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# Fresh product e-tailer’s optimal fresh-keeping strategy under three scenarios

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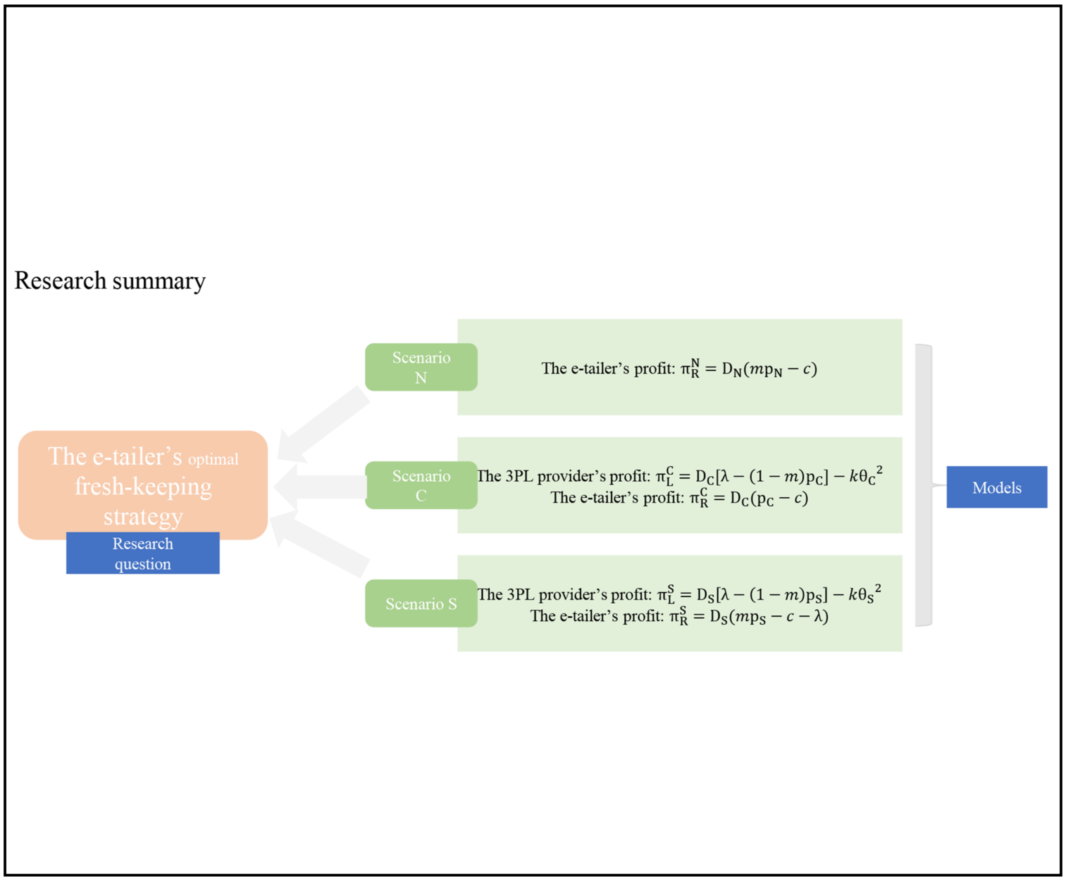
## Graphical abstract



## Public summary

- Investigate the e-tailer’s fresh-keeping strategy in a context fresh-keeping service which is open to the e-tailer and consumers.
- Obtain the conditions of the e-tailer’s optimal fresh-keeping strategy and find that it relates to the coefficient of fresh-keeping cost and the unit fresh-keeping service fee.
- Study the influence of different policyholders of fresh-keeping services on 3PL providers’ fresh-keeping efforts.

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**Abstract:** In the direct sales model, the e-tailers sell fresh products to consumers in the online market and promise consumers a full-refund policy without return. Consumers are always concerned the products' freshness level before purchasing online fresh products. Third-party logistics (3PL) providers will be motivated to exert a fresh-keeping effort to keep the fresh product at the optimum level when offering consumers or e-tailers fresh-keeping services. Considering the fresh-keeping service provided by 3PL providers, to alleviate consumers' concerns about the freshness level and encourage them to purchase fresh products, some e-tailers will purchase fresh-keeping services from 3PL providers and offer them to consumers for free. However, some e-tailers have stopped offering the free service; they have offered consumers the opportunity to purchase fresh-keeping services. To explore an e-tailer's optimal fresh-keeping strategy, we consider a market consisting of an e-tailer and a 3PL provider. Three alternative scenarios are discussed, scenario N: no fresh-keeping service; scenario C: some consumers voluntarily purchase fresh-keeping services; and scenario S: the e-tailer offers a complementary fresh-keeping service. We find that introducing a fresh-keeping service increases the retail price in scenario C when the coefficient of fresh-keeping cost is high and the unit fresh-keeping service fee is low, but that decreases in scenario S when the unit fresh-keeping service fee is low. Comparing the e-tailer's equilibrium profits, we find that introducing a fresh-keeping service does not necessarily benefit the e-tailer. The coefficients of fresh-keeping costs and unit fresh-keeping service fees play a critical role in selecting the fresh-keeping strategy. Meanwhile, the 3PL provider is biased; specifically, the 3PL provider's fresh-keeping effort is related to that of the policyholder.

**Keywords:** fresh product; fresh product supply chain; fresh-keeping service; fresh-keeping effort

**CLC number:** F252; F724.6 **Document code:** A

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## 1 Introduction

With the development of e-commerce, the market for fresh global products has been growing rapidly since 2015. In 2020, affected by the COVID-19 pandemic, fresh product e-commerce, characterized by "contactless delivery", had shined and grown rapidly. In China, the fresh product e-commerce transaction amount in 2021 reached ¥ 311.74 billion, an increase of 18.2% over last year①. Although the market is growing rapidly, fresh product e-commerce is still a big problem, especially for e-tailers. It is reported that fresh food e-commerce companies face many obstacles, such as non-standardized products, high losses, and imperfect cold chain systems②. According to the China e-Business Research Center (CeBRC), in 2014, there were more than 4000 fresh product e-tailers in the Chinese e-market, but only 1% of them yielded positive profits[1]. Among the above problems, poor cold chain logistics and refund issues are the most challenge. For example, low logistics service quality results in a loss of $8.9 billion annually in fresh products, representing approximately 30% of China's annual output[2]. In 2020, "difficulty in refunding" accounts for 24.3% of consumer complaints③.

Consumers could neither examine products physically nor obtain a refund guarantee; as a result, when consumers receive spoiled fresh products, they will face refund problems, which make them take risk to purchase fresh products online. Existing literature mainly discussed e-tailers or suppliers with self-built logistics that exert fresh-keeping efforts by improving cold chain logistics[3–4]. Corresponding to real cases, the value-added service "Youxian Pei" (in Chinese) provided by JD.com promises that consumers can apply for a full refund if the fresh product deteriorated. In contrast to e-tailers with self-built logistics, the e-tailers who outsource logistics to 3PL providers, such as Taobao.com and Missfresh Limited can hardly improve consumers' willingness to pay by improving cold chain logistics. In this situation, 3PL providers, such as SF Express④ and Zhongtong Express⑤, offer fresh-keeping services to e-tailers and consumers. For example, Zhongtong

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① http://www.100ec.cn/detail--6600306.html

② http://www.ifastdata.com/article/index/id/2705/cid/2

③ https://www.sf-express.com/we/ow/chn/sc/prd/express/cold-standard

④ https://www.sf-express.com/we/ow/chn/sc/prd/express/cold-standard

⑤ https://www.zto.com/business/freshDelivery.html

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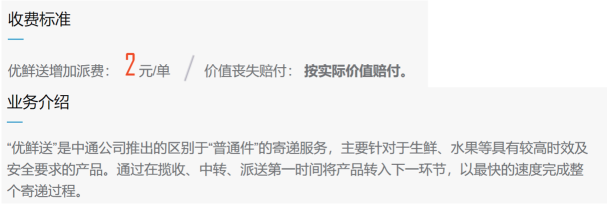
Express launched "Youxian Song" (in Chinese), as shown in Fig. 1, which clarifies the business, charges, and compensation standards. The "Youxian Song" charges an additional ¥ 2 per order as the fresh-keeping service fee based on the transportation fee. Besides, the "Youxian Song" promises to deliver the fresh product as fast as possible and compensate consumers according to the actual value loss. As a result, we can conclude that if the fresh product is spoiled, consumers who purchased the fresh product and the "Youxian Song" will receive a full refund from Zhongtong Express. The fresh-keeping service discussed in our study refers to one of the add-services of the 3PL provider that charges an e-tailer or consumer a fresh-keeping service fee; in return, they will make fresh-keeping efforts by investing in cold-chain logistics and promise a full refund when the fresh product is spoiled. In the case of e-tailers outsourcing logistics to 3PL providers, both e-tailers and 3PL providers face a trade-off. From the e-tailers' perspective, it is conditional to purchase fresh-keeping services. In contrast, fresh-keeping service means 3PL providers exert fresh-keeping efforts, leading to more demand. However, the fresh-keeping service fee is costly, which decreases revenue. Similarly, the decision of the 3PL provider is contradictory. For an exogenous fresh-keeping service fee, lower cold-chain investment of 3PL providers means higher revenue, but it also means a higher full refund risk. Previous literature[1] assumed that the returned fresh product from consumers has no salvage value and cannot be resold, which means that the return of spoiled fresh products is meaningless for consumers and e-tailers. Many fresh product e-tailers on Taobao.com (China's largest e-commerce platform) also indicate that fresh products are special items and do not support returns. Our research considers a full refund without return to replace a full refund with a return, referring to previous research and the actual business model. This study aims to explore and understand the potential basis for e-tailers outsourcing logistics to 3PL providers to select fresh-keeping services. We focus on the following key questions:

(Q1) What is the impact of fresh-keeping service on the e-tailer and 3PL provider?

(Q2) The influence of policyholders of fresh-keeping service on the fresh-keeping effort of the 3PL provider.

(Q3) When should the e-tailer adopt a complimentary fresh-keeping service?

