freight incurred by all the consumers after the return. This hypothesis excludes the limitation and diversity of insurance payment, simplifies the model, and focuses on the three-party game problem.

Assumption 3: Both e-commerce platforms and consumers are rational economic people, that is, they are benefit maximizers. This assumption assumes that participants will try to pursue their own best interests when making decisions. It is a standard assumption in economics and helps to mathematize and theorize model analysis. The rational behavior hypothesis allows the model to predict behavior outcomes, so that decisions can be optimized based on those predictions when setting strategies.

Assumption 4: The e-commerce platform fully understands consumers' needs and preferences for return freight insurance, that is, information symmetry. The assumption of information symmetry simplifies communication and decision-making processes, ensuring that e-commerce platforms can set policies without fear of misinterpretation or withholding of information. This helps the research focus on the desired effects and impacts of return freight insurance policies, rather than being distracted by the market failure caused by possible information asymmetry.

Assumption 5: Considering only the effect of return shipping insurance, assuming that the product quality is intact and accurately described, the return behavior is only related to the subjective satisfaction of the consumer and the return policy (i.e. full refund). The model focuses on analyzing the impact of return freight insurance policy itself on the behavior of return goods by excluding the quality problems and the inauthentic description factors. This assumption ensures the purity of the analysis and avoids the complexity of the model caused by unrelated factors such as product quality, allowing for a more accurate assessment of the impact of changes to the return policy.

Assumption 6: Given that mainstream e-commerce platforms all adopt a distribution model, that is, manufacturers, such as farmers producing agricultural products, manufacturers producing parts and even automobile manufacturers, etc., sell their own products to the platform at wholesale price, and then the platform acts as a retailer to sell to consumers, the model research in this paper is based on the distribution model.

3.2. Symbol Description

Table 1. Symbol Description

Symbol	Instructions
p	Selling price of goods
w	The wholesale price at which the platform acquires the manufacturer's goods
a	Basic market demand
b	Price elasticity of demand
u	Sensitivity coefficient of demand to return compensation
B	Inherent return volume
h	Sensitivity coefficient of return volume to return compensation
c	Unit production cost
s	Shipping charges for each product returned
p_r	Compensation for returned goods
f_c	The consumer pays the price per unit of freight insurance
f_r	The supplier pays the price per unit of freight insurance
v	Residual value of the product
D	Demand function
R	Return function
π	Profit function

4. DECISION MODEL WITHOUT FREIGHT RISK

According to the theorem of supply and demand function, according to literature review, there is a correlation between demand function and return compensation, and the higher the return compensation, the higher the market demand, so in the case of no freight insurance, the demand function is:

$$D = a - bp + up_r$$

In the absence of freight insurance, the consumer bears the freight of the goods, so the consumer's return compensation function is:

$$p_r = p - s$$

In addition, similar to the demand function, the return function is also related to return compensation:

$$R = B + hp_r$$

Since the analysis in this paper is based on the distribution model, the profit function of the e-commerce platform is mainly composed of three parts: one part is the sales revenue that has not been returned for a certain period of time, the other part is the purchase cost, and considering that the returned products can be sold twice, they have a certain residual value, so the profit function is as follows:

$$\pi = p(D - R) - wD + vR$$

The profit function of the manufacturer is:

$$\pi = (w - c)D$$

Because in the distribution mode, after the e-commerce platform purchases goods from the manufacturer at the wholesale price, it is equivalent to the retailer, assuming its own risk and bearing its own profit and loss. Therefore, in order to obtain the optimal pricing of the e-commerce platform, we need to obtain the partial derivative of the profit function of the e-commerce platform, obtain the response function of the sales price, and bring it into the manufacturer's profit function for the partial derivative solution again. And then we can invert it into the two functions and we can find the corresponding maximum profit.

