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Retraction

Retracted: Dual-Source Procurement Strategy of Cross-Border E-Commerce Supply Chain considering Members' Risk Attitude

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This article has been retracted by Hindawi, as publisher, following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of systematic manipulation of the publication and peer-review process. We cannot, therefore, vouch for the reliability or integrity of this article.

Please note that this notice is intended solely to alert readers that the peer-review process of this article has been compromised.

Wiley and Hindawi regret that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

[1] Z. Zhao, Z. Liu, Q. Qian, L. Li, Y. Zhao, and Y. Zhu, "Dual-Source Procurement Strategy of Cross-Border E-Commerce Supply Chain considering Members' Risk Attitude," *Security and Communication Networks*, vol. 2022, Article ID 3592859, 13 pages, 2022.

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Research Article

Dual-Source Procurement Strategy of Cross-Border E-Commerce Supply Chain considering Members' Risk Attitude

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The risk attitude of decision-makers will significantly affect the decision-making of enterprise risk management. Specifically, high risk represents the potential premise of high return for risk preference decision-makers, and for risk-averse decision-makers, the increase of risk degree will stimulate decision-makers' aversion to uncertainty and turn to seek safer business strategies. Although there are many pieces of literature on the risk preference of decision-makers, they usually only assume the risk attitude of one party and rarely consider the risk attitude of suppliers and retailers in the scenario of cross-border e-commerce at the same time. Therefore, under the background of supply disruption, for the cross-border e-commerce supply chain composed of cross-border suppliers, overseas suppliers, overseas retailers, and consumers, combined with the risk attitude preference of enterprise subjects, this paper constructs the mean-variance model dominated by overseas retailers and reversely solves the risk-aversion attitude of a single cross-border supplier. When a single overseas retailer maintains a risk-aversion attitude and both cross-border suppliers and overseas retailers hold a risk-neutral or risk-aversion attitude, the pricing of products in different channels is analyzed. Finally, an example is given to analyze the impact of supply disruption probability, risk-aversion coefficient, channel distribution coefficient, and other parameters on purchase price, market demand, target profit, and utility. It is of great practical significance for improving the stability of cross-border e-commerce supply chain system and reducing revenue loss to study how different degrees of risk-aversion attitudes of cross-border suppliers and overseas retailers affect enterprise procurement pricing strategy, target profit, and utility in case of supply disruption.

1. Introduction

Driven by Internet technology, the world has established an open and interconnected consumer network and a global trade platform. The development of China's cross-border e-commerce industry has entered the fast lane and contributed an important force to economic growth. With the promotion of the "the Belt and Road" strategy, China has close trade exchanges with countries along the belt and road, and economic cooperation has been continuously enhanced. According to the cross-border e-commerce market data report, in 2020, the transaction scale of China's cross-border e-commerce market was 12.5 trillion yuan, the total import and export volume of cross-border e-commerce was 1.69 trillion yuan, the total export volume was 1.12 trillion yuan, and the total import volume was 0.57 trillion yuan. Under the background of trade globalization, although cross-border e-commerce supply chain has the advantages of low cost and high efficiency, with the deepening of integration, the network structure of cross-border e-commerce supply chain is becoming more and more complex, the global trade environment is volatile, and the environmental uncertainty and the complexity of network structure have increased the probability of cross-border e-commerce supply chain interruption risk. Due to the characteristics of multiagent, globalization, digitization, and informatization, cross-border e-commerce has close links between various links, but cross-border e-commerce has great uncertainty and is easy to accumulate risks, among which the risk of supply chain interruption is a more obvious risk. Therefore, it is of great significance for improving the stability of cross-border e-commerce supply chain system and reducing revenue loss to study how supply chain members formulate procurement strategies to meet the target profit and utility in the case of supply disruption.

Existing studies on cross-border e-commerce risks are mostly carried out from risk early warning, risk element identification, and assessment. Wu et al. [1] took Alipay as an example and conducted empirical research on risk early warning based on the establishment of a cross-border mobile payment risk early warning system. Du et al. [2] analyzed the risk factors of cross-border e-commerce small- and medium-sized enterprises through mixed evaluation and ranking method and divided the priority of these risk factors. Fang and Wang [3] evaluated the risk of cross-border e-commerce by establishing the supply chain risk evaluation index system and structural model, combined with the FUZZY-ISM evaluation method. Song et al. [4] proposed a risk assessment method based on text mining and fuzzy rule reasoning, which can quantitatively and semiautomatically assess the risk of cross-border e-commerce commodities and obtain the overall risk of cross-border e-commerce commodities by summarizing the output of relevant risk factors.

The introduction of psychological risk factors into the design of enterprise decision-making behavior can help enterprises make more practical decisions and minimize the impact of subjective factors. Sun et al. [5] constructed an enterprise innovation capability evaluation index system from three aspects: design risk identification, risk response, and risk monitoring. Based on prospect theory and fuzzy TOPSIS method, they analyzed the impact of three different risk attitudes (risk-bearing, neutral, and conservative) on the design decision of innovation alliance. Huo et al. [6] focused on the risk propagation mechanism of supply chain of risk preference enterprises and risk-aversion enterprises, obtained the threshold of supply chain risk and the scale of risk propagation, and revealed the impact of herding and risk preference on supply chain risk propagation. Liu et al. [7] discussed the impact of carbon tax and investment cooperation on energy conservation and emission reduction in agricultural supply chain by constructing three decision-making models. Su et al. [8] used the improved prospect theory to introduce the risk attitude of decision-making enterprises and comprehensively considered the selection decision of virtual enterprise partners. Liu et al. [9] constructed a dual-objective competitive pricing decision model for network service providers based on the market demand price theory. Bi et al. [10] constructed a game decision-making model composed of informal employees, formal employees, and enterprises. Based on the perspective of enterprise risk aversion, they studied the employee incentive under the mixed employment mode. Liu et al. [11, 12], respectively, analyzed the impact of government regulatory attitude on the business decisions of medical waste recycling enterprises and green manufacturing enterprises by using an evolutionary game model. Pang et al. [13], based on the idea of multiattribute and tripartite decision-making, considering the influencing factors of risk attitude, established a data-driven MAGDM method in the environment of interval value uncertainty and made an empirical study on the selection of logistics suppliers in e-commerce enterprises. Qian et al. [14] constructed a credit risk contagion model affected by information dissemination to discuss the interaction mechanism between entrepreneurs with different risk attitudes and enterprise credit level information. Liu et al. [15] established a mathematical model considering lead time, online channel substitution effect, and promotion cost ratio and further studied the impact of interruption risk under a risk-aversion attitude on two-channel pricing and profit strategies.