To answer the above questions, we develop a two-stage supply chain including an e-tailer and a 3PL provider, where the former is the Stackelberg leader, and the latter is the follower. Observing the real cases, we found that fresh product e-tailers do not always provide free fresh-keeping services and some e-commerce platforms do not allow the introduction of fresh-keeping services. we conclude that the e-tailers can provide the fresh-keeping service for free. However, when e-tailers do not offer them, consumers can purchase them. Therefore, we focus on three scenarios, scenario N: there is no fresh-keeping service; scenario C: consumers may purchase fresh-keeping services; and scenario S: the e-tailer offers a complementary fresh-keeping service. In scenario C, consumers voluntarily choose to purchase a fresh-keeping service, which means that some consumers who buy fresh products may not purchase them.



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业务介绍

"优鲜送"是中通公司推出的区别于"普通件"的寄递服务，主要针对于生鲜、水果等具有较高时效及安全要求的产品。通过在揽收、中转、派送第一时间将产品转入下一环节，以最快的速度完成整个寄递过程。

**Fig. 1.** The introduction of "Youxian Song" launched by Zhongtong Express.

In this study, we first compare the optimal results of scenario N with those of scenarios C and S, which enables us to identify the impacts of fresh-keeping services on the e-tailer and 3PL providers. We then compare the optimal fresh-keeping efforts to investigate the influence of different policyholders of fresh-keeping services on the fresh-keeping effort of 3PL providers. Finally, a comparison of scenarios S and C enables us to obtain the e-tailer's optimal fresh-keeping strategy.

The remainder of this paper is organized as follows. Section 2 summarizes the relevant literature. The notations and problem descriptions are presented in Section 3. The impact of fresh-keeping on the e-tailer and the 3PL provider are investigated in Section 4. And we examine the criteria for the e-tailer to choose a fresh-keeping strategy and the impact of several important parameters on this criterion in this section. Finally, conclusions, managerial insights, and future research are presented in Section 5.

## 2 Literature review

Our work primarily relates to two streams of research: consumer risk management and operational management of fresh product supply chains. Below, we review each stream of research and demonstrate how it interacts with our research.

Consumer risk management focuses primarily on return and refund issues. Regarding the return problems, product returns are influenced by the relative product quality uncertainty[5]. Based on the relative quality uncertainty, the e-tailer can choose when to refuse consumer returns[6]. Chesnokova[7] showed that allowing returns makes products closer to substitutes, enhances competition, and reduces prices for defect rates. Considering return freight cost, Lin et al.[8] compared the optimal retail price and refund under the cases of with or without return freight cost. Some insurance companies have developed a new type of insurance called return-freight insurance[9] to compensate for consumers' loss of return freight cost. Compared with the full-refund return policy, free-return freight insurance complements the partial refund return policy[10]. The above researches indicate whether return freight insurance benefits the e-tailer depending on the unit insurance fee and return freight cost. Fan et al.[11] further investigated the e-tailer's optimal return freight insurance strategy in the presence of a return freight cost. Under two different sales models (the reselling and agency selling formats), the e-tailer should decide whether to offer consumers a return-freight insurance[12]. It proposed that offering return freight insurance may narrow the consumer market in the agency selling format, similar to our conclusion in scenario C.

The above studies discussed consumer returns from the retailer's perspective. Ren et al.[13] discussed it from the insurance provider's perspective and showed the insurance provider should be neutral[13], contrary to our conclusion that the policyholder affects the fresh-keeping effort of 3PL providers who provide fresh-keeping services. The following literature considered the situation of “seven days no reason to return” and further studied the impact of the actual return rate on the e-tailer’s return policy. Return-freight insurance (RFI) is related to the retailer’s base return rate. Higher the actual returns, lower the optimal retail price, and more optimal the order quantity[14, 15]. The following literature focused on how the e-tailer adopts a return policy to obtain higher profits. The e-tailer mitigates consumers’ fit uncertainty by designing return policies[16]. The new entrant e-tailer adopts return policies to compete with a well-established retailer that allows a full-refund policy[17].

In addition to the above literature on returns, some studies explore the refund issue. A partial refund is optimal compared to a full refund[18]. An e-tailer’s return depth (full return policy vs. partial return policy) positively influences consumers’ perceived fairness of the return policy and purchase intention[19]. Based on these studies, the money-back guarantee (MBG) is observed in practice for short-life-cycle products facing significant demand uncertainty and a high risk of dissatisfaction[20]. Chen and Bell[21] discussed the e-tailer’s optimal return policies (full, partial, or no refund for returned products). The full-return policy can be preferred over the no-return policy by both agents (retailer and manufacturer) if both are high-risk averse[22]. The literature above considered the refund and return issues caused by a product unfit and discussed the optimal e-tailer refund in different scenarios. There are also studies on product returns when consumers are at fault. On the e-commerce platform, the e-tailer requires consumers to pay to return products when the consumers are wrong[23]. Ferguson et al.[24] addressed the problem of reducing false failure returns using supply chain coordination methods. They discussed normal products when consumers return products owing to product unfit; they still obtain the basic valuation, and the e-tailer still obtains the salvage value of the returned product. However, the fresh products discussed in our research are perishable short-cycle products. When consumers require full-fund to perished fresh products, they will lose the basic valuation, and the returned product means nothing to the e-tailer.

The literature on the operation management of fresh product supply chains is rich, and most of them discussed supply chain self-built logistics. Self-built logistics refer to the fact that other supply chain members, except the 3PL provider, transport fresh products. Cai et al.[25] considered a fresh product supply chain composed of a supplier and distributor undertaking the delivery of fresh products. They found that the distributor’s fresh-keeping effort depends on perishability, fresh-keeping costs, and wholesale prices. Between a supplier deciding on fresh-keeping investment and an e-tailer deciding on information sharing, information sharing cooperation is more likely to occur when the supplier is more economical in terms of fresh-keeping investment[3]. Sometimes, the supply chain consists of an e-tailer who is responsible for advertising and a supplier who exerts a fresh-keeping effort[26], a retailer making a cold chain advertisement and a manufacturer making a cold chain construction investment[4], or a supplier (farmer) and retailer who exert a fresh-keeping effort. The above four pieces of literature discussed supply chain cooperation, and all mentioned the fresh-keeping efforts exerted by different supply chain members[27]. Yang et al.[28] compared retailers’ optimal pricing and fresh-keeping efforts under three sales models: retail, dual-channel, and O2O (online-to-offline) models. Yu and Xiao[29] compared the e-tailer’s equilibrium profits under the logistics provider-first and supplier-first scenarios to obtain an optimal strategy. The profit of a fresh product supply chain is positively related to consumers’ sensitivity to freshness and negatively correlated with their sensitivity to price[30]. Gu et al.[31] analyzed a fresh-product supply chain (FPSC) in which the supplier and e-tailer invest in quality improvement and fresh-keeping efforts under centralized and decentralized models. These studies considered the impact of the fresh-keeping effort of one supply chain member on price and profit under self-built logistics.

The above studies focus on supply chain self-built logistics and a few works of literature considered outsourcing logistics (3PL providers). The logistics service provider (LSP) can use a less expensive logistics contract to induce a seller with a short life cycle of products to deliver more products[32]. When a supplier supplies fresh products to a distant market through a third-party logistics provider, a distributor purchases and sells them to end consumers, the wholesale-price-discount sharing (WDS) contract between the supplier and the 3PL provider can coordinate the supply chain[33]. For a distributor who outsources a third-party logistics service provider (TPLSP), an effective contract is superior to the traditional unit pricing (TUP) contract to motivate the TPLSP to improve its logistics service quality and decrease its logistics service price[2]. These studies considered that the 3PL provider charges the logistics service price to motivate themselves to make fresh-keeping efforts. Contrary to our research, they did not consider the compensation issue owing to the perishability of fresh products.

Summarily, these studies focused on the scenario in that the e-tailer offers a full refund policy. The returned fresh product cannot be sold again with residual value, similar to the real situation where consumers do not have to return spoiled fresh products but can receive a full refund. As a result, to extend the scope of research and consider a realistic situation, our research discusses a situation where fresh product e-tailers promise consumers a full refund without a return. Besides, existing literature primarily focuses on supply chain coordination when 3PL providers provide fresh-keeping services but rarely considers the refund issue.

## 3 Notations and problem description

Relevant notations are shown in Table 1 to make it easier to track the problem description, where $i = \mathrm{N,C,S}$ stands for scenarios N, C, and S, respectively.

This study investigates a two-stage supply chain consisting of an e-tailer, a leader in a Stackelberg game, and a 3PL provider, a follower. The e-tailer sells the fresh product to consumers at $p_i$. Consumers cannot check the freshness level of the fresh product when shopping online, and the freshness level of fresh product they received may be lower than prior expectations. We assume that the freshness level decreases to

**Table 1.** Notations.

| Notations | Descriptions |
|---|---|
| $\lambda$ | Unit fresh-keeping service fee |
| $c$ | Unit production cost |
| $\alpha$ | Consumer sensitivity to freshness level |
| $\theta_i$ | Fresh-keeping effort made by the 3PL provider $\theta_i \in (0,1)$, $i = \mathrm{S}, \mathrm{C}$ |
| $k$ | The coefficient of fresh-keeping cost |
| $c(\theta_i)$ | Fresh-keeping effort cost, $c(\theta_i) = k\theta_i^2$ |
| $\theta_0$ | Basic freshness level when the product reaches consumers without fresh-keeping effort, $\theta_0 \in (0,1)$ |
| $m$ | The probability of freshness level fit, $0 < m < 1$ |
| $r_i$ | The full-refund provided by e-tailer or 3PL provider ($r_i = p_i$) |
| $p_i$ | Retail price of fresh product in scenario $i$ |
| $V$ | The valuation that consumers obtain when they purchase fresh products |
| $\theta_\mathrm{f}$ | Freshness level of fresh products finally received by consumers, $\theta_\mathrm{f} \in (0,1)$ |
| $D_i$ | Fresh product demand in scenarios $i$ |
| $U_i$ | Consumer utility in scenarios $i$ |
| $\pi_i^\mathrm{R}$ | The e-tailer's optimal profit in scenarios $i$ |
| $\pi_i^\mathrm{L}$ | The 3PL provider's optimal profit in scenarios $i$ |

$\theta_0$ when the product reaches the final consumers without any fresh-keeping effort. Here, we set $\theta_0$ as the base freshness level. To ensure the long-term operation of the e-commerce platform, consumers are aware of the base freshness level. When a fresh product's freshness level is lower than a consumer's expectations, the consumer will require full-refund $r_i$(which means $r_i$ is equal to $p_i$).

