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Research on Retailers' Ordering Strategies Considering Customer Behavior Responses Under the Risk of Supply Disruption

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Abstract: On the basis of considering a two-level supply chain consisting of a retailer and two suppliers, the expected profit model under the single-source and dual-source procurement patterns of the retailer was constructed to explore the impact of supply disruption risk on the retailer's choice of suppliers, and then to obtain the optimal ordering strategy and the expected profit of the retailer under different conditions. Results show that: (1) Retailers' ordering strategies are influenced by a variety of factors, such as the risk of supply disruption, the selling price of goods, the retailer's out-of-stock costs, option contract prices, and execution prices. That is, retailers are more inclined to adopt a dual-source sourcing strategy when option prices and strike prices decrease or when selling prices and out-of-stock costs increase. (2) Retailers would choose to single source from risk suppliers rather than option suppliers in order to maximize profits. (3) When the risk of supply interruption increases, the expected profit of retailers would decrease. Although the use of option contracts can withstand certain interruption risks, adding option suppliers is not always better than purchasing from risk suppliers alone.

Keywords: Supply disruption risk, Option contracts, Ordering strategy.

1. Introduction

With the development of global purchasing and sales, business outsourcing, lean production and other operation modes, the supply chain has a more complex network structure, and its interruption risk has also shown an increasing trend [1]. Accenture surveyed 151 large U.S. supply chain companies, and 73% of them experienced severe supply disruptions in the past five years, resulting in significant losses, and 36% of them took more than a month to recover [2]. The increased uncertainty of international trade relations and the unstable development of the new crown epidemic have led many parts of the country to adopt a series of control measures such as "lockdown", control of the movement of people, extension of public holidays and control of transportation, which have exacerbated the risk of supply disruption.

In the face of frequent supply interruptions, enterprises need to formulate reasonable ordering strategies for risk control. At present, the research on ordering strategy mainly includes: the number of suppliers [3-6], order allocation [7-10] and combined contract theory [11-17] Coordinate the entire supply chain, etc. Among them, Huang Ran [3] explored the relationship between enterprise default risk and the selection of supplier number, and the results show that the enterprise default risk changes positively U-shaped with the increase of the number of suppliers. Arnt [4] found that increasing the number of suppliers can reduce the negative impact of information asymmetry on enterprises. Xie Xia [5] explored the specific changes of ordering strategies under dual-source procurement or single-source procurement from the perspective of manufacturers. Niu Baozhuang [6] conducted a separate exploration on the dual-source procurement strategy and found that the dual-source procurement strategy can make the supply more stable, and at the same time, the addition of local backup suppliers can resist cross-border to a certain extent Risk of disruption and enhance supply chain robustness. If you have multiple suppliers, proper order allocation is critical. Under the condition of information asymmetry, Pan Wei [7] constructed and analyzed a multi-product linear order allocation model with fuzzy targets, random constraints and scenario analysis, and formulated an optimal demand allocation strategy. Nengmin [8] establishes a dynamic game theory model to obtain the optimal order quantity and supplier arrangement decision of the enterprise. Furthermore, Dong Yinhong [9] incorporated supply risk into the model and studied the impact of supply risk on order allocation under the dual-source procurement model. Some scholars have introduced contract theory into supply chain risk management to increase supply chain flexibility and reduce the negative impact of supply interruption risk. The current literature on contract theory mainly includes wholesale price contracts [10], revenue sharing contracts [11], and repurchase contracts [12], option contracts [13-17]. The main purpose of the contract is to urge participants to maximize profits by sharing the required resources, enhance communication and collaboration between enterprises, and jointly resist the risk of supply disruption and reduce losses.

Among them, options, as a risk avoidance tool derived from futures, are a financial means, which have the characteristics of quantitative flexible contracts and the essence of return strategies. Among them, Merzifonluoglu [13] determines customer demand, selection, and commodity purchase quantity with the goal of optimizing option contracts in the presence of the spot market. Options are further divided into one-way options and two-way options, and one-way options include put options and call options. Wang [14] introduced put options into the ordering strategy of fresh products to explore the impact of option contracts on the optimal ordering strategy, while Hu [15] introduced put options and call options into the research of rescue material ordering strategies, respectively, to seek the optimal purchase quantity under the option contract to achieve the best rescue effect. Patra [16] introduced two-way option contracts into the procurement strategy model, and flexibly adjusted the purchase volume to reduce the risk of supply interruption and the risk of excess inventory. In addition, Aghajani [17] designed a new two-phase option contract combining supplier selection to explore the impact of increasing the option duration on retailers' purchasing strategies.