At the same time, many scholars have analyzed the positive and negative effects of risk attitude from different angles. Dai [16] found that the establishment of cost allocation coefficient and performance punishment coefficient is directly related to the risk attitude of suppliers and customers. When both suppliers and customers belong to risk aversion, with the increase of suppliers' risk aversion, the cost allocation coefficient should be reduced, and the performance punishment coefficient should be improved. Zhu and Dou's [17] research shows that, under the retailer-led mode, the degree of risk aversion of manufacturers has a greater impact on the balance of various factors. Liu et al. [18] constructed the evaluation index system of green finance by using fuzzy principal component analysis. Kang et al. [19] further analyzed the impact of supply chain decision-makers' risk attitude on financing and pricing strategies and found that when retailers have capital constraints, suppliers should give priority to deferred payment strategies. The risk attitude and financing interest rate of suppliers and retailers have an impact on the choice of retailer financing strategy. Li and Ma [20] found that the market strategies adopted by risk-averse manufacturers are different in the case of service spillover effect and without considering service spillover effect. The service spillover effect has a positive impact on the demand, expected return, and service level of retailers of both sides of the supply chain. Chen et al. [21] incorporated risk attitude and risk perception into the study of farmers' carbon sequestration forest circulation and conducted an empirical test by using a binary logistics model and intermediary effect model, pointing out that risk preference farmers have higher transfer intention than risk-averse farmers.

Value-at-risk models in risk research methods are often used to characterize the magnitude of risk. Ma and Hong [22] used this theory to study the dynamic game of pricing and service strategies in a dual-channel supply chain with risk attitude and free rider and pointed out that different risk preferences will produce different equilibrium results.

Merzifonluoglu [23] constructed a mathematical model considering risk-neutrality and risk-aversion objectives (CVaR) under the conditions that the spot market is unavailable and can only be purchased and available for sale and studied the selection of a risk-aversion supply portfolio. Liu et al. [24] compared the operation results of the genetic algorithm and hybrid algorithm and considered that the hybrid algorithm is more effective. Liu et al. [25] portrayed the risk attitudes of each member of the closed-loop supply chain through the mean-variance method and found that risk-neutral recyclers benefit all supply chain members and risk-neutral retailers and manufacturers benefit only themselves. You et al. [26] further found that members' risk attitudes and loan rates can influence the optimal decision and utility of closed-loop supply chains.

The above literature shows that the subject's risk attitude has a significant impact on various decision-making behaviors of enterprises, and the optimal decision-making and achievement effects are different under different risk preferences [27–29]. Therefore, it is necessary to bring the member's risk attitude into the discussion of optimizing and coordinating the cross-border e-commerce supply chain [30–33]. At the same time, although many scholars have studied the risk preference of decision-makers, they rarely involve the complex scenario of the cross-border e-commerce supply chain and usually only assume that a member holds a certain risk attitude without considering the risk attitude of various suppliers and retailers in the cross-border e-commerce supply chain. The impact of different risk attitudes and product pricing on the income of cross-border e-commerce supply chain members and the relationship between risk attitudes and the optimal pricing decision of products will affect the smooth operation, optimization, and coordination of cross-border e-commerce supply chain [34–36]. This chapter constructs the mean-variance model dominated by overseas retailers to obtain the optimal purchase pricing strategy of enterprises with different degrees of risk-aversion attitudes.

2. Assumptions and Problem Description

Consider building a cross-border e-commerce supply chain system composed of cross-border suppliers, overseas suppliers, and overseas retailers. Its operation mode is shown in Figure 1. The cost of cross-border suppliers is to sell to overseas suppliers at wholesale price and to overseas retail sellers at main channel purchase price, respectively. After the overseas suppliers increase the price of products, they sell to overseas retailers at standby channel purchase price. Overseas retailers eventually sell their products to consumers at a price, $c < w < w_a < w_b < p$. Overseas retailers can purchase products from both cross-border suppliers and overseas suppliers. There is no difference in the quality of products provided by cross-border suppliers and overseas suppliers. The distribution coefficient of products allocated by overseas retailers to cross-border suppliers is β $(0.5 < \beta < 1)$. Cross-border suppliers sell products at lower prices, but due to the impact of distance and policies, the supply chain of cross-border suppliers is at risk of interruption. It is assumed that the probability of interruption of cross-border suppliers is r $(0 < r < 1)$, and it can still provide products with proportion θ after interruption $(\theta < \beta)$. After the interruption, the overseas supplier can respond quickly, but at this time, the overseas supplier will increase the price of the product, and the purchase price of the standby channel becomes w_c $(\lambda > 1)$. In addition, it is assumed that the market demand is $D = D_0 + \varepsilon$, where D_0 is a deterministic demand, which is affected by the product price, and ε is a random variable that changes with market demand, $\varepsilon \sim N(0, \sigma^2)$. Therefore, if there is no interruption, the market demand of the main channel and standby channel is $D_k = \beta D - m w_a + n w_b$ and $D_h = (1-\beta)D - m w_b + n w_a$, respectively. In case of interruption, the market demand of the main channel and the standby channel is $D_k^* = \theta D - m w_a + n w_c$ and $D_h^* = (1-\theta)D - m w_c + n w_a$, respectively, and the product prices of different purchase channels will be different. In order to maximize their own interests, overseas retailers in the downstream will inevitably tend to order from low price suppliers. In order to distinguish this difference, m and n are, respectively, the sensitivity of overseas retailers to the purchase price of the main channel and the purchase price of the standby channel $(m > n)$. In order to consider the impact of overseas retailers' risk attitude, the objective function of overseas retailers and cross-border suppliers changes from profit maximization to utility maximization, and the objective function becomes $U(\pi) = E(\pi) - \rho\sqrt{Var(\pi)}$, where $Var(\pi) = E[\pi - E(\pi)]^2$, ρ is the risk attitude coefficient, the larger $|\rho|$, the more obvious the attitude, and $\rho > 0$ is risk-aversion attitude.

3. All Participants in the Cross-Border Supply Chain Hold a Risk-Neutral Attitude

When major suppliers face the risk of supply disruption, due to the differences in the size, cultural concept, and upstream and downstream distribution of enterprise entities, different enterprise entities in the supply chain of cross-border e-commerce enterprises may have different attitudes and decisions on risk issues. This section studies that, in general, all participants in the supply chain of cross-border e-commerce enterprises hold a risk-neutral attitude towards the interruption of cross-border suppliers' main channel supply; that is, when $\rho = 0$, it discusses the changes in the expected returns of the participants in the supply chain system.