If consumers do not purchase fresh-keeping services when the e-tailer does not provide them with a complementary fresh-keeping service, they will receive fresh products with a basic freshness level. The e-tailer can choose to spend $\lambda$ to purchase a fresh-keeping service and provide it free to consumers to guarantee a higher freshness level. The fresh-keeping service fee incurred in each scenario is an exogenous variable related to the 3PL provider's fresh-keeping effort cost. Generally, the higher the fresh-keeping effort cost, the higher the fresh-keeping service fee that the e-tailer or consumers need to pay. Suppose consumers purchase fresh products with complimentary fresh-keeping services. In that case, they can receive fresh products with higher freshness levels owing to the 3PL provider's freshness-keeping effort $\theta_i$. Additionally, if the e-tailer does not provide this service, consumers can consider purchasing fresh-keeping services independently. Based on this, we focused on three scenarios:

Benchmark: scenario N, where there is no fresh-keeping service. In this scenario, consumers receive fresh products at a basic freshness level. If consumers receive spoiled fresh products, they can require the e-tailer's full refund $r_i$.

Scenario C: some consumers voluntarily purchase fresh-keeping services. While purchasing online, consumers must decide whether to spend $\lambda$ to buy fresh-keeping services if the e-tailer does not offer complimentary fresh-keeping services. These are then divided into two parts. Consumers who purchase fresh-keeping services receive fresh products with higher freshness levels and higher utility, and who do not purchase fresh-keeping services will obtain lower utility from the basic freshness level. Both of them will receive a full refund $r_i$ if they received spoiled products, while the 3PL provider provides the former and the e-tailer offers the latter.

Scenario S: the e-tailer offers a complementary fresh-keeping service. All consumers receive fresh products with fresh-keeping services in this scenario and obtain a higher utility. Additionally, if consumers receive spoiled fresh products, they will receive a full refund $r_i$ provided by the 3PL provider.

The decision sequence establishes that the e-tailer first announces the retail price $p_i$, and then the 3PL provider decides the fresh-keeping effort $\theta_i \in (0,1)$ (under scenarios C and S). Finally, consumers decide whether to require a full refund and purchase fresh-keeping services.

Based on this research, we propose three basic assumptions. First, our model allows for consumer heterogeneity in the product valuation that consumers derive from the fresh product, denoted by $V$, where $V$ is a random variable with support [0,1]. Second, our model assumes that consumers purchase one unit of the fresh product, and if the fresh product they received is spoiled, they can require a full refund. Finally, to simplify our calculation, we standardized the unit transportation fee to 0.

We compare scenarios N, C, and S. These comparisons can help us identify the impacts of introducing fresh-keeping services on supply chain members' decisions. Section 4 analyzes the equilibrium profit under Scenarios C and S to clarify the e-tailer's fresh-keeping strategy.

## 4 Results and discussion

### 4.1 Analysis

In this section, we consider consumers' full refund issues (see Fig. 2). We first construct and solve the model for the above three scenarios. Then, we compare the equilibrium solutions under scenarios N and C, N, and S to clarify the impact of introducing fresh-keeping services.

### 4.1.1 No fresh-keeping service (scenario N)

A consumer's expected utility is $U_{\mathrm{N}} = V - p_{\mathrm{N}} + \alpha\theta_0$, which means that only consumers with valuation $V > p_{\mathrm{N}} - \alpha\theta_0$ will purchase fresh products online referring to existing research. Then we can obtain the demand $D_{\mathrm{N}} = \int_{p_{\mathrm{N}}-\alpha\theta_0}^{1} \mathrm{d}v = 1 - p_{\mathrm{N}} + \alpha\theta_0$. The e-tailer's profit is

$$\pi_R^{\mathrm{N}} = D_{\mathrm{N}}(mp_{\mathrm{N}} - c) \ . \tag{1}$$

According to the principle of profit maximization, it is easy to prove the following results using backward induction.

**Lemma 4.1.** In scenario N, the fresh product e-tailer's optimal retail price is $p_{\mathrm{N}}{}^* = \dfrac{c + m + m\alpha\theta_0}{2m}$, demand is $D_{\mathrm{N}}{}^* = \dfrac{m + m\alpha\theta_0 - c}{2m}$, and profit is $\pi_R^{\mathrm{N}*} = \dfrac{(m + m\alpha\theta_0 - c)^2}{4m}$.

Lemma 4.1 clarifies that retail prices and demand increase as the basic freshness level increases. Consumers need to consider a situation in which the basic freshness level may not match their puechase expectations. As the basic freshness level increases, consumers enjoy higher utility from purchasing fresh products, resulting in more demand. The e-tailer hopes to create more profits by raising the retail price. Additionally, the retail price decreases with an increase in the chance of freshness level fit, whereas the demand increases with an increase. A high probability of freshness level fit means more consumers are satisfied with fresh products making the e-tailer confident about fresh products and encouraging the e-tailer to obtain more demand by reducing retail prices. Intuitively, a low retail price improves consumers' willingness to pay, resulting in more demand.

### 4.1.2 Consumer purchasing fresh-keeping service (scenario C)

We now examine the scenario that consumers purchase fresh-keeping services independently, which means that the e-tailer does not offer complementary fresh-keeping services. Contrary to scenario N, the 3PL provider in scenario C will exert fresh-keeping efforts to avoid a full refund when consumers purchase fresh-keeping services. Like the setting in references, we assume a quadratic relationship between the fresh-keeping effort cost and fresh-keeping effort [34–36]. Thus, the fresh-keeping effort cost is defined as $c(\theta_i) = k\theta_i{}^2$, $k$ refers to the coefficient of the fresh-keeping cost. Therefore, consumers purchasing both fresh-keeping services and fresh products will obtain higher utility from the fresh-keeping effort $U_{\mathrm{C1}} = V - p_{\mathrm{C}} + \alpha(\theta_0 + \theta_{\mathrm{C}}) - \lambda$. Consumers with valuation $V > \lambda + p_{\mathrm{C}} - \alpha(\theta_0 + \theta_{\mathrm{C}})$ purchase fresh products and fresh-keeping services. The utility of consumers purchasing fresh products is $U_{\mathrm{C2}} = V - p_{\mathrm{C}} + \alpha\theta_0$. Consumers with valuation $V > p_{\mathrm{C}} - \alpha\theta_0$ will purchase only fresh products online. Therefore, we can derive the demand for purchasing a fresh product $D_{\mathrm{C}} = \int_{p_{\mathrm{C}}-\alpha\theta_0}^{1} \mathrm{d}v = 1 - p_{\mathrm{C}} + \alpha\theta_0 = D_{\mathrm{C1}} + D_{\mathrm{C2}}$; the number of consumers purchasing fresh products and fresh-keeping services is $D_{\mathrm{C1}} = \int_{\lambda+p_{\mathrm{C}}-\alpha(\theta_0+\theta_{\mathrm{C}})}^{1} \mathrm{d}v = 1 - \lambda - p_{\mathrm{C}} + \alpha(\theta_0 + \theta_{\mathrm{C}})$; the number of consumers only purchasing the fresh products is $D_{\mathrm{C2}} = \int_{p_{\mathrm{C}}-\alpha\theta_0}^{\lambda+p_{\mathrm{C}}-\alpha(\theta_0+\theta_{\mathrm{C}})} \mathrm{d}v = \lambda - \alpha\theta_{\mathrm{C}}$.

**Assumption** The unit fresh-keeping service fee is relatively high, so some consumers in scenario C will not always purchase fresh-keeping service, mathematically, $\lambda > \alpha\theta_{\mathrm{C}}$ can be simplified to when $0 < k < \dfrac{\alpha^2}{2}$, $0 < \lambda < \widehat{\lambda} = \dfrac{2k(m-1)\alpha^2(1 + c + \alpha\theta_0)}{(2k - \alpha^2)(4k + (m-1)^2\alpha^2)}$ and when $k > \dfrac{\alpha^2}{2}$, all $\lambda$ matches the condition.

The 3PL provider's profit is

$$\pi_{\mathrm{L}}^{\mathrm{C}} = D_{\mathrm{C1}}\left[\lambda - (1-m)p\right] - k\theta_{\mathrm{C}}{}^2 . \tag{2}$$

The e-tailer's profit is

$$\pi_{\mathrm{R}}^{\mathrm{C}} = D_{\mathrm{C}}(p_{\mathrm{C}} - c) . \tag{3}$$

**Lemma 4.2.** In scenario C, the optimal retail price is $p_{\mathrm{C}}{}^* = \dfrac{(1-m)\alpha^2\lambda + 2k(1 + c + \alpha\theta_0 + (m-1)\lambda)}{2(2k + (m-1)^2\alpha^2)}$, the optimal fresh-keeping effort is

$$\theta_{\mathrm{C}}{}^* = \frac{\alpha((m-1)^2\alpha^2\lambda + 2k((m-1)(1+c+\alpha\theta_0)+3\lambda-2m\lambda+m^2\lambda))}{4k(2k + (m-1)^2\alpha^2)},$$

the demand is

$$D_{\mathrm{C}}{}^* = \frac{(m-1)(\lambda+2m-2)\alpha^2-2k(c+m\lambda-\lambda-1)+2\alpha(k+(m-1)^2\alpha^2)\theta_0}{2(2k + (m-1)^2\alpha^2)},$$