From the existing literature, the research of option contracts in the supply chain is mostly the impact of option contracts on the optimal order quantity and pricing under single-source procurement, while this paper studies the ordering strategy of retailers in a two-level supply chain composed of one retailer and two suppliers, one supplier is a risk supplier, the goods provided are at risk of supply interruption, and the other supplier provides goods to retailers in the form of option contracts, called option suppliers. This paper discusses the objective function of retailers with the highest expected return under constant demand, constructs a model to obtain the optimal order quantity under the implementation of single-source procurement or dual-source procurement strategy, and finally discusses the influence of relevant parameters on the optimal order quantity and expected profit through numerical analysis.

2. Description of the Problem and Assumptions

2.1. Problem Description and Assumptions

This paper considers a two-tier supply chain consisting of two suppliers and one retailer, as shown in Figure 1. Providers are divided into risk providers and options providers. When a retailer orders a quantity of goods from supplier A with Q, supplier A provides a quantity of goods of xQ. x is the interrupt risk coefficient, which is a random variable between [0,1] with a probability density function f(x) and a distribution function F(x). B option supplier through the signing of option contract stable supply, option unit price is c_{b1}, contract execution unit price is c_{b2}, if the option contract signing quantity is q, the maximum number of goods supplied by the option supplier is q.

This paper assumes that suppliers and retailers in the two-tier supply chain are information-symmetrical, and that decision-makers are risk-neutral and in a perfectly competitive market. Two suppliers offer a single homogeneous commodity, allowing for shortages and backlogs of goods; Retailers are completely rational and only consider the maximization of their own interests; When the market environment is stable, the market demand is constant D.

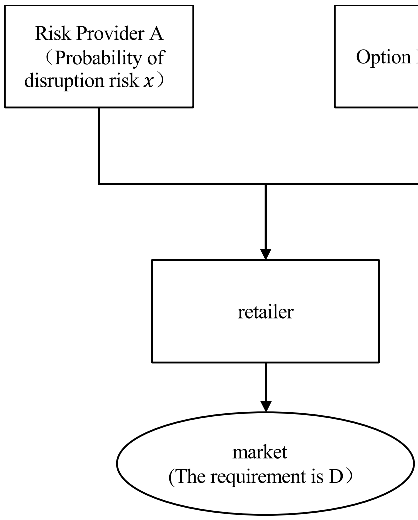

Figure 1. Two-tier supply chain model

2.2. Definition of parameters and decision variables

Table 1 describes the variables used in this article and their descriptions

Table 1. Related variables and descriptions

Symbol		Illustrate
Decision variables	Q	Order quantity from risk supplier A
	q	Purchase the amount of the option from option provider B
Objective function	π_1	The retailer only purchases profit from risk supplier A
	π_2	The retailer makes a profit when entering into an option contract
Parameter	c_{a1}	The unit price of purchase from risk vendor A
	c_{b1}	The unit purchase price of the option
	c_{b2}	The unit strike price of the option
	b	Unit out-of-stock cost
	h	Salvage value per unit of goods
	P	The unit item sales price
	D	Market demand under market stability

In this model, the main difference between a risk provider and an options provider is the price at which the commodity is offered. Options contracts have a purchase price and an execution price. In order to the option contract to be meaningful, the option strike price needs to be lower than the commodity price offered by the risk provider. Risky suppliers, on the other hand, are subject to the risk of supply disruption and will not offer retailers at prices higher than the market retail price. To avoid unnecessary meaningless solutions, set $P > c_{a1} > c_{b2}$. Based on the above variables and parameters, retailers can build relevant models to analyze how retailers choose between two suppliers when faced with changes in various parameters.

