

Research on a new fresh food logistics sharing mode under carbon tax policy

Ping He

South China University of Technology, Guangzhou, China, and

Yujia Sun

*School of Business Administration, South China University of Technology,
Guangzhou, China*

Abstract

Purpose – The current development of e-commerce in fresh food industry has struggled in a bottleneck, while traditional physical retailers (T-retailers) also struggle in the O2O transformation process. To solve those operational problems, this paper aims to propose a new fresh food logistics (FFL) sharing mode (FLS mode) between T-retailers and E-retailers, illustrate its operation, feasibility and value.

Design/methodology/approach – We illustrate the operation and feasibility of FLS mode through literature analysis. Furthermore, we use Stackelberg models to stimulate a fresh food supply chain theoretically and investigate the FLS mode's impacts through comparison and numerical analysis.

Findings – First, a low competition intensity between channels always benefits the firms and consumers. Second, FLS mode could reduce the offline retail price and market demand simultaneously. Third, the firms could benefit from FLS mode, especially with the development of e-commerce in fresh food market. Last, consumer surplus in the offline channel is more at risk of decreasing after FLS. Particularly, FLS mode could show its best value in the online dominated market with low price-sensitive consumers and loose carbon tax policy.

Originality/value – We provide a logistics sharing strategy for T-retailers and E-retailers, give specific managerial insights for T-retailers who have great cold chain logistics systems, such as Walmart, Yonghui, etc. as well as those E-retailers who deliver fresh food through third-party logistics (3PL), such as Meituan Preferred, DuoDuo Grocery etc. In this case, T-retailers could enlarge their income sources, and E-retailers also could improve their product freshness.

Keywords Logistics sharing, Carbon tax, Stackelberg game, Fresh food logistics mode

Paper type Research paper

1. Introduction

With the development of e-commerce technology, fresh food e-commerce has experienced explosive expansion. Leading Internet companies start to expand the fresh food e-commerce business and add the fresh food category into their online shopping objects. In this case, many traditional offline retailers (T-retailer) have faced double risks from e-commerce and consumption transition, and freshness gradually becomes an important quality indicator, especially for fresh food e-commerce retailers (E-retailers). Notably, the deterioration of fresh food can not only cause a quantity loss, but also affect the market demand (Macheka *et al.*, 2017; Han *et al.*, 2021). Statistics show that less than 20% of perishable agricultural products are delivered with cold chain logistics, which causes substantial capital losses (Xi, 2021; Pan

© Ping He and Yujia Sun. Published in *Modern Supply Chain Research and Applications*. Published by Emerald Publishing Limited. This article is published under the Creative Commons Attribution (CC BY 4.0) licence. Anyone may reproduce, distribute, translate and create derivative works of this article (for both commercial and non-commercial purposes), subject to full attribution to the original publication and authors. The full terms of this licence may be seen at <http://creativecommons.org/licences/by/4.0/legalcode>

We greatly appreciate the comments and suggestions from the editor and the anonymous reviewers. This work was supported in part by grants from the National Natural Science Foundation of China (Grant Approval No.: 71971087, 72471093), the Innovative Research Group Project of National Natural Science Foundation of China (72321001), and the Fundamental Research Funds for the Central Universities (CXTD202407).



et al., 2021). This low efficiency of the fresh food logistics (FFL) has caused E-retailers bearing great commodity deterioration and plenty of after-sales disputes.

However, since there are distinguished geographical dispersion and diversity of Chinese farming households, the resistance to the FFL development is considerable (Lin *et al.*, 2021). With the high equipment acquisition cost and scope limitation, building cold chain logistics is not realistic for major fresh retailers to generally construct their own cold chain logistics, especially for E-retailers who have low-price strategies (Liu *et al.*, 2021; Han *et al.*, 2021).

Furthermore, since excessive packaging and low utilization in FFL have caused huge carbon emissions, increasingly prevalent carbon regulations also stimulate fresh retailers, i.e. T-retailers and E-retailers, to optimize their logistics modes to reduce carbon emission costs. Many T-retailers start to promote their cold chain logistics construction. For example, as a leading physical supermarket in China, Yonghui built a comprehensive cold chain logistic system since 2015, and the total operational area of its logistics center reached 450,000 square meters in 2018 (Lin *et al.*, 2021).