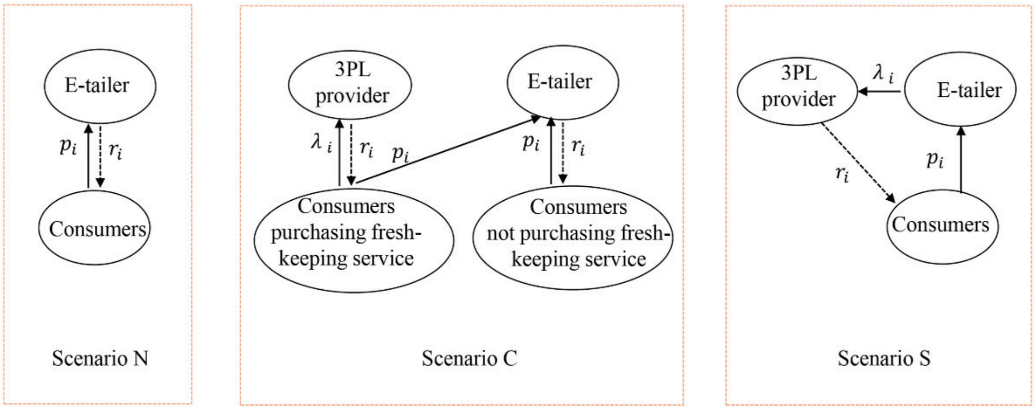

**Fig. 2.** The flow of money in three scenarios.

and profits are

$$\pi_{\mathrm{R}}^{\mathrm{C}*}=\frac{1}{8k\left(2k+(m-1)^2\alpha^2\right)}((m-1)^2\alpha^4\lambda^2-4k(m-1)\alpha^2(\lambda+(m-1)\cdot \lambda^2+c(\lambda+2m-2))+4k^2(c^2+2c((m-1)\lambda-1)+(1+(m-1)\lambda)^2)-4k\alpha((-1)\alpha^2(2c(m-1)+\lambda)+2k(c-m\lambda+\lambda-1))\theta_0+4k^2\alpha^2\theta_0^2),$$

$$\pi_{\mathrm{L}}^{\mathrm{C}*}=\frac{1}{16\left(2k+(m-1)^2\alpha^2\right)}((m-1)^2\alpha^2\lambda+2k((m-1)(1+c+\alpha\theta_0)+3\lambda-2m\lambda+m^2\lambda))((m-1)^2\alpha^4\lambda-8k^2(c+m\lambda+\lambda-1)+2k\alpha^2(3+c(m-1)+m^2(4-3\lambda)-3\lambda+m(-7+8\lambda))+2k\alpha\theta_0(4k+\alpha^2(3-7m+4m^2))).$$

Consistent with Lemma 4.1, retail price and demand increase with an increase in the basic freshness level. However, the relationship between the two and the probability of freshness-level fit is quite different from that in Lemma 4.1. Based on Lemma 4.1, Lemma 4.2 shows the relationship between fresh-keeping effort and basic freshness level. The fresh-keeping effort decreases with an increase in basic freshness level. The 3PL provider understands that a high basic freshness level means low full-refund risk, so they will reduce fresh-keeping efforts to save costs.

### *4.1.3 E-tailer offering complimentary fresh-keeping service (scenario S)*

This section discusses a scenario in which the e-tailer provides consumers with complementary fresh-keeping services. Similar to scenario C, consumers in this scenario obtain higher utility from the 3PL provider’s fresh-keeping effort. What is different from scenario C is that consumers do not pay fresh-keeping service fees themselves. Then, the consumers’ expected utility $U_{\mathrm{S}}=V-p_{\mathrm{S}}+\alpha(\theta_0+\theta_{\mathrm{S}})$. Thus, only consumers with a valuation $V>p_{\mathrm{S}}-\alpha(\theta_0+\theta_{\mathrm{S}})$ will purchase fresh products online. Then, the demand in scenario S is $D_{\mathrm{S}}=1-p_{\mathrm{S}}+\alpha(\theta_0+\theta_{\mathrm{S}})$.

The 3PL provider’s profit is

$$\pi_{\mathrm{L}}^{\mathrm{S}}=D_{\mathrm{S}}[\lambda-(1-m)p_{\mathrm{S}}]-k\theta_{\mathrm{S}}^2. \tag{4}$$

The e-tailer’s profit is

$$\pi_{\mathrm{R}}^{\mathrm{S}}=D_{\mathrm{S}}(p_{\mathrm{S}}-c-\lambda). \tag{5}$$

**Lemma 4.3.** In scenario S, the optimal retail price is $p_{\mathrm{S}}{}^*=\dfrac{2k(c+\lambda+\alpha\theta_0+1)+\alpha^2(c-cm+2\lambda-m\lambda)}{2(2k+(1-m)\alpha^2)}$, the optimal fresh-keeping effort is

$$\theta_{\mathrm{S}}{}^*=\frac{\alpha((m-1)(c-cm-m\lambda)\alpha^2+2k((m-1)(c+1+\alpha\theta_0)+m\lambda+\lambda))}{4k(2k+(1-m)\alpha^2)},$$

the demand is

$D_{\mathrm{S}}{}^*=\dfrac{(mc-c+m\lambda)\alpha^2-2k(c+\lambda-\alpha\theta_0-1)}{4k}$, and profits are

$$\pi_{\mathrm{R}}^{\mathrm{S}*}=\frac{((mc-c+m\lambda)\alpha^2-2k(c+\lambda-\alpha\theta_0-1))^2}{8k(2k+(1-m)\alpha^2)},$$

$$\pi_{\mathrm{L}}^{\mathrm{S}*}=\frac{1}{16k((m-1)\alpha^2-2k)^2}((m-1)(mc-c+m\lambda)\alpha^2-2k((1+c+\alpha\theta_0)(m-1)+m\lambda+\lambda))(((c+\lambda-1)8k^2-6k\alpha^2(m-1)(c+\lambda-1)+(m-1)(mc-c+m\lambda)\alpha^4+(6k(m-1)\alpha^3-8k^2\alpha)\theta_0).$$

Lemma 4.3 clarifies that, as in Lemma 4.2, retail price, demand, and fresh-keeping effort increase with the basic freshness level. As for the probability of freshness-level fit, demand is proportional to the probability of freshness-level fit. Consumers in scenario S will enjoy higher utility owing to complimentary fresh-keeping services, which improves their willingness to pay, resulting in more demand.

### *4.1.4 Comparison analysis*

In previous sections, we obtained the equilibrium solutions for the three scenarios. Upon comparing the equilibrium solutions in scenarios N and C, and scenarios N and S, we now try to determine the impact of fresh-keeping services on demand and retail prices. We mainly investigate how the two key factors, namely, the coefficient of fresh-keeping cost and the unit fresh-keeping service fee, affect the fresh-keeping service decision. First, we discuss the impact of fresh-keeping services on the price and demand. From Lemmas 4.1–4.3, we obtain the following proposition. All proofs are provided in the Appendix.

**Proposition 4.1.** The impact of retail price and demand on the unit fresh-keeping service fee is related to the coefficient of the fresh-keeping costs.

(i) $\dfrac{\partial p_{\mathrm{C}}{}^*}{\partial\lambda}>0$, if $0<k<\dfrac{\alpha^2}{2}$, $\dfrac{\partial p_{\mathrm{S}}^*}{\partial\lambda}>0$;

(ii) $\dfrac{\partial D_{\mathrm{C}}^*}{\partial\lambda}>0$, if $k>\dfrac{\alpha^2}{2}$; $\dfrac{\partial D_{\mathrm{S}}{}^*}{\partial\lambda}>0$, if $0<k<\dfrac{m\alpha^2}{2}$.

First, from Proposition 4.1, we find that the policyholder of a fresh-keeping service has a different effect on retail price and demand. The retail price in scenario S constantly increases with the unit fresh-keeping service fee owing to the price transfer caused by the e-tailer’s complimentary fresh-keeping service. In scenario C, the retail price shows the same trend only when the coefficient of the fresh-keeping cost is low. Because a lower coefficient of fresh-keeping cost means that more consumers purchase fresh-keeping services at the same retail price. With the increase in the unit fresh-keeping service fee, the number of consumers who only buy fresh products under scenario C increases, meaning the number of consumers who require the e-tailer to provide full refund increases. This motivates the e-tailer to increase the retail price to reduce the compensation risk, resulting in less demand. When the coefficient of the fresh-keeping cost is high, the retailer lowers the retail price to ensure sufficient demand. Additionally, demand shows a different trend towards the unit fresh-keeping service fee in the two scenarios. Because in scenario C, when the coefficient of fresh-keeping cost is high, consumers’ confidence in the fresh product’s freshness level will improve, which motivates the e-tailer to increase the retail price. The demand shows the opposite trend to the retail price in scenario C. The demand in scenario C increases with an increase in the unit fresh-keeping service fee when the

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fresh-keeping cost coefficient is high. When the fresh-keeping cost coefficient is low, the demand in scenario S is proportional to the unit fresh-keeping service fee.

We compare the optimal retail price in scenarios N and C and Scenarios N and S to investigate the impacts of fresh-keeping services on the e-tailer's pricing, as shown in Proposition 4.2.

**Proposition 4.2.** Fresh-keeping services have different effects on the retail price under each scenario.

(ⅰ) When $0 < k < \frac{\alpha^2}{2}$, if $0 < \lambda < \widehat{\lambda}$, $p_{\mathrm{N}}^* > p_{\mathrm{C}}^*$; when $k > \frac{\alpha^2}{2}$, if $\lambda > \lambda_{\mathrm{NC}}$, $p_{\mathrm{N}}^* > p_{\mathrm{C}}^*$, if $0 < \lambda < \lambda_{\mathrm{NC}}$, $p_{\mathrm{C}}^* > p_{\mathrm{N}}^*$.

(ⅱ) $p_{\mathrm{N}}^* > p_{\mathrm{S}}^*$ if $0 < \lambda < \lambda_{\mathrm{PNS}}$, otherwise, $p_{\mathrm{S}}^* > p_{\mathrm{N}}^*$.

$\widehat{\lambda}$, $\lambda_{\mathrm{NC}}$ and $\lambda_{\mathrm{PNS}}$ can be seen in the proof of Proposition 4.2.

From Proposition 4.2, we find that the introduction of fresh-keeping services has different effects on retail prices. Proposition 4.2 (ⅰ) proposes that when the coefficient of fresh-keeping cost and the unit fresh-keeping service fee are both low or high, the retail price in scenario C is lower than that in scenario N. However, when the coefficient of fresh-keeping cost is high, and the unit fresh-keeping service fee is low, the retail price in scenario C will be higher than that in scenario N. Proposition 4.2 (ⅱ) proposes that when the unit fresh-keeping service fee is low, the retail price in scenario S is lower than that in scenario N; otherwise, it will be higher. The reasons for this are as follows. In scenario C, consumers voluntarily choose to purchase a fresh-keeping service to ensure higher utility. Thus, the e-tailer may hope to earn more profits from this voluntary behavior by increasing the retail price. Given the price increase in scenario S, conversely, the provision of the fresh-keeping service can alleviate the impact of freshness level on consumers' willingness to pay; in contrast, the high fresh-keeping service fee inevitably leads to a high retail price.

In Proposition 4.3, we study the impact of fresh-keeping services on demand.