The expected return function of cross-border suppliers is

$$E(\pi_k) = (1-r)\left[(w_a - c)D_k + (w - c)D_h\right] + r\left[(w_a - c)D_k^* + (w - c)D_h^*\right]. \quad (1)$$

The expected return function of overseas retailers is

$$E(\pi_r) = (1-r)\left(pD - w_a D_k - w_b D_h\right) + r\left(pD - w_a D_k^* - w_c D_h^*\right). \quad (2)$$

In this Stackelberg model, overseas retailers dominate. First, determine the product retail price p. Then, overseas suppliers make decisions on the purchase price of standby channels according to the sales price of retailers. Finally,

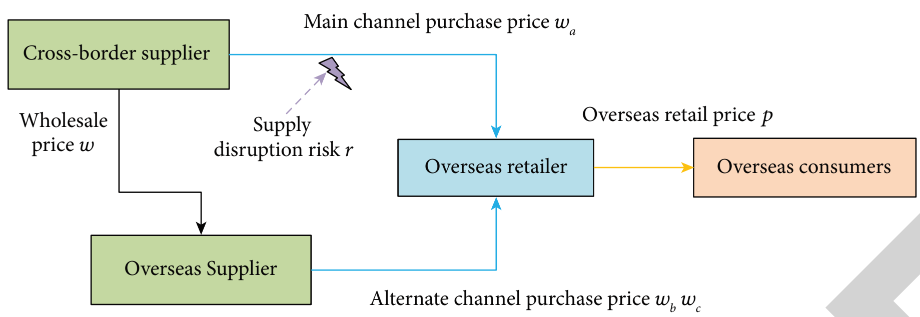

Figure 1: Cross-border e-commerce supply chain operation mode.

cross-border suppliers determine the purchase price of main channels w_a and overseas wholesale price w according to the determined product retail price and the purchase price of standby channels. According to the reverse induction method, firstly, the optimal response function of cross-border suppliers' purchase price in main channels after supply disruption is $w_a = -cn - cm - D\beta - nw - nw_b + D\beta r - D\theta r + nrw_b - nrw_c/2m$, then it is brought into the expected return function of overseas retailers, and the partial derivatives of w_b and w_c are obtained as follows:

$$\begin{aligned}\frac{\partial E(\pi_r)}{\partial w_b} &= \frac{(1-r)\left(cn^2 - cmn + 4m^2 w_b - n^2 w - 3n^2 w_b + 3n^2 r w_b - 3n^2 r w_c\right.}{2m}\\ &+ \frac{(1-r)(m\beta D - n\beta D + nr\beta D - nr\theta D - mD)}{m},\\ \frac{\partial E(\pi_r)}{\partial w_c} &= \frac{r\left(cn^2 + 4m^2 w_c - n^2 w - 3n^2 w_b + 3n^2 r w_b - 3n^2 r w_c - cmn\right.}{2m}\\ &+ \frac{r(m\theta D - m\beta D + nr\beta D - nr\theta D - mD)}{m}.\end{aligned} \tag{3}$$

Therefore, the simultaneous equations with $\partial E(\pi_r)/\partial w_b = \partial E(\pi_r)/\partial w_c = 0$ are obtained by assuming conditions

$$w_b^N = \frac{-4Dm - 2wn^2 + 4D\beta m + 2cn^2 - 2cnm - 4D\beta n + 4D\beta nr - 4D\theta nr}{-8m^2 + 6n^2} + \frac{3D\theta n^2 r - 3D\beta n^2 r}{-8m^3 + 6mn^2}, \tag{4}$$

$$w_c^N = \frac{-4Dm - 2wn^2 + 4D\theta m + 2cn^2 - 2cnm - 4D\beta n + 4D\beta nr - 4D\theta nr}{-8m^2 + 6n^2} + \frac{3Dn^2(1-r)(\beta - \theta)}{-8m^3 + 6mn^2}. \tag{5}$$

Bring w_b^N and w_c^N into w_a to get the value of w_a^N:

$$\begin{aligned}w_a^N &= \frac{2cm^2 + 2nwm + nD + 2D\beta m - cn^2 - 2cnm - 2D\beta rm + 2D\theta rm - D\beta n + D\beta nr - D\theta nr}{4m^2 - 3n^2}\\ &+ \frac{2cn^3 - 2wn^3 - D\beta n^2 + D\beta rn^2 - Dn^2 r\theta}{2m\left(4m^2 - 3n^2\right)}.\end{aligned} \tag{6}$$

Lemma 1. *Without considering the enterprise's risk attitude, the purchase prices w_b, w_c, and w_a provided by each supplier in the cross-border e-commerce supply chain are inversely proportional to the supply disruption probability of rr. The higher the probability of supply disruption, the lower the purchase price of different channels. This is because with the increase of the probability of supply chain risk, in order to deal with the impact of market demand fluctuation on enterprise income, cross-border suppliers and overseas suppliers consciously provide lower purchase prices to encourage overseas retailers to increase the order quantity and strive to improve the demand of the consumer market.*

It is proved that the partial derivatives of equations (4)–(6) with respect to r can be found from the assumption; it can be found from the hypothetical conditions $\partial w_a^N/\partial r = (4Dm^2 - Dn^2 - 2mn)(\beta - \theta)/ - 8m^3 + 6mn^2 < 0$ *and* $\partial w_b^N/\partial r = \partial w_b^N/\partial r = (3n^2 - 4Dmn)(\beta - \theta)/8m^3 - 6mn^2 < 0$.

4. Some Enterprises in the Cross-Border Supply Chain Take a Risk-Averse Attitude

In the cross-border e-commerce supply chain system, some enterprises may hold a risk-averse attitude, and some enterprises may hold a risk-neutral attitude. It is discussed that when the dual-channel cross-border supply chain is dominated or influenced by upstream suppliers, the expected return goal of the supply chain system will be transformed into the expected utility goal.

4.1. Risk-Averse Cross-Border Suppliers. In this case, it is assumed that overseas suppliers and overseas retailers hold a neutral attitude towards the risk of supply disruption, and cross-border suppliers hold a risk-averse attitude due to problems such as transportation distance and productivity. They do not want to have the risk of supply disruption, endanger the enterprise's reputation, and cause a loss of profits. The variance of cross-border suppliers is obtained from equation (1):

$$\begin{aligned} Var(\pi_k) &= E[\pi - E(\pi)]^2 \\ &= [(w - c) + (1 - r)\beta(w_a - w) + r\theta(w_a - w)]^2\sigma^2. \end{aligned} \tag{7}$$

The expected utility function is the difference between the mean value of random income and risk cost.

$$\begin{aligned} U(\pi_k) = (1 - r)&[(w_a - c)(\beta D - mw_a + nw_b) + (w - c)(D - \beta D - mw_b + nw_a)] \\ &+ r[(w_a - c)(\theta D - mw_a + nw_c) + (w - c)(D - \theta D - mw_c + nw_a)] \\ &- \rho[(w - c) + (w_a - w)(\beta - r\beta + r\theta)]\sigma. \end{aligned} \tag{8}$$

According to the reverse induction method, first calculate the response function of the main channel purchase price of risk-averse cross-border suppliers.