In conclusion, the current FFL of E-retailers normally has poor performance and causes a large amount of carbon emissions in China. Even though the development of FFL is at an accelerated stage, the cold chain logistics has a long payback cycle and need a relatively long time to build; it is neither efficient nor practical for fresh retailers to generally build their own cold chain logistics. Facing with the increasingly completed carbon regulations and the development of e-commerce, both T-retailers and E-retailers have reached a critical development point. Therefore, we propose an innovative FFL sharing mode (FLS mode) where T-retailers share their logistics system with E-retailers. In this case, T-retailers rise the efficiency of their cold-chain logistics systems, enlarge their income sources and could further improve their logistics systems. E-retailers may improve their product freshness through superior cold chain logistics provided by T-retailers with relatively low costs.

Specifically, we consider a fresh supply chain that involves three participants: a T-retailer (she) and an E-retailer (he) who compete with each other, as well as a third-party logistics service company (3PL) who can provide logistics services for the E-retailer. In particular, T-retailers represent those traditional offline fresh retailers who have great cold chain logistics systems, such as Walmart, Yonghui and other large-scale supermarkets. E-retailers represent those fresh food e-commerce retailers who do not have physical stores and deliver fresh food through 3PLs, such as Meituan Preferred, DuoDuo Grocery etc. The delivery quality of E-retailers is generally unsatisfied, as they tend to use cheap logistics services to ensure price competitiveness.

Since the FLS mode changes the profits of T-retailer and E-retailer in many aspects, the T-retailer needs to balance the benefits of extra income and the loss of competitive advantage in logistics. Furthermore, facing with carbon tax policy and consumers' freshness sensitivity, firms' price decisions could be affected by many aspects, such as tax rate, consumer's freshness sensitivity and the competition intensity between channels. In order to investigate the feasibility of FLS mode and its effects on the firms' profits and decisions, we take the logistics modes of Yonghui and Meituan Preferred as examples to illustrate the firms' sharing willingness. Then, we focus on the effects of FLS mode on the supply chain (i.e. on the firms and society) in the context of carbon tax policy, propose the following research questions:

- (1) With or without FLS mode, what are the impacts of consumer's sensitivity and carbon tax rate on the firms' pricing and profits?
- (2) How does the FLS mode affect the firms' pricing and profits? Can the FLS mode increase the profits of both firms simultaneously?
- (3) What are the impacts of FLS mode on the market demands and consumer surplus? How does carbon tax policy change these impacts?

To answer the above questions, we use Stackelberg game and construct two models. The first model (N-FLS model) simulates the scenario without FLS, while the second model (FLS model)

simulates the scenario with FLS. After solving these two models, we conduct sensitivity analysis to explore the impacts of parameters on the firms' decisions and profits as well as the consumer surplus in the two scenarios. Comparing FLS model with N-FLS model, we get the changes of the firms' profit, price decisions and the consumer surplus, to reveal the impacts of FLS mode on the firms and consumers. Furthermore, we particularly conduct numerical analysis to show the impacts of carbon tax rate and consumer's price sensitivity on the FLS's effects.

The rest of the part of this paper is as follows. In [Section 2](#), we review the associated research from three aspects and position our research in the literature. In [Section 3](#), we elaborate on the operation mechanism of FLS mode and the firms' sharing interests. In [Section 4](#), we give assumptions of our models, build and solve the two models, i.e. N-FLS model and FLS model. Based on the results, we also conduct sensitivity analysis and comparative analysis. In [Section 5](#), we show the benefits change of firms and consumers after FLS with graphs to extend the robustness of our results. In [Section 6](#), we summarize our key findings and management insights, and provide some future research directions.

2. Literature review

Since our research is mainly focused on the fresh FLS and decision-making under carbon tax policy, we summarize the relevant literature from three dimensions, i.e. studies about logistics service sharing, FFL and logistics strategies under carbon tax policy.

2.1 Logistics service sharing

With the development of Internet, logistics service sharing has been proposed since the mid-1990s, most research were aimed at improving organization-building and coordination mechanisms. [Luo et al. \(2021\)](#) give advice on the choice of sharing mechanism (i.e. cost-sharing or benefit-sharing) for a two-tier supply chain.