**Proposition 4.3.** Whether the introduction of fresh-keeping services can expand the market size depends on the coefficient of fresh-keeping costs and fresh-keeping service fees.

(ⅰ) When $0 < k < \frac{\alpha^2}{2}$, if $0 < \lambda < \widehat{\lambda}$, $D_{\mathrm{C}}^* > D_{\mathrm{N}}^*$; when $k > \frac{\alpha^2}{2}$, if $\lambda > \lambda_{\mathrm{NC}}$, $D_{\mathrm{C}}^* > D_{\mathrm{N}}^*$, if $0 < \lambda < \lambda_{\mathrm{NC}}$, $D_{\mathrm{N}}^* > D_{\mathrm{C}}^*$.

(ⅱ) When $0 < k < \frac{m\alpha^2}{2}$, if $0 < \lambda < \lambda_{DNS}$, $D_{\mathrm{N}}^* > D_{\mathrm{S}}^*$, otherwise, $D_{\mathrm{S}}^* > D_{\mathrm{N}}^*$; when $k > \frac{m\alpha^2}{2}$, if $\lambda > \lambda_{\mathrm{DNS}}$, $D_{\mathrm{N}}^* > D_{\mathrm{S}}^*$, otherwise, $D_{\mathrm{S}}^* > D_{\mathrm{N}}^*$.

$\lambda_{\mathrm{NC}}$ and $\lambda_{\mathrm{DNS}}$ can be seen in proof of Proposition 4.3.

Proposition 4.3 (ⅰ) finds that when the coefficient of fresh-keeping cost and unit fresh-keeping service fee are both low or high, the demand in scenario C is higher than that in scenario N. However, when the coefficient of fresh-keeping cost is high and the unit preservation cost is low, the demand in scenario C is lower than that in Scenario N. Proposition 4.3 (ⅱ) finds that when the coefficient of fresh-keeping cost and unit fresh-keeping cost are both low or high, the demand in scenario S is lower than that in scenario N. However, when the coefficient of fresh-keeping cost is low and the unit fresh-keeping service fee is high, the demand is higher than the demand in scenario N. The reasons for this are as follows. The demand in scenario C decreases with the retail price. The impact of the fresh-keeping service on demand is opposite to its effect on the retail price. However, the demand in scenario S is jointly affected by retail price and fresh-keeping efforts. Demand decreases with retail prices and increases with the fresh-keeping effort. When the coefficients of fresh-keeping cost and unit fresh-keeping cost are both low or high, the negative effect of retail price on demand dominates, resulting in lower demand.

We study the impact of fresh-keeping services on the e-tailer's profit, as shown in Proposition 4.4.

**Proposition 4.4.** The introduction of a fresh-keeping service does not always benefit e-tailers.

(ⅰ) In scenario C, when $0 < k < \frac{\alpha^2}{2}$, if $0 < \lambda < \lambda_{\pi\mathrm{NC}2}$, $\pi_{\mathrm{R}}^{\mathrm{N}*} > \pi_{\mathrm{R}}^{\mathrm{C}*}$, if $\lambda > \lambda_{\pi\mathrm{NC}2}$, $\pi_{\mathrm{R}}^{\mathrm{C}*} > \pi_{\mathrm{R}}^{\mathrm{N}*}$; when $k > \frac{\alpha^2}{2}$, if $\lambda_{\pi\mathrm{NC}1} < \lambda < \lambda_{\pi\mathrm{NC}2}$, $\pi_{\mathrm{R}}^{\mathrm{N}*} > \pi_{\mathrm{R}}^{\mathrm{C}*}$, if $\lambda > \lambda_{\pi\mathrm{NC}2}$ or $0 < \lambda > \lambda_{\pi\mathrm{NC}1}$, $\pi_{\mathrm{R}}^{\mathrm{C}*} > \pi_{\mathrm{R}}^{\mathrm{N}*}$.

(ⅱ) In scenario S, when $0 < k < \frac{m\alpha^2}{2}$, if $0 < \lambda < \lambda_{\pi\mathrm{NS}2}$, $\pi_{\mathrm{R}}^{\mathrm{N}*} > \pi_{\mathrm{R}}^{\mathrm{S}*}$, if $\lambda > \lambda_{\pi\mathrm{NS}2}$, $\pi_{\mathrm{R}}^{\mathrm{S}*} > \pi_{\mathrm{R}}^{\mathrm{N}*}$; when $k > \frac{m\alpha^2}{2}$, if $\lambda_{\pi\mathrm{NS}1} < \lambda < \lambda_{\pi\mathrm{NS}2}$, $\pi_{\mathrm{R}}^{\mathrm{N}*} > \pi_{\mathrm{R}}^{\mathrm{S}*}$, if $\lambda > \lambda_{\pi\mathrm{NS}2}$ or $0 < \lambda < \lambda_{\pi\mathrm{NS}1}$, $\pi_{\mathrm{R}}^{\mathrm{S}*} > \pi_{\mathrm{R}}^{\mathrm{N}*}$.

$\lambda_{\pi\mathrm{NC}1}$, $\lambda_{\pi\mathrm{NC}2}$, $\lambda_{\pi\mathrm{NS}1}$, and $\lambda_{\pi\mathrm{NS}2}$ can be observed in the proof of Proposition 4.4.

Proposition 4.4 (ⅰ) implies that in scenario C, when the coefficient of fresh-keeping cost and the unit fresh-keeping service fee are low or the coefficient of fresh-keeping cost is high and the unit fresh-keeping service fee is moderate, not introducing fresh-keeping services will create more profits for the e-tailer. Owing to the fresh-keeping service option, when the coefficient of fresh-keeping cost and the unit fresh-keeping service fee are not attractive enough for consumers, few consumers will purchase fresh-keeping services to obtain higher utility and are less willing to purchase fresh products. Thus, fresh-keeping services weaken part of the demand (see Proposition 4.3), and the e-tailer's profit is not as good as when fresh-keeping services are not introduced. Proposition 4.4 (ⅱ) reveals that when the coefficient of fresh-keeping cost is low and the unit fresh-keeping service fee is higher, or when the coefficient of fresh-keeping cost is high and the unit fresh-keeping service fee is high or low, an e-tailer with a complimentary fresh-keeping service will create more profits. This is affected jointly by demand and retail prices.

## 4.2 Discussion

This section investigates when the e-tailer should offer complimentary fresh-keeping services and whether policyholders of fresh-keeping services influence fresh-keeping efforts. We first analyzed the 3PL provider's fresh-keeping efforts to explore the impact of fresh-keeping service policyholders on fresh-keeping efforts. We then compare the equilibrium profits of the two scenarios in which the e-tailer offers a complimentary fresh-keeping service. We also explore how the e-tailer's profit gap is related to the unit fresh-keeping service fee in three scenarios to clarify the e-tailer's fresh-keeping strategy.

### 4.2.1 The-third party logistics provider's fresh-keeping effort

To explore the impact of fresh-keeping service policyholders on the 3PL provider's fresh-keeping efforts, we compare them under scenarios C and S and discuss whether the 3PL provider will make different fresh-keeping efforts under the two scenarios, as shown in Proposition 4.5.

**Proposition 4.5.** When the unit fresh-keeping service fee is high, the 3PL provider exerts a higher fresh-keeping effort in scenario C. If $\lambda > \lambda_{\theta\mathrm{CS}}$, $\theta_{\mathrm{C}}{}^{*} > \theta_{\mathrm{S}}{}^{*}$, otherwise, $\theta_{\mathrm{S}}{}^{*} > \theta_{\mathrm{C}}{}^{*}$. $\lambda_{\theta\mathrm{CS}}$ can be seen in the proof of Proposition 4.5.

Proposition 4.5 compares the optimal fresh-keeping effort under scenarios C and S. The fresh-keeping effort in scenario S is higher than that in scenario C when the unit fresh-keeping service fee is low. This is because when the unit fresh-keeping service fee is low, the retail price in scenario C is higher than that in scenario S (see Proposition 4.6), and the 3PL provider's fresh-keeping effort is inversely proportional to the retail price ($\frac{\partial \theta_i^*}{\partial p_i^*} < 0$). This means that when the unit fresh-keeping service fee is low, the e-tailer should provide consumers with free fresh-keeping services to ensure a higher fresh-keeping effort to guarantee freshness level. It is observed that when the 3PL provider charges a low fresh-keeping service fees, to avoid a full refund, the e-tailers claim that the fresh product is shipped by air and promises a full-refund guarantee, which is consistent with the above conclusion and intuitive.

### 4.2.2 Fresh-keeping strategy

To explore the impact of the policyholder of the fresh-keeping service on the e-tailer's pricing, we compare the retail prices under scenarios C and S, as shown in Proposition 4.6.

**Proposition 4.6.** The e-tailer will set higher prices in the former strategy when the unit fresh-keeping service fee is high under the scenario of offering a complementary fresh-keeping service. If $0 < \lambda < \lambda_{P\mathrm{CS}}$, $p_{\mathrm{C}}{}^{*} > p_{\mathrm{S}}{}^{*}$, otherwise, $p_{\mathrm{S}}{}^{*} > p_{\mathrm{C}}{}^{*}$. $\lambda_{P\mathrm{CS}}$ can be seen in the proof of Proposition 4.6.

Proposition 4.6 provides comparison results for equilibrium retail prices under scenarios C and S. The result is not monotonous. The retail price in scenario S is higher than that in scenario C when the unit fresh-keeping service fee is high. This result is reasonable. When the unit fresh-keeping service fee is high, the e-tailer in scenario S transfers the fresh-keeping service fee to consumers by increasing the retail price, leading to a higher retail price.

We compare the profits of the e-tailer in scenarios C and S and discuss whether the e-tailer can benefit from complimentary fresh-keeping services, as shown in Proposition 4.7.

**Proposition 4.7.** Whether the e-tailer offers a complementary fresh-keeping service depends on the coefficient of the fresh-keeping cost and the unit fresh-keeping service fee.