3. Model Construction and Analysis

3.1. Single-source ordering

If a retailer uses a single-source ordering strategy and orders Q unit goods at a price from risk supplier c_{a1}A, the retailer's profit function is:

$$\pi_1 = Pmin(D, xQ) - c_{a1}xQ - bmax(D - xQ, 0) + hmax(xQ - D, 0) \quad (1)$$

The first item on the right side of the medium is sales revenue, the second item is the purchase cost, the third item is the out-of-stock cost, and the fourth item is the residual value of the goods. For a retailer to be profitable, the variables need to be satisfied:$P > c_{a1} > b > h > 0$. According to this, the average of the supply disruption risk factor $E[\min(Q, x)] = \int_0^Q [1 - F(x)]dx$, The mean risk in supply is μ. So the retailer's expected profit can be reduced to:

$$E(\pi_1) = (-P - b + h)Q \int_0^{\frac{D}{Q}} F(x)dx + (P - h)D + (h - c_{a1})\mu Q \quad (2)$$

Proposition 1: Under the single-source procurement strategy, the optimal purchase volume of retailers is satisfied $\int_0^{\frac{D}{Q_1^*}} xf(x)dx = \frac{(c_{a1}-h)\mu}{P+b-h}$.

Proof: The $E(\pi_1)$first derivative and second derivative of Q will be found respectively:

$$\frac{dE(\pi_1)}{dQ} = (-P - b + h)[\int_0^{\frac{D}{Q}} F(x)dx - \frac{DF\left(\frac{D}{Q}\right)}{Q}] + (h - c_{a1})\mu \quad (3)$$

$$\frac{d^2E(\pi_1)}{dQ^2} = \frac{(-P-b+h)D^2 f\left(\frac{D}{Q}\right)}{Q^3} \quad (4)$$

Because, $P > c_{a1} > b > h > 0,\ h - P - b < 0$, Launched $\frac{\partial^2 E(\pi_1)}{\partial Q^2} < 0$. So, it can be seen that Equation (4) is a concave function. Then let Equation (3) equal to zero, that is, we can get the optimal order quantity for single-source procurement satisfied Q_1^*: $\frac{DF\left(\frac{D}{Q_1^*}\right)}{Q_1^*} - \int_0^{\frac{D}{Q_1^*}} f(x)dx = \frac{(c_{a1}-h)\mu}{P+b-h}$. Finally, the simplification conversion can be:

$$\int_0^{\frac{D}{Q_1^*}} xf(x)dx = \frac{(c_{a1}-h)\mu}{P+b-h} \quad (5)$$

In the common equation (5), it is assumed above, so $P > c_{a1}$ it is known $\frac{(c_{a1}-h)}{P+b-h} < 1$. And $\mu = \int_0^1 xf(x)dx$ in turn, you can get. It shows that in the case of a retailer adopting a single-source order $\frac{D}{Q_1^*} < 1$, the optimal order quantity is greater than the demand value due to the risk of supply interruption.

Nature 1: Under the single-source procurement strategy, the optimal order quantity (Q_1^*), increases with the increase of purchase price (c_{a1}), and the average μ of interruption risk, and decreases with the increase of sales price, out-of-stock cost, and salvage value.

Proof: Suppose $G(Q_1^*) = \int_0^{\frac{D}{Q_1^*}} xf(x)dx$, then equation (5) can be simplified to $G(Q_1^*) = \frac{(c_{a1}-h)\mu}{P+b-h}$, the above equation is paired, and c_{a1}、μ、P、b、h can be derived:

$$\frac{dG}{dc_{a1}} = \frac{\mu}{P + b - h} > 0$$

$$\frac{dG}{d\mu} = \frac{c_{a1} - h}{P + b - h} > 0$$

$$\frac{dG}{dP} = -\frac{(c_{a1} - h)\mu}{(P + b - h)^2} < 0$$

$$\frac{dG}{db} = -\frac{(c_{a1} - h)\mu}{(P + b - h)^2} < 0$$

$$\frac{dG}{dh} = \frac{(c_{a1} - h)\mu - \mu(P + b - h)}{(P + b - h)^2} = \frac{(c_{a1} - P - b)\mu}{(P + b - h)^2} < 0$$

Therefore, the optimal order quantity is about the commodity price of the Q_1^* risk supplier, the c_{a1} average value of interruption risk μ monotonically increasing, the sales price P, the out-of-stock cost b, and the residual value of the commodity h Monotonically diminishing.