$w_a = D\beta + cm- \quad cn + nw + nw_b - D\beta r + D\theta r - nrw_b + nrw_c - \beta\rho\sigma + \beta r\rho\sigma - \theta r\rho\sigma/2m$. Substitute formula (2) to derive w_c and w_b.

$$\begin{aligned} \frac{\partial E(\pi_r)}{\partial w_b} &= \frac{(1 - r)(-cn + nw + 3nw_b - 3nrw_b + 3nrw_c + cmn - \beta n\rho\sigma + \beta nr\rho\sigma - \theta nr\rho\sigma)}{2m} \\ &\quad \frac{(Dm - 2mw_b - D\beta m + D\beta n - D\beta nr + D\theta nr)(1 - r)}{m}, \\ \frac{\partial E(\pi_r)}{\partial w_c} &= \frac{r\left(cn^2 - n^2w - 3n^2w_b + 3n^2rw_b - 3n^2rw_c - cmn + \beta n\rho\sigma - \beta nr\rho\sigma + \theta nr\rho\sigma\right)}{2m} \\ &\quad \frac{r\left(2m^2w_c - Dm - D\beta n + D\theta m + D\beta nr - D\theta nr\right)}{m}. \end{aligned} \tag{9}$$

Solve the above equations together to obtain the purchase prices under the risk-aversion attitude of cross-border suppliers:

$$w_b^K = \frac{2D\beta m - 2Dm - n^2 w + cn^2 - cnm - 2D\beta n + 2D\beta nr - 2D\theta nr}{-4m^2 + 3n^2} + \frac{n\rho\sigma(\beta - \beta r + \theta r)}{-4m^2 + 3n^2} + \frac{3D\theta rn^2 - 3D\beta rn^2}{-8m^3 + 6mn^2},$$

$$w_c^K = \frac{-2Dm - wn^2 + 2D\theta m + cn^2 - cnm - 2D\beta n + 2D\beta nr - 2D\theta nr}{-4m^2 + 3n^2} + \frac{\rho\sigma n(\beta - \beta r + \theta r)}{-4m^2 + 3n^2} + \frac{3Dn^2(\beta - \theta - \beta r + \theta r)}{-8m^3 + 6mn^2}, \tag{10}$$

$$w_a^K = \frac{2cn^3 - 2wn^3 - D\beta n^2 + D\beta rn^2 - D\theta rn^2}{8m^3 - 6mn^2} + \frac{2cm^2 + 2nwm - cn^2 - 2cnm}{4m^3 - 3mn^2} \frac{\rho\sigma\left(2\beta rm^2 - 2\beta m^2 - \beta n^2 - \beta rn^2 - 2\theta rm^2 + \theta rn^2\right)}{4m^3 - 3mn^2} + \frac{D(n + 2\beta m - 2\beta rm + 2\theta rm - \beta n + \beta nr - \theta nr)}{4m^3 - 3mn^2}.$$

4.2. Risk-Averse Overseas Retailers. Assuming this situation, overseas suppliers and cross-border suppliers hold a neutral attitude towards the risk of supply disruption. Facing uncertain market demand, overseas retailers hope to have stable procurement channels, reduce the probability of interruption risk, and take a risk-averse attitude. The variance of overseas retailers is obtained from equation (2):

$$Var(\pi_r) = E[\pi - E(\pi)]^2 = \left[p - (1-r)(w_a\beta + w_b - w_b\beta) - r(w_a\theta + w_c - \theta w_c)\right]^2\sigma^2. \tag{11}$$

The expected utility function is

$$U(\pi_r) = (1-r)\left(pD - w_a D_k - w_b D_h\right) + r\left(pD - w_a D_k^* - w_c D_h^*\right) - \rho\left[p - (1-r)(w_a\beta + w_b - w_b\beta) - r(w_a\theta + w_c - \theta w_c)\right]\sigma. \tag{12}$$

According to the reverse induction method, first calculate the response function of the main channel purchase price of cross-border suppliers, which has been calculated above.

$$w_a = -\frac{cn - cm - D\beta - nw - nw_b + D\beta r - D\theta r + nrw_b - nrw_c}{2m}. \tag{13}$$

The results are brought into the expected utility function of risk-averse overseas retailers, and the first-order derivatives of w_c and w_b are obtained, respectively.

$$\frac{\partial U(\pi_r)}{\partial w_b} = \frac{(1-r)\left[cmn + n^2(w - c + 3w_b - 3rw_b + 3rw_c) + n\rho\sigma(\beta r - \theta r - \beta)\right]}{2m} + \frac{(1-r)(D\beta n - D\beta nr + D\theta nr)}{m} + (1-r)\left(2m - 2mw_b - D\beta - \rho\sigma + \beta\rho\sigma\right),$$

$$\frac{\partial U(\pi_r)}{\partial w_c} = \frac{r\left[n^2(c - w - 3w_b + 3rw_b - 3rw_c) - cmn + (\beta n - \beta nr + \theta nr)\rho\sigma\right]}{2m} r\left(2mw_c - D + D\theta + \rho\sigma - \theta\rho\sigma\right) + \frac{D(\beta nr - \theta nr - \beta n)}{m}. \tag{14}$$

By solving the simultaneous equations and substituting them into the above formula, the purchase prices of standby channels before and after supply disruption can be obtained as follows:

$$\begin{aligned}
w_b^R &= \frac{3Drn^2(\beta-\theta)+\rho\sigma\left(4\beta m^2-2\beta mn-3\beta rn^2+3\theta rn^2+2\beta mnr-2\theta mnr\right)}{8m^3-6mn^2} \\
&\quad + \frac{2Dm-2\rho\sigma m+wn^2-2D\beta m-cn^2+cnm-2D\beta n-2D\beta nr+2D\theta nr}{4m^2-3n^2}, \\
w_c^R &= \frac{3n^2(D-\rho\sigma)(\theta+\beta r-\beta-\theta r)+(4\theta m+2\beta nr-2\beta n-2\theta nr)m\rho\sigma}{8m^3-6mn^2} \\
&\quad + \frac{2Dm-2\rho\sigma m+wn^2-2D\theta m-cn^2+cnm+2D\beta n-2D\beta nr-2D\theta nr}{4m^2-3n^2}, \\
w_a^R &= \frac{2cnm-2cm^2-2nwm+(2\beta rm-n-2\beta m-2\theta rm+\beta n-\beta nr+\theta nr)D}{-4m^2+3n^2} \\
&\quad + \frac{wn^3-cn^3+cmn^2+\rho\sigma mn(1-\beta+\beta r-2\theta r)}{-4m^3+3mn^2} \\
&\quad + \frac{[D\beta-D\beta r+D\theta r+\rho\sigma(\beta-\beta r+\theta r)]n^2}{-8m^3+6mn^2}.
\end{aligned} \tag{15}$$