(ⅰ) When $k$ is enough low, if $\lambda_{\pi\mathrm{CS2}} < \lambda < \lambda_{\pi\mathrm{CS1}}$, $\pi_{\mathrm{R}}^{\mathrm{S}*} > \pi_{\mathrm{R}}^{\mathrm{C}*}$, otherwise, $\pi_{\mathrm{R}}^{\mathrm{C}*} > \pi_{\mathrm{R}}^{\mathrm{S}*}$;

(ⅱ) When $k$ is high, if $\lambda_{\pi\mathrm{CS1}} < \lambda < \lambda_{\pi\mathrm{CS2}}$, $\pi_{\mathrm{R}}^{\mathrm{C}*} > \pi_{\mathrm{R}}^{\mathrm{S}*}$, otherwise, $\pi_{\mathrm{R}}^{\mathrm{S}*} > \pi_{\mathrm{R}}^{\mathrm{C}*}$.

$\lambda_{\pi\mathrm{CS1}}$ and $\lambda_{\pi\mathrm{CS2}}$ can be seen in the proof of Proposition 4.7.

Proposition 4.7 reveals that the fresh-keeping cost coefficient and the unit fresh-keeping service fee jointly affect the e-tailer's decision. When the coefficient of fresh-keeping cost is high and the unit fresh-keeping service fee is moderate, a complimentary fresh-keeping service will benefit the e-tailer. When the coefficient of the fresh-keeping cost is sufficiently low, the result is completely the opposite.

Conversely, complimentary fresh-keeping services can promote consumer utility and improve consumers' willingness to pay. Note that this positive effect depends on the fresh-keeping effort. The higher the unit fresh-keeping service fee, the higher the fresh-keeping effort $\left(\frac{\partial \theta_i^*}{\partial \lambda} > 0\right)$. In contrast, the e-tailer charges a higher retail price when the unit fresh-keeping service fee is high (as shown in Proposition 4.2) after offering a complementary fresh-keeping service, which reduces consumers' willingness to pay. Therefore, when the coefficient of fresh-keeping cost is sufficiently low, if the unit fresh-keeping service fee is moderate, the negative effect of the retail price plays a dominant role. Similarly, if the unit fresh-keeping service fee is low or sufficiently high, the positive effect of the fresh-keeping effort plays a dominant role. Our findings provide valuable insights for management. For example, the fresh product e-tailers on Pinduoduo.com always choose the SF Express to ensure freshness and full refund. Because among domestic express companies, SF Express has invested the most in cold chains and charges a moderate fresh-keeping service fee, consistent with our conclusion.

We then explore the impacts of the unit fresh-keeping service fee on the fresh-keeping strategy. As illustrated in Fig. 3, we explore how the e-tailer's profit gap relates to the unit fresh-keeping service fee. We find that when the unit fresh-keeping service fee is low, not offering complimentary fresh-keeping service will create the greatest profit for the e-tailer. When the unit fresh-keeping service fee is moderate, it is optimal not to introduce fresh-keeping service. When the unit fresh-keeping service fee is high, the e-tailer should provide consumers with complimentary fresh-keeping service. Referring to the Ref. [28], we set the basic parameter values as $k = 5$, $m = 0.8$, $\alpha=1$, $c = 0.5$, and $\theta_0 = 0.6$.

## 5 Conclusions

To determine the influence of introducing a fresh-keeping service, we study a two-stage supply chain consisting of an e-tailer and a 3PL provider. We then develop a game model to find suitable situations for e-tailers to offer free fresh-keeping services. The key results are summarized as follows:

First, introducing a fresh-keeping service depends on the coefficient of the fresh-keeping cost and the unit fresh-keeping service fee. When the coefficient of fresh-keeping costs and unit fresh-keeping service fees are low, or the coefficient of fresh-keeping cost is high, and the unit fresh-keeping service fee is moderate, the e-tailer will benefit from consumers' voluntary purchase. When the coefficient of fresh-keeping cost is low, and the unit fresh-keeping service fee is high, or when the coefficient of fresh-keeping cost is high, and the

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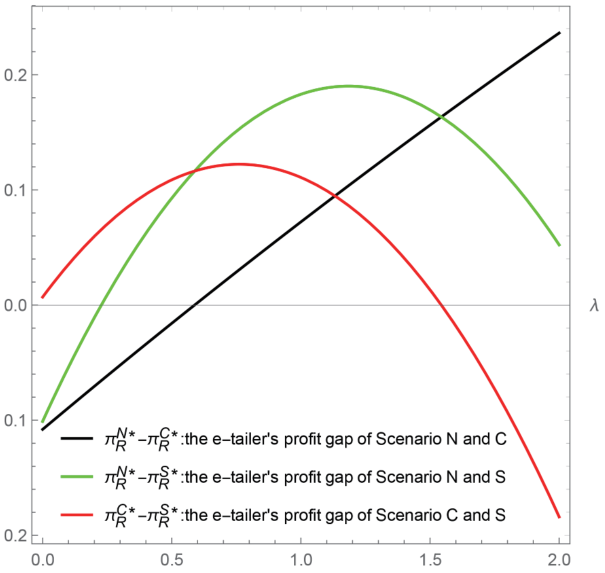

**Fig. 3.** E-tailer’s fresh-keeping strategy.

unit fresh-keeping cost is low or high, the complimentary fresh-keeping service benefits the e-tailer. Therefore, when the 3PL provider invests much in the cold chain and charges a high fresh-keeping service or when the 3PL provider invests less in the cold chain and charges a low fresh-keeping service, we do not recommend the e-tailer introduce a fresh-keeping service.

Second, the policyholder influences the 3PL provider’s fresh-keeping efforts. When the unit fresh-keeping service fee is low, the fresh-keeping effort when the e-tailer offers a complimentary fresh-keeping service is higher than when the e-tailer does not offer a complementary fresh-keeping service, retail price is lower. As a result, when the e-tailer offers complimentary fresh-keeping services to consumers, 3PL providers, such as SF Express, should deliver the fresh product faster.

Third, the coefficient of the fresh-keeping cost and the unit fresh-keeping service fee play a vital role in the e-tailer’s decision. When the coefficient of fresh-keeping cost is high and the unit fresh-keeping service fee is moderate, a complimentary fresh-keeping service will benefit the e-tailer. Therefore, when the 3PL provider invests much in the cold chain and charges a high fresh-keeping service or when the 3PL provider invests less in the cold chain and charges a low fresh-keeping service, the e-tailer should offer a complementary fresh-keeping service.The main contributions of this study are as follows: First, we consider the fresh-keeping provided by the 3PL provider to the fresh product e-tailer’s full refund problem. Second, we model the common situation in which the e-tailer promises consumers a full refund without return and explain the e-tailer’s optimal fresh-keeping strategy under the direct sales model. Third, we further explore whether different policyholders influence to the 3PL provider’s fresh-keeping efforts. Our results show that when the unit fresh-keeping service fee is moderate, the e-tailer tends to offer a complementary fresh-keeping service, which provides useful decision-making support for the e-tailer.

Our findings provide several practical insights from a managerial perspective. For the pricing strategy, after introducing a fresh-keeping service, when consumers voluntarily purchase it, the e-tailer should raise the retail price if the unit fresh-keeping fee is low. When the e-tailer offers a complementary fresh-keeping service, the retailer should lower the retail price if the unit fresh-keeping service fee is high. For example, when purchasing valuable fresh products online, such as king crabs, if consumers are provided with fresh-keeping services, the retail price is often higher than without a fresh-keeping guarantee.

Future studies should consider the following two aspects. First, we can extend the model to a three-tier supply chain with the manufacturer and consider the situation where manufacturers and e-tailers share the fresh-keeping service fee. Second, the insurer also provides insurance similar to fresh-keeping services. However, he does not undertake delivery of fresh products, which means that he cannot control full-refund risk by exerting fresh-keeping efforts. We can then explore how the 3PL provider’s fresh-keeping service affects the insurer. These issues should be addressed in future studies.

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## Conflict of interest

The authors declare that they have no conflict of interest.

## Biographies

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# Appendix

**Proof of Proposition 4.1.** Finding the first derivative, we can easily have $\frac{\partial p_{\mathrm{C}}{}^{*}}{\partial \lambda} = \frac{(m-1)(2k-\alpha^2)}{2(2k+(m-1)^2\alpha^2)}$ because $0 < m < 1$ and $2\left(2k+(m-1)^2\alpha^2\right) > 0$, therefore, if $0 < k < \frac{\alpha^2}{2}$, $\frac{\partial p_{\mathrm{C}}{}^{*}}{\partial \lambda} > 0$. Similarly, $\frac{\partial p_{\mathrm{C}}{}^{*}}{\partial \lambda} > 0$ because $0 < m < 1$, and $\frac{\partial p_{\mathrm{S}}{}^{*}}{\partial \lambda}$ is always greater than 0. $\frac{\partial D_{\mathrm{C}}{}^{*}}{\partial \lambda} = \frac{(m-1)(\alpha^2-2k)}{2(2k+(m-1)^2\alpha^2)}$, because $0 < m < 1$, if $k > \frac{\alpha^2}{2}$, $\frac{\partial D_{\mathrm{C}}{}^{*}}{\partial \lambda} > 0$. Next, we find $\frac{\partial D_{\mathrm{S}}{}^{*}}{\partial \lambda} = \frac{m\alpha^2-2k}{4k}$, because $k > 0$, if $0 < k < \frac{m\alpha^2}{2}$, $\frac{\partial D_{\mathrm{S}}{}^{*}}{\partial \lambda} > 0$.