Due to the contradiction between extra incomes and logistics competitiveness loss, firms' logistics sharing decisions are conflicted. In order to reveal the reasons behind, [He et al. \(2019\)](#) investigate the impacts of business to customer (B2C) e-commerce logistics sharing on consumers and firms. [He et al. \(2020\)](#) explore logistics sharing decision and coordination in a dual-channel supply chain. [Qin et al. \(2020\)](#) examine the influence of two factors, i.e. market potential and the 3PL's logistics service level, on the logistics sharing effectiveness.

As logistics activities cause significant carbon emissions in the supply chain and carbon emissions in fresh supply chains are much more than that of common supply chains, with the development of carbon regulations, the impacts of logistics sharing on firms have broadened to carbon emission costs. However, it can be concluded that the existing research on logistics service sharing is normally conducted in regular supply chains, regardless of carbon emissions in logistics and the freshness sensitivity of consumers. In contrast, our study on logistics service sharing contains both carbon emissions and consumer's freshness sensitivity aspects, which makes our study more relevant to reality.

2.2 Fresh food logistics

To improve the freshness and efficiency of logistics systems, research on FFL is mainly about advanced technology application, mode innovation and decision optimization. To improve the application of new technologies and increase consumer satisfaction, [Macheka et al. \(2017\)](#) analyze the impacts of external environment such as farmers, vehicles and modes on post-harvest quality losses of agricultural products. [Pal and Kant \(2020\)](#) improve the interactivity of FFL system by using technologies like sensor and Internet of things.

Furthermore, scholars build various models to promote FFL effectiveness, [Zhang et al. \(2023\)](#) discuss the optimal invest strategies of fresh-keeping technology for an agricultural supply chain under different sales models. [Pan et al. \(2021\)](#) innovate a mathematical model to optimize the forklift loading algorithm for FFL to minimize the total transport spoilage.

Mahmoodi (2020) builds Stackelberg models to investigate the joint pricing and inventory decision for supply chains with deteriorating items. Driven by the high emission feature, there are extensive FFL literature that takes carbon emissions into consideration. Liu *et al.* (2021) point out the high efficiency of hybrid algorithm in FFL route optimization and minimize the total logistics cost including carbon emission cost, food refrigeration cost, etc.

It is clear that the efficient development of FFL has received lots of attention from scholars. Scholars mostly use qualitative analyses to discuss the feasibility and value of their proposed FFL modes. However, with quantitative analysis, these feasibility and value could be presented more convincingly and graphically. The few studies that include quantitative analysis are mainly about vehicle route optimization and firms' decision-makings, not considering logistics service sharing. In contrast, our study combines qualitative and quantitative analyses to accurately analyze the changes in firms' profits and decisions after logistics sharing, which improves the rigor of research on FFL modes.

2.3 Logistics strategies under carbon tax policy

As carbon regulations have been implemented for years, and carbon tax policy is broadly practiced due to its flexibility and adaptability, to provide suggestions for government, Yu *et al.* (2019) and Cao *et al.* (2020) explore the economic and social benefits of carbon tax policy in different supply chains and confirm the ability of carbon tax policy in improving firms' environmental performance. However, the benefits of carbon tax policy can be affected by external environment such as industry and region. Jiang *et al.* (2019) design a multi-modal green logistics network for city clusters with stochastic demand by considering the selective behavior of logistics users. An *et al.* (2021) use the Belt and Road countries as a reflection to indicate the importance of green logistics in the economic, environmental and social development of countries.

To provide suggestions for firms, scholars mostly study the impacts of carbon tax policy on business operations and strategies in terms of price, production and inventory decisions. He and Sun (2024) examine the impacts of retailer's carbon tax on the supply chain and the coordination of supply chain when both the retailer and the manufacturer are subject to carbon tax policy. Xu and Yue (2021) study the power structure strategies of two-tier supply chains in the face of carbon tax policy. Both Ma and Lu (2023) and Wang *et al.* (2021) give the optimal price decisions and carbon emissions for retailers and manufacturers under carbon tax policy. Tang *et al.* (2020) give specific instructions for decisions on energy efficiency and inventory.

It can be concluded that research that involves carbon tax policy is mainly from the perspective of government or firms. Studies from the firms' perspective mostly discuss how firms can optimize their price, order quantity and emission reduction level decisions under carbon tax policy. However, the logistics sharing decision greatly affects the firms' logistics carbon emission costs, which further leads to their operational adjustments. Therefore, our study concentrates on the innovation of FFL mode and the firms' logistics sharing decisions under carbon tax policy.