3.2. Dual-source ordering strategy

The retailer adopts a dual-source ordering strategy, i.e. ordering Q units at price from risk supplier A $c_{a1}$and option supplier B Conclude an option contract with a unit price of c_{b1} The option quantity is q and the option strike price is c_{b2} In order to ensure that the retailer is profitable, it is assumed that $P + b > c_{b1} + c_{b2}$, the profit function of the retailer under the dual-source ordering strategy is:

$$\pi_2 = Pmin(D, xQ + q) - c_{a1}xQ - c_{b1}q - c_{b2}\min(\max(D - xQ, 0), q) - bmax(D - xQ - q, 0) + hmax(xQ - D, 0) \quad (6)$$

The first item on the right side of the equation is the total revenue received by the retailer, the second item is the cost of the retailer ordering from risk supplier A, the third item is the price of the option contract with option supplier B, and the fourth item is the option contract after it becomes effective Option Supplier B's purchase cost, the fifth item is the out-of-stock cost, and the last item is the residual value of the remaining goods. The retailer's profit expectations can be reduced to:

$$E(\pi_2) = (-P + c_{b2} - b)Q \int_0^{\frac{D-q}{Q}} F(x)dx - (c_{b2} - h)Q \int_0^{\frac{D}{Q}} F(x)dx + (P - h)D + (h - c_{a1})\mu Q - c_{b1}q \quad (7)$$

$$E(\pi_2) = (-P + c_{b2} - b)Q\int_0^{\frac{D-q}{Q}} F(x)dx - (c_{b2} - h)Q\int_0^{\frac{D}{Q}} F(x)dx + (P-h)D + (h - c_{a1})\mu Q - c_{b1}q$$

Proposition 2: The retailer's expected profit is a $E(\pi_2)$ joint concave function about Q and q.

Prove:

$$\frac{\partial E(\pi_2)}{\partial Q} = (-P + c_{b2} - b)\left(\int_0^{\frac{D-q}{Q}} F(x)dx - \frac{D-q}{Q}F\left(\frac{D-q}{Q}\right)\right) - (c_{b2} - h)\left(\int_0^{\frac{D}{Q}} F(x)dx - \frac{D}{Q}F\left(\frac{D}{Q}\right)\right) + (h - c_{a1})\mu$$

$$\frac{\partial^2 E(\pi_2)}{\partial Q^2} = \frac{(-P+c_{b2}-b)(D-q)^2 f\left(\frac{D-q}{Q}\right) - (c_{b2}-h)D^2 f\left(\frac{D}{Q}\right)}{Q^3}$$

$$\frac{\partial E(\pi_2)}{\partial q} = -(-P + c_{b2} - b)F\left(\frac{D-q}{Q}\right) - c_{b1}$$

$$\frac{\partial^2 E(\pi_2)}{\partial q^2} = \frac{(-P+c_{b2}-b)f\left(\frac{D-q}{Q}\right)}{Q}$$

$$\frac{\partial^2 E(\pi_2)}{\partial q \partial Q} = \frac{\partial^2 E(\pi_2)}{\partial Q \partial q} = \frac{(-P+c_{b2}-b)(D-q)f\left(\frac{D-q}{Q}\right))}{Q^2}$$

$$|H_1| = \frac{\partial^2 E(\pi_2)}{\partial Q^2} < 0$$

$$|H_2| = \begin{vmatrix} \frac{\partial^2 E(\pi_2)}{\partial Q \partial q} & \frac{\partial^2 E(\pi_2)}{\partial Q \partial q} \\ \frac{\partial^2 E(\pi_2)}{\partial q \partial Q} & \frac{\partial^2 E(\pi_2)}{\partial q^2} \end{vmatrix} = -\frac{(P-c_{b2}+b)(h-c_{b2})D^2 f\left(\frac{D-q}{Q}\right)f\left(\frac{D}{Q}\right)}{Q^4} > 0$$

Because the Hesse matrix is negative, the retailer's $E(\pi_2)$ expected profit is a joint concave function of Q and q.

So, $\frac{\partial \mathrm{E}(\pi_2)}{\partial \mathrm{Q}} = 0$ the order can get the optimal order quantity $\frac{\partial \mathrm{E}(\pi_2)}{\partial \mathrm{q}} = 0$ of the retailer to risk provider A and option supplier B, Q_2^* and q_2^*

Proposition 3: The retailer needs to order quantities from risk supplier A.