**Proof of Proposition 4.2.** We construct the function

$$(p_{\mathrm{NC}}) = p_{\mathrm{N}}{}^{*} - p_{\mathrm{C}}{}^{*} = \frac{(m-1)(-2ck+c(m-1)\alpha^2-2km\lambda+m\alpha^2(m+\lambda-1)+(m-1)m\alpha^3\theta_0)}{2m\left(2k+(m-1)^2\alpha^2\right)}.$$

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Let $F(p_{\rm NC})=0$, we can obtain $\lambda_{\rm NC}=\dfrac{c(m-1)\alpha^2+(m-1)m\alpha^2+(m-1)m\alpha^3\theta_0-2ck}{m(2k-\alpha^2)}$, due to $\dfrac{\partial F(p_{\rm NC})}{\partial\lambda}=\dfrac{(1-m)(2k-\alpha^2)}{2\left(2k+(m-1)^2\alpha^2\right)}$, and if $0<k<\dfrac{\alpha^2}{2}$, $\dfrac{\partial F(p_{\rm NC})}{\partial\lambda}>0$. Combining this with the assumption in scenario C, we can conclude that when $0<k<\dfrac{\alpha^2}{2}$, if $0<\lambda<\widehat{\lambda}$, $p_{\rm N}{}^*>p_{\rm C}{}^*$; and when $k>\dfrac{\alpha^2}{2}$, if $\lambda>\lambda_{\rm NC}$, $p_{\rm N}{}^*>p_{\rm C}{}^*$. Similarly, we also constructed a function $F(p_{\rm NS})=p_{\rm N}{}^*-p_{\rm S}{}^*=\dfrac{c(m-1)(2k-(m-1)\alpha^2)+m(2k\lambda+\alpha^2(m-1+2\lambda-m\lambda))+(m-1)m\alpha^3\theta_0}{2m((m-1)\alpha^2-2k)}$. Let $F(p_{\rm NS})=0$, we can obtain $\lambda_{\rm PNS}=\dfrac{(m-1)(m\alpha^2+c(2k+(1-m)\alpha^2)+m\alpha^3\theta_0)}{m(-2k+(-2+m)\alpha^2)}$, due to $\dfrac{\partial F(p_{\rm NS})}{\partial\lambda}=\dfrac{2k+(2-m)\alpha^2}{2((m-1)\alpha^2-2k)}>0$. Thus, we can conclude that if $0<\lambda<\lambda_{PNS}$, $p_{\rm N}{}^*>p_{\rm S}{}^*$, otherwise, $p_{\rm S}{}^*>p_{\rm N}{}^*$.

**Proof of Proposition 4.3.** Similar to the proof of Proposition 4.2, we construct the function $F(D_{\rm NC})=D_{\rm N}{}^*-D_{\rm C}{}^*=\dfrac{(1-m)(c(m-1)\alpha^2-2km\lambda-2ck+m\alpha^2(m+\lambda-1)+(m-1)m\alpha^3\theta_0)}{2m\left(2k+(m-1)^2\alpha^2\right)}$. Let $F(D_{\rm NC})=0$, then obtain $\lambda_{\rm NC}=\dfrac{c(m-1)\alpha^2+(m-1)m\alpha^2+(m-1)m\alpha^3\theta_0-2ck}{m(2k-\alpha^2)}$, because $\dfrac{\partial F(p_{\rm NC})}{\partial\lambda}=m(\alpha^2-2k)$, and $0<m<1$, if $0<k<\dfrac{\alpha^2}{2}$, $\dfrac{\partial F(p_{\rm NC})}{\partial\lambda}>0$. Then, considering the assumption proposed if scenario C, we can conclude that when $0<k<\dfrac{\alpha^2}{2}$, if $0<\lambda<\widehat{\lambda}$, $D_{\rm C}{}^*>D_{\rm N}{}^*$; when $k>\dfrac{\alpha^2}{2}$, if $\lambda>\lambda_{\rm NC}$, $D_{\rm C}{}^*>D_{\rm N}{}^*$and if $0<\lambda<\lambda_{NC}$, $D_{\rm N}{}^*>D_{\rm C}{}^*$. Then we construct a function $F(D_{\rm NS})=D_{\rm N}{}^*-D_{\rm S}{}^*=\dfrac{(2k-m\alpha^2)(c(-1+m)+m\lambda)}{4km}$. Let $F(D_{\rm NS})=0$, the solution if $\lambda_{\rm DNS}=\dfrac{c(1-m)}{m}$, due to $\dfrac{\partial F(D_{\rm NS})}{\partial\lambda}=\dfrac{2k-m\alpha^2}{4k}$, $0<m<1$ and $c>0$, if $0<k<\dfrac{m\alpha^2}{2}$, $\dfrac{\partial F(D_{NS})}{\partial\lambda}<0$. We can conclude: when $0<k<\dfrac{m\alpha^2}{2}$, if $0<\lambda<\lambda_{\rm DNS}$, $D_N{}^*>D_S{}^*$, otherwise, $D_{\rm S}{}^*>D_{\rm N}{}^*$; when $k>\dfrac{m\alpha^2}{2}$, if $\lambda>\lambda_{DNS}$, $D_{\rm N}{}^*>D_{\rm S}{}^*$, otherwise, $D_{\rm S}{}^*>D_{\rm N}{}^*$.

**Proof of Proposition 4.4.** We construct a function

$$(\pi_{\rm NC})=\pi_{\rm R}^{\rm N*}-\pi_{\rm R}^{\rm C*}=\frac{m-1}{8km\left(2k+(m-1)^2\alpha^2\right)}(2k(2k(m-c^2)+(m-1)\bullet(c+m)^2\alpha^2)-4(1+c)km(2k-\alpha^2)\lambda-(m-1)m(\alpha^2-2k)^2\lambda^2+$$
$$2km\alpha\theta_0(2\alpha^2((-1+m)(c+m)+\lambda)-4k(-1+\lambda)+(2k\alpha+(m-1)m\alpha^3)\theta_0)).$$

Let $F(\pi_{\rm NC})=0$, We have two different solutions: one is

$$\lambda_{\pi{\rm NC1}}=\frac{2km(2k-\alpha^2)(1+c+\alpha\theta_0)-\sqrt{2}\sqrt{km(\alpha^2-2k)^2(2k+(m-1)^2\alpha^2)(c+m+m\alpha\theta_0)^2}}{(1-m)m(\alpha^2-2k)^2},$$

$$\lambda_{\pi{\rm NC1}}=\frac{2km(2k-\alpha^2)(1+c+\alpha\theta_0)-\sqrt{2}\sqrt{km(\alpha^2-2k)^2(2k+(m-1)^2\alpha^2)(c+m+m\alpha\theta_0)^2}}{(1-m)m(\alpha^2-2k)^2},$$

and

$$\lambda_{\pi{\rm NC2}}=\frac{2km(2k-\alpha^2)(1+c+\alpha\theta_0)+\sqrt{2}\sqrt{km(\alpha^2-2k)^2(2k+(m-1)^2\alpha^2)(c+m+m\alpha\theta_0)^2}}{(1-m)m(\alpha^2-2k)^2}$$

and $\lambda_{\pi{\rm NC2}}=\dfrac{2km(2k-\alpha^2)(1+c+\alpha\theta_0)+\sqrt{2}\sqrt{km(\alpha^2-2k)^2(2k+(m-1)^2\alpha^2)(c+m+m\alpha\theta_0)^2}}{(1-m)m(\alpha^2-2k)^2}$ and $\lambda_{\pi{\rm NC1}}<\lambda_{\pi{\rm NC2}}$. Owing to $\dfrac{\partial(\pi_{\rm NC})}{\partial\lambda}=\dfrac{2m(1-m)m(2k-\alpha^2)((1-m)\alpha^2\lambda+2k(1+c+(m-1)\lambda)+2k\alpha\theta_0)}{8km\left(2k+(m-1)^2\alpha^2\right)}$ and $\dfrac{\partial F(\pi_{\rm NC})^2}{\partial^2\lambda}=-\dfrac{(m-1)^2(2k-\alpha^2)^2}{4k\left(2k+(m-1)^2\alpha^2\right)}<0$. We can conclude: ① when $0<k<\dfrac{\alpha^2}{2}$, if $0<\lambda<\lambda_{\pi{\rm NC2}}$, $\pi_{\rm R}^{\rm N*}>\pi_{\rm R}^{\rm C*}$; if $\lambda<\lambda_{\pi{\rm NC2}}$, $\pi_{\rm R}^{\rm C*}>\pi_{\rm R}^{\rm N*}$; ② when $k>\dfrac{\alpha^2}{2}$, if $\lambda_{\pi{\rm NC1}}<\lambda<\lambda_{\pi{\rm NC2}}$, $\pi_{\rm R}^{\rm N*}>\pi_{\rm R}^{\rm C*}$; if $\lambda>\lambda_{\pi{\rm NC2}}$ or $0<\lambda<\lambda_{\pi{\rm NC1}}$, $\pi_{\rm R}^{\rm C*}>\pi_{\rm R}^{\rm N*}$. Then we construct another function

$$(F(\pi_{\rm NS}))=\pi_{\rm R}^{\rm N*}-\pi_{\rm R}^{\rm S*}=\frac{2k-m\alpha^2}{8km\left(2k+(m-1)^2\alpha^2\right)}((m-1)(m-1)\alpha^2-2k)c^2-2cm(2k+(1-m)\alpha^2)\lambda+m\left(\left(m-(\lambda-1)^2\right)2k+m\alpha^2\lambda^2\right)+$$
$$4km\alpha(m+\lambda-1)\theta_0+2k(m-1)m\alpha^2\theta_0^2.$$

If $F(\pi_{\rm NS})=0$, we have two solutions: one is $\lambda_{\pi{\rm NS1}}=\dfrac{2(1+\alpha\theta_0-c)km-cm\alpha^2(1-m)-\sqrt{2}\sqrt{km(2k+\alpha^2-m\alpha^2)(-c+m+m\alpha\theta_0)^2}}{m(2k-m\alpha^2)}$, the other is $\lambda_{\pi \mathrm{NS}2} = \dfrac{2(1+\alpha\theta_0-c)km - cm\alpha^2(1-m) + \sqrt{2}\sqrt{km(2k+\alpha^2-m\alpha^2)(-c+m+m\alpha\theta_0)^2}}{m(2k-m\alpha^2)}$ and $\lambda_{\pi \mathrm{NS}1} < \lambda_{\pi \mathrm{NS}2}$. Similar to the above proof, we can conclude: ① when $0 < k < \dfrac{m\alpha^2}{2}$, if $0<\lambda<\lambda_{\pi \mathrm{NS}2}$, $\pi_{\mathrm{R}}^{\mathrm{N}*} > \pi_{\mathrm{R}}^{\mathrm{S}*}$; if $\lambda > \lambda_{\pi NS2}$, $\pi_R^{S*} > \pi_R^{N*}$; ② when $k > \dfrac{m\alpha^2}{2}$, if $\lambda_{\pi \mathrm{NS}1} < \lambda < \lambda_{\pi \mathrm{NS}2}$, $\pi_{\mathrm{R}}^{\mathrm{N}*} > \pi_{\mathrm{R}}^{\mathrm{S}*}$; if $\lambda > \lambda_{\pi \mathrm{NS}2}$ or $0 < \lambda < \lambda_{\pi \mathrm{NS}1}$, $\pi_{\mathrm{R}}^{\mathrm{S}*} > \pi_{\mathrm{R}}^{\mathrm{N}*}$.