5. Both Cross-Border Suppliers and Overseas Retailers Hold a Risk-Averse Attitude

In this case, assuming that both cross-border suppliers and overseas retailers are averse to the risk of supply disruption, the expected utility functions of equations (8) and (12) are obtained, respectively. As the leader, the overseas retailer decides the retail price p of the product, and then the cross-border supplier decides the overseas wholesale price w and the main channel purchase price w_a on the basis of the retail price and the standby channel purchase price. According to the reverse induction method, first calculate the response function of the cross-border supplier's main channel purchase price, which has been calculated under the risk-aversion attitude above, $w_a = D\beta + cm - cn + nw + nw_b - D\beta r + D\theta r - nrw_b + nrw_c - \beta\rho\sigma + \beta r\rho\sigma - \theta r\rho\sigma/\ 2m1/2$. The results are brought into the expected utility function of overseas retailers, and partial derivatives are obtained for w_c and w_b, respectively.

$$\begin{aligned}
\frac{\partial U(\pi_r)}{\partial w_b} &= \frac{n(D-\rho\sigma)(\beta-\beta r+\theta r)(r-1)}{m} + \frac{(r-1)\left[(w-c+3w_b-3rw_b+3rw_c)n^2+cmn\right]}{2m} \\
&\quad + (D-2mw_b-D\beta-\rho\sigma+\beta\rho\sigma)(r-1), \\
\frac{\partial U(\pi_r)}{\partial w_c} &= \frac{r\left[(c-w-3w_b+3rw_b-3rw_c)n^2-cmn\right]}{2m} + \frac{n(D-\rho\sigma)(\beta r-\theta r-\beta)}{m} \\
&\quad + \left[2mw_c+(1-\theta)(\rho\sigma-D)\right]r.
\end{aligned} \tag{16}$$

By solving the equations, we can get the purchase price of the main channel and the standby channel. The purchase price of the main channel of cross-border suppliers will change under different risk attitudes. The purchase price of the standby channel of the cross-border supply chain is related to the enterprise's risk attitude and the probability of interruption risk.

$$
\begin{aligned}
w_b^Y &= \frac{n^2(2mw-2cm)+(D-\rho\sigma)\left[4mn(\beta-\beta r+\theta r)-3n^2 r(\theta-\beta)\right]}{8m^3-6mn^2} \\
&\quad+\frac{m(2D-2\rho\sigma-2D\beta+2\beta\rho\sigma+cn)}{4m^2-3n^2}, \\
w_c^Y &= \frac{[2m(w-c)+3D(r-1)(\beta-\theta)]n^2}{8m^3-6mn^2}+\frac{(2D-2\rho\sigma+cn)m+2Dn(\beta-\beta r+\theta r)}{4m^2-3n^2} \\
&\quad+\frac{\rho\sigma\left[\left(3\beta n^2+4\theta m^2-3\theta n^2-4\beta mn\right)+n(4rm-3rn)(\beta-\theta)\right]}{8m^3-6mn^2}, \\
w_a^Y &= \frac{4cm^3+2cn^3-2wn^3+\left(4m^2-n^2\right)(D\beta-D\beta r+D\theta r-\beta\rho\sigma)+r\rho\sigma n(\theta-\beta)(2m+n)}{8m^3-6mn^2} \\
&\quad\frac{Dn(1+\beta r-\beta-\theta r)+n(2wm-2cm+\beta\rho\sigma-cn-\rho\sigma)+(\beta-\theta)2rm\rho\sigma}{4m^2-3n^2}.
\end{aligned}
\tag{17}
$$

Lemma 2. *When r satisfies the following conditions, the purchase price of the main channel will be lower than the purchase price of the backup channel before and after the interruption. This is because when the risk probability of cross-border supplier interruption exceeds a certain range, even if the purchase price of its main channel is reduced, overseas retailers will still tend to purchase goods from alternate channels in order to avoid the loss of stock-out caused by supply disruption.*

$$
\begin{aligned}
r &> \left[m^2(2D-2\rho\sigma+3cn-2nw-2cm-4D\beta+4\beta\rho\sigma)+mn(\rho\sigma-D+3D\beta-3\beta\rho\sigma)\right]/(\theta-\beta)(m-n)(D-\rho\sigma)(2m-n) \\
&\quad+n^2(2mw-2cn+2wn+D\beta-\beta\rho\sigma)/2(\theta-\beta)(m-n)(D-\rho\sigma)(2m-n).
\end{aligned}
\tag{18}
$$

Proof. It can be known from the hypothetical conditions $w_a < w_b < w_c$. We can get $w_b^Y - w_a^Y > 0$ and $w_c^Y - w_a^Y > 0$, and then the above results are obtained by calculation. □

6. Example Analysis

Based on the above model, the simulation analysis is carried out to study the impact of risk attitude on the profit of cross-border e-commerce supply chain system and the changes in wholesale prices of main and backup channels before and after supply disruption. This paper takes the Amazon cross-border e-commerce platform in the United States as an example; that is, the cross-border e-commerce supply chain is composed of suppliers in China (cross-border suppliers) and local suppliers in the United States (overseas suppliers). The sales data and supplier procurement data of the category of commodities are discussed repeatedly with relevant industry experts and scholars to adjust the simulation data and value ranges. The specific values do not represent the actual amount, but only the relative size of each parameter. The assignment of each parameter is as follows.

The product cost of cross-border suppliers is $c = 2$, the wholesale price provided by cross-border suppliers to overseas suppliers is $w = 8$, the distribution coefficient of direct orders from overseas retailers to cross-border suppliers is $\beta = 0.6$, the proportion of products that cross-border suppliers can still provide after interruption is $\theta = 0.2$, and the deterministic demand in the consumer market is $D_0 = 60$. Random variables vary with market demand, $\varepsilon \sim N(0, 5^2)$. The sensitivity of overseas retailers to the purchase price of the main channel and the purchase price of the standby channel is $n = 0.1, m = 0.25$. In order to simplify the model calculation, the risk attitudes of cross-border suppliers and overseas retailers are consistent, so that $\rho = 0.5$.