To sum up, certain features of our study distinguish it from the existing literature mentioned above. In particular, in order to show the contribution of our paper to the literature more clearly, we summarize the differences between the most relevant studies and our paper in Table 1.

3. FLS mode

As FLS mode has not been practiced, to be clear, this logistics sharing mode should be applied among T-retailers and E-retailers. T-retailers are physical fresh food retailers who have their own logistics systems, and E-retailers are e-commerce platforms who deliver fresh food through 3PLs.

Since most T-retailers or E-retailers have similar logistics modes, we select two representative companies, i.e. YongHui Supermarket as a T-retailer, and Meituan Preferred

Table 1. Summary of the difference between the most relevant studies and our paper

Related studies	Logistics sharing	Fresh food logistics	Carbon policy	Comparison Transportation fee	Profit of firms	Consumer surplus
He <i>et al.</i> (2019)	√				√	√
He <i>et al.</i> (2020)	√				√	
Qin <i>et al.</i> (2020)	√			√	√	
Mahmoodi (2020)		√			√	
Liu <i>et al.</i> (2021)		√	√			
Jiang <i>et al.</i> (2019)			√		√	√
He and Sun (2024)			√		√	√
Xu and Yue (2021)			√		√	√
Ma and Lu (2023)			√		√	
Our study	√	√	√	√	√	√
Source(s): Authors' own creation						

as an E-retailer. The operation of FLS mode could be demonstrated by analyzing the logistics distribution and procurement patterns of these two firms. Furthermore, in order to illustrate the mode's feasibility, we also address problems that can be solved and benefits that can be brought through FLS from perspectives of these two firms.

From the perspective of T-retailers, YongHui like most large-scale supermarkets in fresh industry adopts three procurement modes, i.e. national unified procurement, regional direct procurement and supplier procurement. Although some large-scale supermarkets choose to collaborate with 3PLs, their needs for self-built logistics systems (S-LS) are still growing in the face of increasingly fierce competition. On the one hand, with the continuous innovation of fresh retail mode, T-retailers gradually invest on their own logistics systems, which inevitably causes problems such as capital shortage, low yield etc. On the other hand, the current network coverage of T-retailers' logistics systems still needs to be enlarged (Zhang *et al.*, 2019). Therefore, how to solve problems such as capital shortage and low return on investment to further improve their cold chain logistics system is crucial to the development of T-retailers.

From the perspective of E-retailers, as an emerging business mode, the development of fresh e-commerce largely relies on the logistics system. Under the cost constraints of capital and time of S-LS, most E-retailers work with 3PLs to deliver fresh food. However, considering the volatility of transportation fee, the complexity of accountability and the lack of competitiveness, this delivery mode based on 3PLs can hardly meet the needs of E-retailers in the long term (Xi, 2021). For example, Meituan Preferred applies a novel fresh e-commerce business mode which has realized the supply-side reform of "demand-driven production and supply-demand synergy" (Shang, 2021). Nevertheless, its multi-level supply chain, i.e. "supplier→shared warehouse→central warehouse→grid station→self-pickup point", is redundant and lack of flexibility, which results in the instability of product quality along with huge environmental pollution and capital losses. Consequently, E-retailers' consumers always have poor purchase experience and precarious buying behavior.

Combining the current development issues of both T-retailers and E-retailers mentioned above, we propose an innovative logistics sharing mode (FLS mode). Through the supplier's

information sharing platform, the T-retailer shares her self-built FFL from logistics distribution center to store stage with the E-retailer, replacing his transport process from shared warehouse to grid warehouse, which is further demonstrated with Figure 1. Through FLS mode, the T-retailer can (1) further improve her cold chain logistics with the additional revenue from logistics sharing; (2) promote the utilization of logistics facilities to increase her transportation efficiency and return on investment; (3) enhance her brand awareness and consumer stickiness. At the same time, the E-retailer can (1) relieve the pressure of self-built FFL and enhance his market competitiveness of logistics services; (2) improve the quality of goods his consumers received and increase the consumer's satisfaction and loyalty; (3) enhance the predictability of his transportation costs and contribute to his financial budget and analysis.