**Proof of Proposition 4.5.** We construct a function $F(\theta_{\mathrm{CS}}) = \theta_{\mathrm{C}}{}^* - \theta_{\mathrm{S}}{}^* = \dfrac{\alpha(m-1)}{4k(2k+(1-m)\alpha^2)\left(2k+(m-a)^2\alpha^2\right)}\cdot$ $(2km\alpha^2 - 2km^2\alpha^2 + c(-1+m)^2\alpha^2(-2k+(-1+m)\alpha^2) - 8k^2\lambda + 4k^2m\lambda - 6k\alpha^2\lambda + 8km\alpha^2\lambda - 4km^2\alpha^2\lambda - \alpha^4\lambda + 3m\alpha^4\lambda - 3m^2\alpha^4\lambda + m^3\alpha^4\lambda -$ $2k(-1+m)m\alpha^3\theta_0)$. Let $F(\theta_{\mathrm{CS}}) = 0$, we can obtain $\lambda_{\theta \mathrm{CS}} = \dfrac{(1-m)\alpha^2(2km + c(m-1)(2k+\alpha^2-m\alpha^2) + 2km\alpha\theta_0)}{4k^2(2-m) + 2k(3-4m+2m^2)\alpha^2 + (1-m)^3\alpha^4}$. And $\dfrac{\partial F(\theta_{\mathrm{CS}})}{\partial \lambda} =$ $\dfrac{\alpha(m-1)(4k^2(-2+m) - 2k(3-4m+2m^2)\alpha^2 + (-1+m)^3\alpha^4)}{4k(2k+(1-m)\alpha^2)\left(2k+(m-a)^2\alpha^2\right)} > 0$. Thus, we can conclude that if $\lambda > \lambda_{\theta \mathrm{CS}}$, $\theta_{\mathrm{C}}{}^* > \theta_{\mathrm{S}}{}^*$, otherwise, $\theta_{\mathrm{S}}{}^* > \theta_{\mathrm{C}}{}^*$.

**Proof of Proposition 4.6.** We construct a function $F(p_{\mathrm{CS}}) = p_{\mathrm{C}}{}^* - p_{\mathrm{S}}{}^* = \dfrac{1}{2(2k+\alpha^2-m\alpha^2)(2k+\alpha^2-2m\alpha^2+m^2\alpha^2)}\cdot$ $(2km\alpha^2 - 2km^2\alpha^2 + c(-1+m)^2\alpha^2(-2k+(-1+m)\alpha^2) - 8k^2\lambda + 4k^2m\lambda - 6k\alpha^2\lambda + 8km\alpha^2\lambda - 4km^2\alpha^2\lambda - \alpha^4\lambda + 3m\alpha^4\lambda - 3m^2\alpha^4\lambda + m^3\alpha^4\lambda -$ $2k(-1+m)m\alpha^3\theta_0)$. Let $F(p_{\mathrm{NC}}) = 0$, we can obtain $\lambda_{\mathrm{PCS}} = \dfrac{(m-1)\alpha^2(2km + c(m-1)(2k+\alpha^2(1-m)) + 2km\alpha\theta_0)}{4k^2(m-1) - 2k(3-4m+2m^2)\alpha^2 + (m-1)^3\alpha^4}$, similar to the proof of Proposition 4.2, we can conclude: if $0 < \lambda < \lambda_{PCS}$, $p_{\mathrm{C}}{}^* > p_{\mathrm{S}}{}^*$, otherwise, $p_{\mathrm{S}}{}^* > p_{\mathrm{C}}{}^*$.

**Proof of Proposition 4.7.** We construct a function

$$F(\pi_{\mathrm{CS}}) = \pi_{\mathrm{R}}^{\mathrm{C}*} - \pi_{\mathrm{R}}^{\mathrm{S}*} = \frac{1}{8k\left(2k+(-1+m)^2\alpha^2\right)(2k+(1-m)\alpha^2)}(4k^2m\alpha^2 - 4k^2m^2\alpha^2 - c^2(-1+m)\alpha^2(4k^2(-2+m) - 2k(3-5m+2m^2)\alpha^2 +$$
$$(-1+m)^3\alpha^4) + 16k^3m\lambda + 8k^2\alpha^2\lambda - 16k^2m\alpha^2\lambda + 4k\alpha^4\lambda - 12km\alpha^4\lambda + 12km^2\alpha^4\lambda - 4km^3\alpha^4\lambda - 16k^3m\lambda^2 + 8k^3m^2\lambda^2 - 8k^2\alpha^2\lambda^2 +$$
$$20k^2m\alpha^2\lambda^2 - 4k^2m^3\alpha^2\lambda^2 - 2k\alpha^4\lambda^2 + 12km\alpha^4\lambda^2 - 20km^2\alpha^4\lambda^2 + 8km^3\alpha^4\lambda^2 + \alpha^6\lambda^2 - 3m\alpha^6\lambda^2 + 2m^2\alpha^6\lambda^2 + m^3\alpha^6\lambda^2 - m^4\alpha^6\lambda^2 +$$
$$2c(2k-1+m)\alpha^2)(4k^2(-2+m)\lambda + (1+m)^2m^4\lambda - 2k^2(1-2m(1+\lambda) + m^2(1+\lambda))) - 4k(c(-1+m)^2\alpha^2(2k-1+m)\alpha^2) -$$
$$4k^2m\lambda + (-1+m)^3\alpha^4\lambda + 2k\alpha^2(-m+m^2-\lambda+2m\lambda)\theta_0 - 4k^2(-1+m)m\alpha^4\theta_0^2.$$

Let $F(\pi_{\mathrm{CS}}) = 0$, we can obtain $\lambda_{\pi \mathrm{CS}1} = \dfrac{\Delta_1 + \sqrt{\Delta_2}}{\Delta_3}$, $\lambda_{\pi \mathrm{CS}2} = \dfrac{\Delta_1 - \sqrt{\Delta_2}}{\Delta_3}$, among them,

$$\Delta_1 = 2k(4k^2m + 2k(1-2m)\alpha^2 - (-1+m)^3\alpha^4) + c(8k^3(-2+m) - 4k^2(2-5m+2m^2)\alpha^2 + 2km(3-5m+2m^2)\alpha^4 - (-1+m)^3m\alpha^6) +$$
$$2k\alpha\theta_0(4k^2m + 2k(1-2m)\alpha^2 - (-1+m)^3\alpha^4),$$
$$\Delta_2 = (2k(4k^2m + 2k(1-2m)\alpha^2 - (-1+m)^3\alpha^4) + c(8k^3(-2+m) - 4k^2(2-5m+2m^2)\alpha^2 + 2km(3-5m+2m^2)\alpha^4 - (-1+m)^3m\alpha^6) +$$
$$2k\alpha(4k^2m + 2k(1-2m)\alpha^2 - (-1+m)^3\alpha^4)\theta_0)^2 + (-1+m)\alpha^2(8k^3(-2+m)m - 4k^2(2-5m+m^3)\alpha^2 + 2k(-1+6m-10m^2+4m^3)\alpha^4 -$$
$$(-1+m)^2(-1+m+m^2)\alpha^6)(4k^2m + 4ck(-1+m)(2k-(-1+m)\alpha^2) + c^2(4k^2(-2+m) - 2k(3-5m+2m^2)\alpha^2 + (-1+m)^3\alpha^4) +$$
$$4k\alpha(2km + c(-1+m)(2k+\alpha^2-m\alpha^2))\theta_0 + 4k^2m\alpha^2\theta_0^2)),$$
$$\Delta_3 = 8k^3(2-m)m + 4k^2(2-5m+m^3)\alpha^2 + 2k(1-2m)(1+2(m-2)m)\alpha^4 + (m-1)^2(m^2+m-1)\alpha^6.$$

Whether $\Delta_3$ is greater than 0 is closely related to the conclusion, but it is difficult to determine it. As a result, we set some values of $m$ and $\alpha$ to summarize the relationship between $\Delta_3$ and $k$ (see Fig. A1.). It was found that regardless of how $m$ and $\alpha$ change, when $k$ is high, $\Delta_3$ is greater than 0, and when $k$ is sufficiently low, $\Delta_3$ is less than 0. Similar to the proof of Proposition 4.5, we can conclude that ① when $k$ is sufficiently low, if $0 < \lambda < \lambda_{\pi CS2}$ or $\lambda > \lambda_{\pi \mathrm{CS}1}$, $\pi_{\mathrm{R}}^{\mathrm{C}*} > \pi_{\mathrm{R}}^{\mathrm{S}*}$, otherwise, $\pi_{\mathrm{R}}^{\mathrm{S}*} > \pi_{\mathrm{R}}^{\mathrm{C}*}$; and ② when $k$ is high, if $\lambda_{\pi \mathrm{CS}1} < \lambda < \lambda_{\pi \mathrm{CS}2}$, $\pi_{\mathrm{R}}^{\mathrm{C}*} > \pi_{\mathrm{R}}^{\mathrm{S}*}$, otherwise, $\pi_{\mathrm{R}}^{\mathrm{S}*} > \pi_{\mathrm{R}}^{\mathrm{C}*}$.

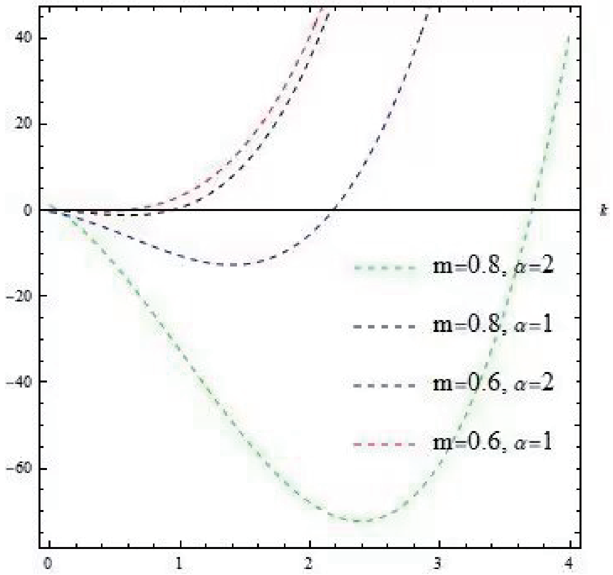

**Fig. A1.** The impact of $k$.