6.1. Comparative Analysis of Interruption Risk Probability on Purchase Prices of Different Channels. After the risk of interruption in the cross-border e-commerce supply chain occurs, due to the different decisions taken by the enterprise entities in the supply chain to reduce the risk, whether it is conscious avoidance measures or unconscious price reduction strategies, the change of the probability of supply disruption will affect the purchase price of the retailer's main channel and the purchase price of the standby channel. According to Lemma 2, bring in the set parameters to know when $r > 0.1551$, and make the model meet the conditions $w_a < w_b < w_c$. Suppose the value range of r is $[0.2, 0.9]$. The changes of purchase prices provided by cross-border suppliers and overseas suppliers under the four risk attitudes are shown in Figure 2.

It can be seen from the above figure that as the risk of supply disruption of cross-border suppliers increases, the purchase prices provided by suppliers from different

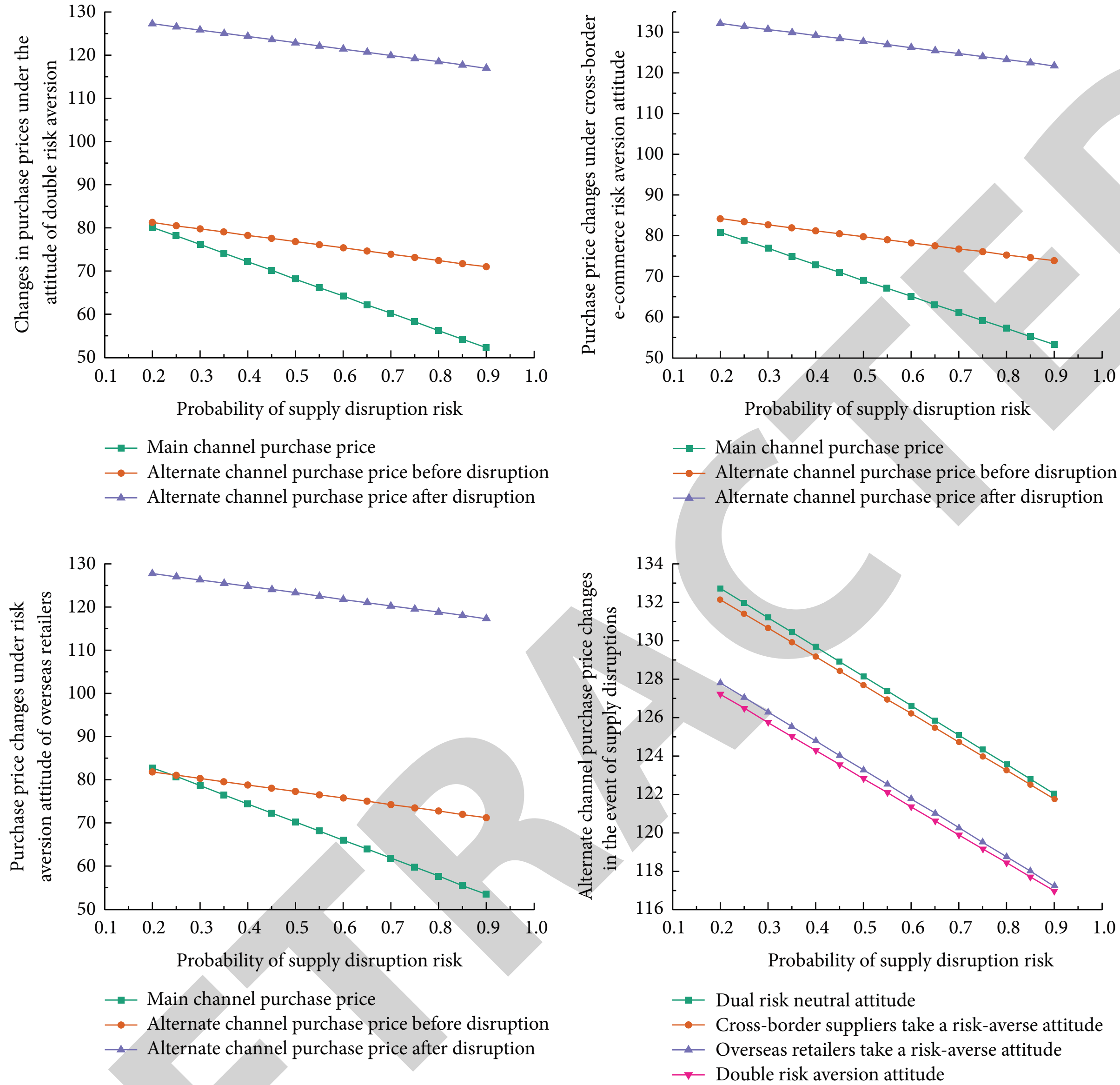

FIGURE 2: Purchase price changes of overseas retailers under different supply disruption probabilities.

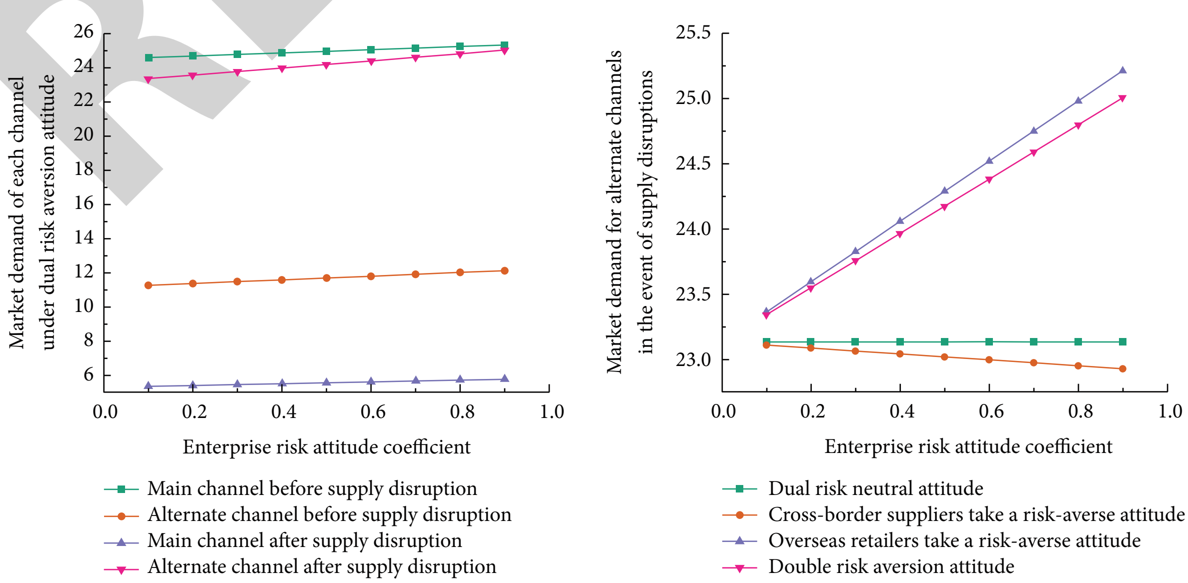

FIGURE 3: Relationship between enterprise risk attitude coefficient and market demand.