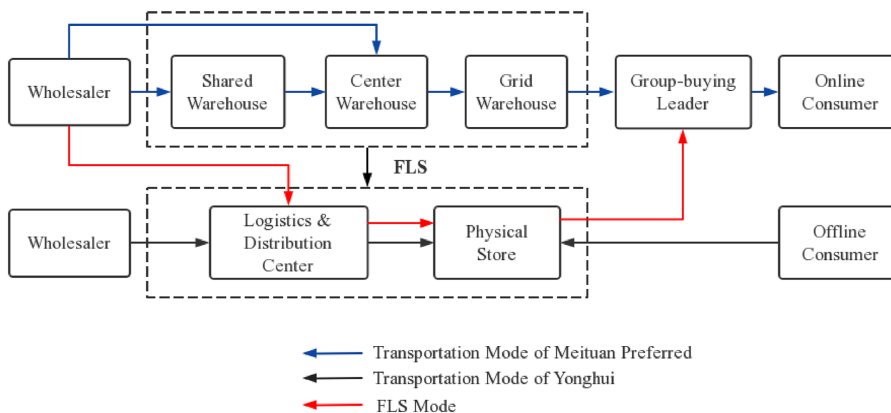
Undeniably, FLS mode brings benefits for the firms from many aspects, but it also leads to several risks for T-retailers and E-retailers. For the T-retailer, she may lose the competitive advantage brought by her logistics service or face an overload of her logistics system. For the E-retailer, a potential higher transportation fee should also be noticed. Therefore, we use Stackelberg game theory to stimulate the firms' optimal decisions in two scenarios, i.e. with and without FLS mode, to further explore this sharing model in Section 4.

4. Models

In this section, in order to investigate FLS mode theoretically, we propose a few assumptions in Section 4.1 and build Stackelberg models in two scenarios, i.e. with FLS and without FLS. Then we solve models through backward induction method and derive the firms' optimal decisions under different conditions in Section 4.2–4.3, obtain the major findings through sensitivity analysis and comparative analysis. All the proofs for the theorems and propositions in this section are presented in Appendix A.

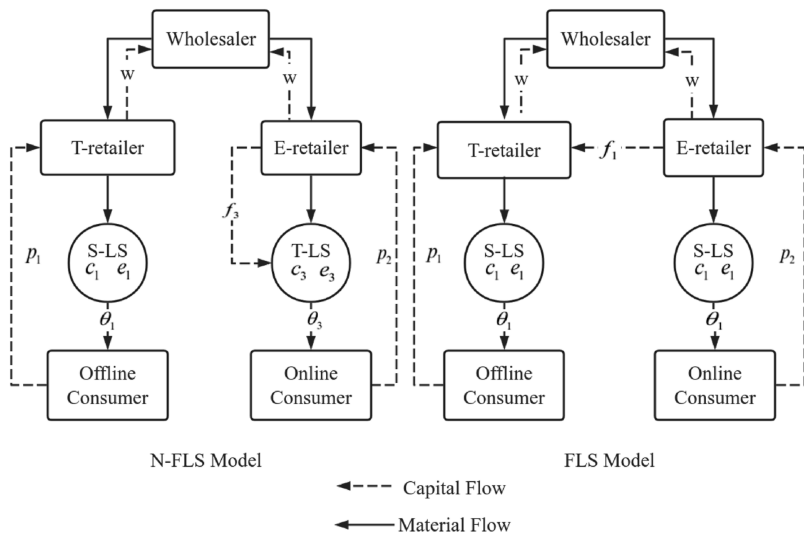
4.1 Research problem and assumptions

Based on the illustration in Section 3, we involve three participants in our models: a T-retailer, an E-retailer and a 3PL. Under the carbon tax policy, the E-retailer can choose to share the superior FFL of the T-retailer (S-LS) or use the FFL of 3PL (T-LS), i.e. the two scenarios we mainly consider: without FLS (N-FLS Scenario) and with FLS (FLS Scenario). In particular, we specifically show the supply chain structure in Figure 2.



Source(s): Authors' own creation

Figure 1. The operation diagram of FLS



Source(s): Authors' own creation

Figure 2. Model framework diagram

We treat the T-retailer as the decision leader, the 3PL and the E-retailer as the followers. In N-FLS scenario, the T-retailer delivers fresh foods with her S-LS and the E-retailer uses logistics services from the 3PL (T-LS) to deliver fresh food. After the T-retailer deciding her offline retail price (p_1), the 3PL decides the transportation fee (f_3) and the E-retailer decides the online retail price (p_2). In FLS scenario, the T-retailer shares her S-LS with the E-retailer, she decides the offline retail-price (p_1) and transportation fee (f_1) first, then the E-retailer decides the online retail-price (p_2). We summarize the variables and parameters used in the models in Table 2, and the decision sequence of each subject in the two scenarios is shown in Figures 3 and 4.