Proof: Using the Lagrange multiplier method for calculation, the Lagrange multiplier λ_1 is introduced to λ_2 form the Lagrange function as , and the KKT condition has the following formula: $L(Q, q, \lambda_1, \lambda_2) = E(\pi_2) + \lambda_1 Q + \lambda_2 q$:

$$\begin{cases} \lambda_1 Q = 0 & ① \\ \lambda_2 q = 0 & ② \\ \frac{\partial L}{\partial Q} = \frac{\partial E(\pi_2)}{\partial Q} + \lambda_1 = 0 & ③ \\ \frac{\partial L}{\partial \mathrm{q}} = \frac{\partial E(\pi_2)}{\partial \mathrm{q}} + \lambda_2 = 0 & ④ \\ q \geq 0, Q \geq 0, \lambda_1 \geq 0，\lambda_2 \geq 0 & ⑤ \end{cases} \quad (8)$$

If Q=0, then the retailer does not $F\left(\frac{D-q}{Q}\right) = F\left(\frac{D}{Q}\right) = 1$ order from risk supplier A, then it must order from option supplier B, so $q > 0$. According to (2) can be obtained $\lambda_2 = 0$, the above conditions can be brought into (4) to solve:

$$-(-P + c_{b2} - b)F\left(\frac{D-q}{Q}\right) - c_{b1} + \lambda_2 = 0$$

The above formula can be simplified, indicating that if the retailer only $P + b = c_{b1} + c_{b2}$ purchases goods from supplier B, the breakeven is inconsistent with the previous assumptions, so the retailer will purchase goods from risk supplier A in order to make a profit $P + b > c_{b1} + c_{b2}$. Instead of relying solely on option contracts for the purchase and sale of goods.

According to propositions 2 and 3, there are two types of retailer procurement strategies, one is to purchase goods from risk supplier A separately, which confirms that the previous single-source procurement strategy assumptions are correct; The second is to purchase from both risk provider A and option supplier B, and proposition 4 can be obtained when seeking the optimal order quantity.

Proposition 4: If the optimal strategy of the retailer is to order from $\frac{c_{\mathrm{b1}}}{P+b-c_{\mathrm{b2}}} \geq F\left(\frac{D}{Q}\right)$ a single source, that is, only order unit goods from risk supplier A; If so, the retailer's $\frac{c_{\mathrm{b1}}}{P+b-c_{\mathrm{b2}}} < F\left(\frac{D}{Q}\right)$ optimal strategy is a dual-source ordering strategy $Q^* = Q_2^*, q^* = q_2^*$.

Proof: $q = 0, Q > 0$. According to equation (8), it is $\lambda_1 = 0, \lambda_2 \geq 0$substituted into (3)(4):

$$\frac{\partial L}{\partial Q} = (-P + h - b)\left(\int_0^{\frac{D}{Q}} F(x)dx - \frac{D}{Q}F\left(\frac{D}{Q}\right)\right) + (h - c_{a1})\mu = 0$$

$$\frac{\partial L}{\partial q} = -(-P + c_{b2} - b)F\left(\frac{D}{Q}\right) - c_{b1} + \lambda_2 = 0$$

The solution can be obtained $\lambda_2 = c_{b1} + (-P + c_{b2} - b)\frac{Q}{D}[\int_0^{\frac{D}{Q}} F(x)dx + \frac{(c_{a1}-h)\mu}{P+b-h}] \geq 0$, reduced to. $\int_0^{\frac{D}{Q}} F(x)dx \leq \frac{c_{b1}D}{(P+b-c_{b2})Q} - \frac{(c_{a1}-h)\mu}{P+b-h}$. If, $q = 0, Q > 0$ then Q satisfies equation (5) , substitution yields $\int_0^{\frac{D}{Q}} F(x)dx \leq \frac{c_{b1}D}{(P+b-c_{b2})Q} - \frac{(c_{a1}-h)\mu}{P+b-h}$. Then simplify to get $\frac{c_{\mathrm{b1}}}{P+b-c_{\mathrm{b2}}} \geq F\left(\frac{D}{Q}\right)$. So, at that time, retailers used single-source $\frac{c_{\mathrm{b1}}}{P+b-c_{\mathrm{b2}}} \geq F\left(\frac{D}{Q}\right)$ ordering.