channels will decrease. This is because cross-border suppliers and overseas suppliers will adopt price reduction strategies as the risk increases in order to compete for market share, meet consumer demand, and reduce the purchase concerns of downstream retailers. However, before and after the supply disruption, the price of the standby channel is always higher than the purchase price of the main channel. Especially after the supply disruption, the price of the standby channel of overseas suppliers will increase significantly, which is far higher than the purchase price of the main channel and the original price. When overseas retailers tend to avoid risk and cross-border suppliers and overseas suppliers hold a risk-neutral attitude, the purchase price of standby channels will be higher than that of main channels only when the probability of interruption risk is increased to 0.267, indicating that when the risk is increased to a certain extent, even if it is an evasive overseas retailer, it still needs reaction time to formulate risk-aversion strategies. At the same time, it can be found that when both overseas retailers and cross-border suppliers hold a risk-aversion attitude, the retailer's purchase price is the lowest, and the change range is the largest. When both overseas retailers and cross-border suppliers hold a risk-neutral attitude, the purchase price is the highest, and the change range is the smallest.

6.2. Influence of Enterprise Risk Attitude Coefficient on Market Demand of Different Channels. Enterprises in the cross-border e-commerce supply chain hold different risk attitudes. With the increase of the risk attitude coefficient, it means that the stronger the enterprise's awareness of risk aversion is, the more the attention it will pay to the problem of supply disruption, which will inevitably affect the order quantity of retailers in the main and standby channels, that is, the market demand. Assuming the probability of interruption risk $r = 0.3$, both cross-border suppliers and overseas retailers hold a risk-aversion attitude. In the other three cases, the change of risk attitude coefficient and market demand of different channels is shown in Figure 3.

It can be seen from the analysis of Figure 3 that, in the cross-border e-commerce supply chain, with the enhancement of risk-aversion awareness ρ of the participants, no matter whether the cross-border suppliers have the problem of supply disruption, the purchase volume of retailers from different channels, that is, market demand, will increase, and vice versa. The total market demand before the supply disruption is much higher than that after the supply disruption. The reason is that, after the interruption, the supply of cross-border suppliers directly to overseas retailers decreases. Due to market fluctuations and the need to ensure the supply source, overseas retailers will also reduce the procurement volume of main channels and increase the procurement volume of standby channels; that is, the market demand of main channels before the supply disruption is the largest, and the market demand of backup channels for supply disruption is the largest. At the same time, it can be found that, in the four risk attitude situations, the market demand of the standby channel under the dual risk-neutral attitude will not change. When only the cross-border supplier holds the risk-aversion attitude, the demand of its standby channel products will be reduced slightly. At this time, the cross-border supplier will first meet the demand of the main channel, avoid risk, and reduce the intermediate circulation link. However, in the case of a dual risk-aversion attitude and only one overseas retailer holds a risk-aversion attitude, the market demand of backup channels for supply disruption is positively correlated with the risk attitude coefficient. Combined with Figure 4, the supply disruption risk probability and enterprise risk attitude coefficient will have an impact on the market demand of different channels. It is found that the supply disruption probability has a small impact on the market demand of standby channels and a large impact on the market demand of main channels, while the impact of the risk attitude coefficient on the market demand of the two channels is similar. Overall, when the risk awareness of overseas retailers or cross-border suppliers is relatively high, the overall market demand of cross-border e-commerce supply chain will show an upward trend.

6.3. Influence of Parameters on Objective Function of Cross-Border E-Commerce Supply Chain. In order to more intuitively observe the influence of different parameters on the enterprise objective function, set the value range of r as (0.3, 0.9), the value range of ρ as (0.1, 1), and the value range of β as (0.5, 1). The change of objective function in two cases is obtained by simulation analysis. The utility change of a single overseas retailer and cross-border supplier in maintaining a risk-aversion attitude is similar to that of double aversion, so it is not listed.

As can be seen from Figure 5, when both cross-border suppliers and overseas retailers maintain a risk-neutral attitude, retailers increase the distribution coefficient of purchases from cross-border suppliers, and the profits of cross-border suppliers will increase. On the contrary, the profits of overseas retailers do not change significantly. At the same time, as the probability of interruption risk increases, the profits of cross-border suppliers will decrease, while the profits of overseas retailers will not change because at this time, overseas retailers will purchase goods from overseas suppliers. As shown in Figure 5, when both cross-border suppliers and overseas retailers hold a risk-aversion attitude, the fluctuation of enterprise target utility is small, and the expected utility of overseas retailers will not change significantly with the degree of risk aversion and interruption probability. Similar to the double neutral situation, the expected utility of cross-border suppliers will decrease with the increase of interruption probability. In both cases, the expected profit and expected utility of overseas retailers are much higher than those of cross-border suppliers because whether overseas retailers have a risk-averse attitude or not, they are in a dominant position in the supply chain and will replenish to multiple suppliers after supply disruption. Cross-border suppliers expect a large increase in profits only when the distribution coefficient is high. In case of supply disruption, overseas retailers will reduce the procurement distribution coefficient. It is required that cross-border suppliers should have risk-aversion awareness,