Conclusion: Under the condition of no freight insurance, the optimal retail price of e-commerce platform is:

$$p=\frac{b^2c+a(3b+2h-3u)+b\big(-B-(2c+3s)u+h(s+v)\big)+u(B+(c+3s)u-h(3s+v))}{4(b-u)(b+h-u)}$$

The manufacturer's optimal wholesale price is:

$$w=\frac{ab+bB+b^2c+2ah-bhs-au-Bu-2bcu-bsu-hsu+cu^2+su^2-bhv+huv}{2(b-u)^2}$$

By bringing the optimal price into the demand function, the optimal quantity demanded is:

$$D=\frac{-b^2c+a(b+2h-u)-u\big(B+(c-s)u+h(s-v)\big)+b(B+(2c-s)u-h(s+v))}{4(b+h-u)}$$

By bringing the optimal price into the return function, the optimal return quantity can be:

$$R=B-hs+\frac{h(b^2c+a(3b+2h-3u)+b\big(-B-(2c+3s)u+h(s+v)\big)+u(B+(c+3s)u-h(3s+v))}{4(b-u)(b+h-u)}$$

After obtaining the expression of the basic variable of the residual value, the optimal return volume, the optimal demand, the optimal retail price and the optimal wholesale price, we can obtain the relationship between the residual value (the residual value after the return of goods) and the above four optimal solutions by obtaining the partial derivative again.

Because$\frac{\partial p}{\partial v}>0$, $\frac{\partial R}{\partial v}>0$, since the partial derivatives of the optimal retail price and the optimal returned amount with respect to the residual value are both greater than 0, when the residual value of the product increases, the optimal retail price and the optimal returned amount will also increase. In addition, because $\frac{\partial D}{\partial v}<0$, $\frac{\partial w}{\partial v}<0$, the optimal quantity demanded and the optimal wholesale price will decrease when the residual value of the good increases.

To sum up, under the condition of no freight insurance, the higher the value contained in the returned goods, the higher the e-commerce platform's optimal selling price and return volume of the goods, while the optimal demand and wholesale price will decrease. As the residual value of returned goods increases, the cost of the e-commerce platform will decrease, so the price will rise, and the compensation for returned goods of consumers will also rise, so the volume of returned goods will increase, and the market demand will decrease, so for manufacturers, in order to maintain profits, it is necessary to reduce the wholesale price and expand the market demand.

5. DECISION MODEL UNDER FREIGHT RISK SHARED BY PLATFORM AND MANUFACTURER

Under the condition that the e-commerce platform and the manufacturer provide freight insurance free of charge, since the two are faced with a black box situation, that is, they do not know in advance which goods will be returned, the e-commerce platform must carry out freight insurance for each of the purchased goods.

In this case, the demand function is the same as without freight risk:

$$D = a - bp + up_r$$

The return function is:

$$R = B + hp_r$$

Since the consumer is not responsible for shipping costs, the return compensation function is:

$$p_r = p$$

The increase in return compensation will lead to an increase in the demand under the condition that the platform and the manufacturer jointly bear the freight insurance compared to the mode without freight insurance, and the amount of returned goods will also increase, considering the nature of the insurance, it will also increase the insurance cost of each product in disguise.

Since the e-commerce platform and the manufacturer jointly bear the freight insurance of consumers, it is assumed that the freight insurance cost borne by the e-commerce platform accounts for λ, and the cost borne by the manufacturer accounts for $1-\lambda$

Similar to the situation without freight insurance, the profit of the e-commerce platform mainly consists of sales revenue excluding returns, purchase cost, residual value of returned products and insurance expenses. Therefore, the profit of the e-commerce platform at this time is as follows:

$$\pi = p(D - R) - wD + vR - \lambda f_r D$$

Manufacturer's profit is:

$$\pi = (w - c)D - (1 - \lambda) f_r D$$

Conclusion: In this case, the optimal retail price of the e-commerce platform is:

$$p = \frac{a(3b+2h-3u)+(b-u)(-B+bc-cu+hv)+(b-u)^2 f_r}{4(b-u)(b+h-u)}$$

Manufacturer's best wholesale price is:

$$w = \frac{1}{2}\left(\frac{a(b+2h-u)+(b-u)(B+bc-cu-hv)}{(b-u)^2} + (1-2\lambda) f_r\right.$$

By bringing the optimal selling price and the optimal wholesale price into the demand and return function, the optimal demand can be obtained as follows:

$$D = -\frac{a(-b-2h+u)+(b-u)(-B+bc-cu+hv)+(b-u)^2 f_r}{4(b+h-u)}$$

The optimal return volume is:

$$R = \frac{2ah^2+b^2(4B+ch)-3ahu-3Bhu+4Bu^2+chu^2-h^2uv+b\left(3ah+3Bh-8Bu-2chu+h^2v\right)+h(b-u)^2 f_r}{4(b-u)(b+h-u)}$$