If, according to $\frac{c_{b1}}{P+b-c_{b2}} < F\left(\frac{D}{Q}\right)$ proposition 3, it can be seen that the situation does not exist, so $q^* > 0, Q^* = 0$only there is, that is $q^* > 0, Q^* > 0$, the retailer adopts a dual-source purchasing strategy.

Nature 2: When the strike price of an option contract increases or the purchase price of an option unit decreases, the retailer increases the likelihood that the retailer will order from two suppliers at the same time.

It can be seen from the condition of proposition 4 that when c_{b2} increasing, c_{b1} decreasing, $\frac{c_{\mathrm{b1}}}{P+b-c_{\mathrm{b2}}}$ decreasing, the probability of $\frac{c_{\mathrm{b1}}}{P+b-c_{\mathrm{b2}}} \geq F\left(\frac{D}{Q}\right)$ decreases, and the retailer increases the possibility of adopting a dual source purchasing strategy.

Nature 3: When retailers adopt a dual-source procurement strategy, (1) the optimal order quantity $Q_2^*(q_2^*)$ increases (increases) with the increase of retail price and out-of-stock cost, respectively; (2) $Q_2^*(q_2^*)$ increases (decreasing) as the option provider's option strike price and option unit price increase; (3) $Q_2^*(q_2^*)$ decreasing (increasing) as the unit price of the risk supplier increases.

Proof: Because of the complexity of the problem, the optimal order quantity is an implicit solution, and it can be assumed that the probability of interruption risk follows a uniform distribution for ease of calculation，$x \sim U[\mu - a, \mu + a]$, $F(x) = \frac{x-(\mu-a)}{2a}$, 令 $\frac{\partial E(\pi_2)}{\partial Q} = 0$, $\frac{\partial E(\pi_2)}{\partial q} = 0$.

Simplification is available:

$$\begin{cases} m(\frac{D-q}{Q})^2 + t(\frac{D}{Q})^2 - 4ag\mu = 0 \\ \frac{D-q}{Q} = \frac{2ac_{b1}}{m} - a + \mu \end{cases} \tag{9}$$

Solving the above binary primary equation yields the optimal order quantity of:

$$\begin{cases} Q_2^* = \frac{D\sqrt{mt}}{\sqrt{4m\mu a\left(g+\frac{m}{2}-c_{b1}\right)-(m-2c_{b1})^2a^2-m^2\mu^2}} \\ q_2^* = D - (\frac{2ac_{b1}}{m} - a + \mu)\frac{D\sqrt{mt}}{\sqrt{4m\mu a\left(g+\frac{m}{2}-c_{b1}\right)-(m-2c_{b1})^2a^2-m^2\mu^2}} \end{cases}$$

Thereinto $m = P + b - c_{b2}, t = c_{b2} - h, g = c_{a1} - h$。

The above formula derives the risk supplier cost, option strike price, option purchase price, sales price, out-of-stock cost and commodity residual value respectively to obtain property 3.

4. Conclusion

This paper examines how retailers can adopt reasonable ordering strategies to resist the risk of supply disruption in the face of different market needs when they expect to maximize profits. Through theoretical and numerical analysis, the conclusions are as follows:

(1) Changes in supply disruption risk will revere retailers' purchasing strategies and reduce their expected profits. Adding an option provider under certain conditions can effectively reduce losses caused by the risk of supply disruption, but this is not always better than single-source procurement.

(2) The selection of suppliers depends on the value relationship between option price, commodity sales price, out-of-stock loss and supply interruption risk. When the option strike price and the option purchase price gradually decrease, or the commodity price sales grid gradually increases, the retailer moves to the same time The likelihood of purchasing from two suppliers increases.

(3) For retailers, only ordering from option suppliers, reducing inventory costs and resisting the risk of supply interruption is not the optimal strategy; For options providers, offering options contracts at lower prices does not necessarily increase retailers' orders; For at-risk suppliers, efforts to improve their capabilities and reduce the risk of disruption caused by endogenous causes will increase the number of orders retailers place from them.

This paper only considers the impact of supply-side uncertainty on retailers' ordering strategies and does not consider the uncertainty on the demand side, which is also the next research content.

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