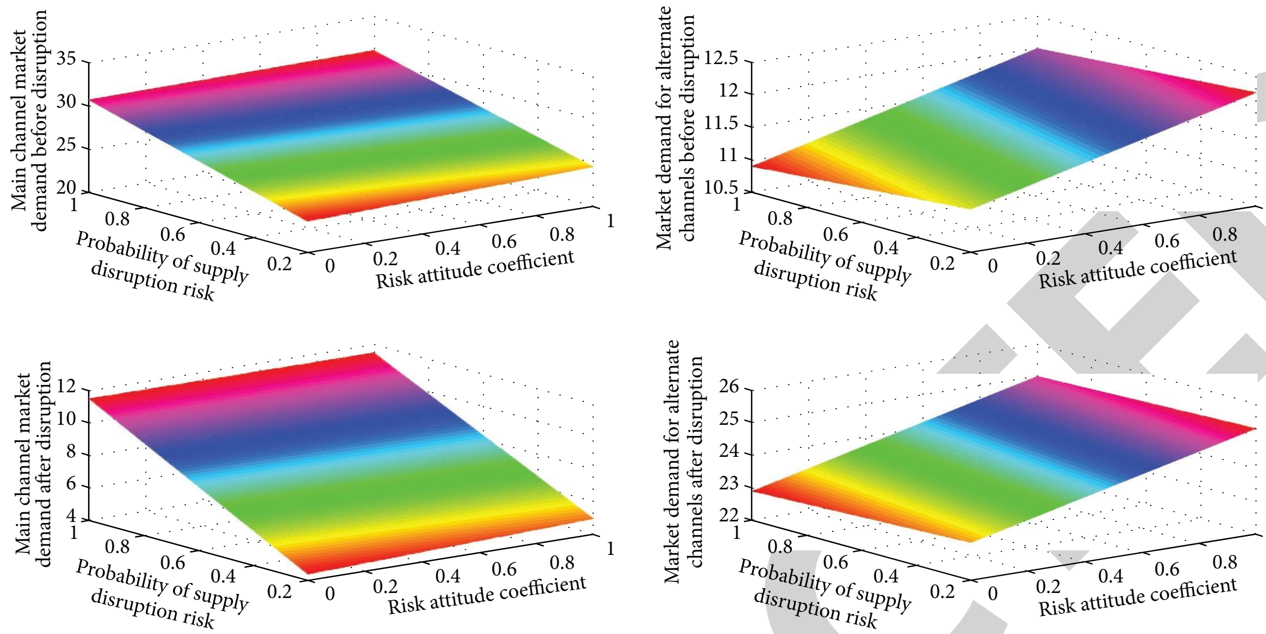

Figure 4: Impact of ρ and r on market demand in the case of dual risk-aversion attitude.

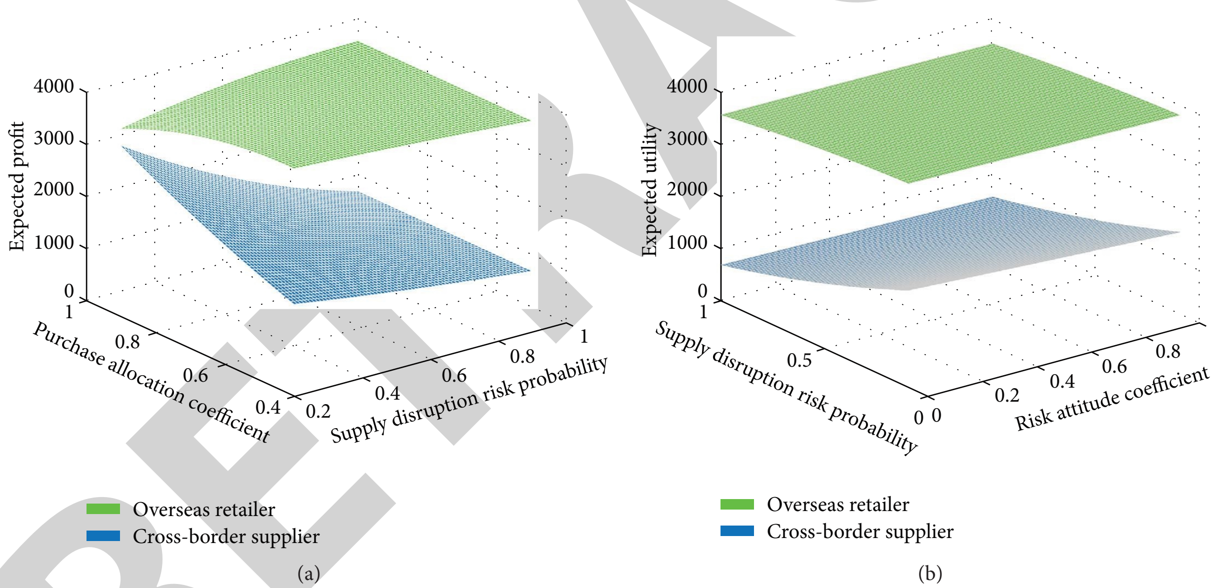

Figure 5: Changes of parameters, expected profit, and utility of enterprises under dual neutral and dual risk-aversion attitude. (a) Influence of parameters β and r on enterprise target profit. (b) Influence of parameters β and r on enterprise target utility.

formulate risk-aversion strategies, and resume supply as soon as possible.

7. Conclusion

Aiming at the enterprise risk decision-making problem of supply chain prone to supply disruption, this paper constructs a cross-border e-commerce supply chain composed of cross-border suppliers, overseas suppliers, overseas retailers, and consumers. Combined with the enterprise's risk attitude preference, it has a risk avoidance attitude towards a single cross-border supplier. This paper analyzes the pricing decision, market demand, target profit, and utility of products in different channels under the four situations of a single overseas retailer maintaining a risk-aversion attitude and cross-border suppliers and overseas retailers holding a risk-neutral or risk-aversion attitude. The results show that, with the increase of supply disruption risk probability of cross-border suppliers, the purchase price will show a downward trend in all four cases, among which the purchase price of main channels will decline the most, and when the interruption probability reaches a certain degree, the price difference between main channels and standby channels will become larger and larger. The simulation results show that, before the interruption, the market demand of the main channel is the main demand, and after the interruption, the market demand of the standby channel is the main demand. Affected by the enterprise's risk attitude coefficient, with the enhancement of risk-aversion awareness, the demand of a single overseas retailer with risk aversion and dual risk-aversion attitude will increase. At the same time, it is found that the risk probability of supply disruption and risk-aversion coefficient have little impact on the expected utility of overseas retailers but have a greater impact on the expected utility of cross-border suppliers.

Therefore, in the dual-channel supply chain of cross-border e-commerce where overseas retailers are dominant, the risk-averse attitude of cross-border suppliers will have an important impact on the product purchase price and expected utility, and cross-border suppliers should try to improve their risk-averse awareness and adopt proactive pricing strategies. At the same time, each member of the cross-border e-commerce supply chain should be committed to the research of scientific risk prediction methods and do risk assessment in advance in order to reduce the risk loss brought by supply disruption. In the subsequent research, we can further consider how to construct a cross-border e-commerce risk early warning model and assessment system and how noncore members of the supply chain holding risk-averse attitudes can gain advantages under the dual-source procurement pricing decision.

Data Availability

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

Conflicts of Interest

All authors declare no conflicts of interest in this paper.

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