(1) It can be inferred from the above expression that because $\frac{\partial p}{\partial f_r} > 0$, $\frac{\partial R}{\partial f_r} > 0$, $\frac{\partial D}{\partial f_r} < 0$, when the unit freight insurance cost borne by the manufacturer and the e-commerce platform increases, the optimal price and the number of returns will increase. This is because the increase in the unit freight insurance cost means the increase in cost. In order for the platform to maintain profits, it is necessary to increase the selling price of the commodity. According to the demand function, the increase in the selling price means the decrease in the market demand for the commodity, and the increase in the selling price also means the increase in the return compensation, which is proportional to the return

compensation. That is, platforms and manufacturers will eventually pass on the increased costs to consumers, who will bear the extra costs.

(2) This section discusses the proportion of insurance costs borne by the manufacturer and the platform, and takes a partial derivative to obtain $\frac{\partial w}{\partial \lambda} < 0$ which indicates that the larger the proportion borne by the e-commerce platform, the smaller the wholesale price of the manufacturer will be. In addition, when λ is in $[0, 0.5)$, $\frac{\partial w}{\partial f_r} > 0$, which means that when the manufacturer bears more than half of the freight, the manufacturer's wholesale price rises, and the excess cost is transferred to the e-commerce platform, whereas when λ is in $[0.5, 1]$, $\frac{\partial w}{\partial f_r} < 0$, the manufacturer will tend to reduce the wholesale price to compensate.

6. DECISION MODEL UNDER BUYER'S BEARING FREIGHT INSURANCE

Under the condition that the platform and the manufacturer do not provide freight insurance, consumers can voluntarily choose whether to buy freight insurance, do not buy belongs to the first case, we assume that the proportion of consumers who choose to insure is τ.

The return compensation that consumers receive when they choose insurance is:

$$p_r = p - f_c$$

When the consumer chooses not to insure, as in the first model, the return compensation is:

$$p_r = p - s$$

Then we can find out all consumers' expectations about return compensation:

$$p_r = \tau(p - f_c) + (1 - \tau)(p - s)$$

The demand function is as follows:

$$D = a - bp + u\tau(p - f_c) + (1 - \tau)(p - s)$$

The return function is:

$$R = B + h\tau(p - f_c) + (1 - \tau)(p - s)$$

At this time, the profit of the e-commerce platform is:

$$\pi = p(D - R) - wD + vR$$

Manufacturer's profit is:

$$\pi = (w - c)D$$

Conclusion: In this case, the optimal selling price of the e-commerce platform is

$$p = \frac{\begin{matrix}(-bB+b^2c+bhs+a(3b+2h-3u)+Bu-2bcu-3bsu+3hsu+cu^2+3su^2+bhv-huv-bhs\tau+3bsu\tau+3hsu\tau-3su^2\tau \\ (b(h-3u)+3u(u-h))\tau f_c\end{matrix}}{4(b-u)(b+h-u)}$$

Manufacturers exist the best wholesale price is:

$$w = \frac{ab+bB+b^2c+2ah-bhs-au-Bu-2bcu-bsu-hsu+cu^2+su^2-bhv+huv+bhs\tau+bsu\tau+hsu\tau-su^2\tau-bh\tau f_c-bu\tau f_c-hu\tau f_c+u^2\tau f_c}{2(b-u)^2}$$

(1) The optimal solution is obtained after, can get when $b \leq \frac{3u(u-h)}{3u-h}$, $\frac{\partial p}{\partial f_c} > 0$, so the optimal unit sales price as buyers bear the freight insurance costs increase and improve, $b > \frac{3u(u-h)}{3u-h}$, $\frac{\partial p}{\partial f_c} < 0$, The optimal selling price decreases as the buyer's cost of unit freight insurance increases. In other words, when consumers are sensitive to price and the cost of freight insurance borne by consumers increases, the e-commerce platform tends to reduce the selling price to increase sales volume, while when consumers are not sensitive to price, the platform will continue to increase the selling price. At this time, the increase in profits brought by the increase in selling price exceeds the decrease in profits brought by the decrease in demand.

(2) Because $\frac{\partial w}{\partial f_c} < 0$, $\frac{\partial D}{\partial f_c} < 0$, with the increase of freight insurance cost borne by consumers, the demand decreases, and the manufacturer reduces the wholesale price to expand the demand in order to maintain profits.

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