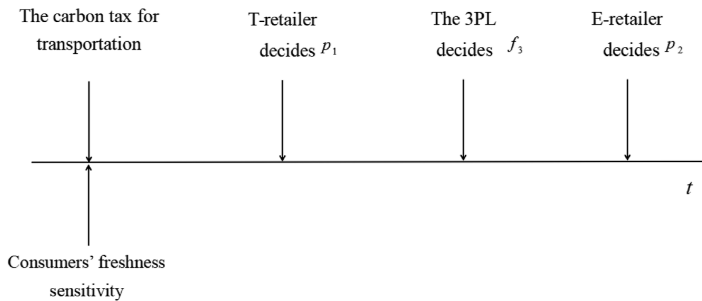
To facilitate the solution of models, we make the following assumptions:

- Assumption 1.* Since the difference in fresh food price is relatively small, and consumers are normally more concerned about the food's freshness than its price, we do not consider the price competition between channels (Han et al., 2021).
- Assumption 2.* The demand is linearly related to the food price and freshness, offline and online channel have market shares of ψ and $(1 - \psi)$ respectively, and the potential market demand X is assumed to be sufficiently large (He et al., 2021).
- Assumption 3.* As we mainly discuss the FLS mode and do not involve the logistics investment decisions, we assumed that the capacity of the T-retailer's FFL is sufficient, and her logistics service level is not affected by logistics sharing (He et al., 2020).
- Assumption 4.* To concentrate on the FLS mode and firms' price decisions, we normalize the costs of production and logistics facilities to be zero, which will not affect the firms' optimal decisions (Xu and Yue, 2021; Li et al., 2021).

Table 2. Parameters and variables

Notation	Definition
Superscript	
N	N-FLS scenario
S	FLS scenario
Subscript	
1,2,3	The T-retailer/offline channel, the E-retailer/online channel, the 3PL, respectively
Parameters	
X	Potential market demand
ψ	Consumer preference for offline channel
α	Consumer's price sensitivity
β	Consumer's freshness sensitivity
γ	The freshness competition intensity between channels (channel competition intensity)
w	Wholesale price
t	Carbon tax rate
e_i	Carbon emissions generated in per unit of product transportation of i , $i = 1, 3$
c_i	Unit transportation cost of i , $i = 1, 3$
θ_i	Logistics freshness level of i , $i = 1, 3$
Decision variables	
p_i	Retail price of i , $i = 1, 2$
f_i	Unit transportation fee of carriers i , $i = 1, 3$
Other variables	
q_i^j	Consumer demand of i in j , $i = 1, 2$, $j = N, S$
π_i^j	The profit of i in j , $i = 1, 2, 3$, $j = N, S$
CS_i^j	Consumer surplus of i in j , $i = 1, 2$, $j = N, S$

Source(s): Authors' own creation



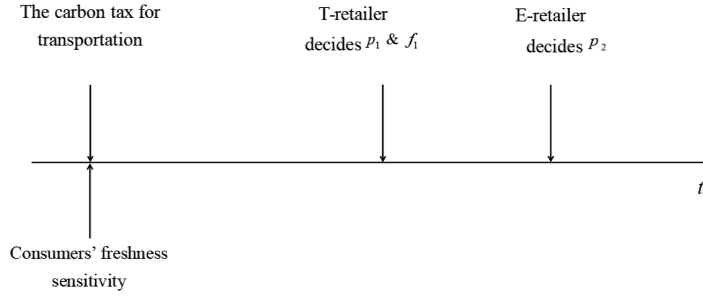
Source(s): Authors' own creation

Figure 3. Decision-making sequence of scenario N-FLS

Assumption 5. Due to the complexity of the relationship between carbon emissions and logistics freshness levels, we assume that carbon emissions of carriers are independent of their logistics freshness abilities for the model tractability.

4.2 Model in scenario N-FLS

In this case, the E-retailer relies on the 3PL to complete the transportation and sells fresh products to consumers through online channel. The T-retailer relies on her S-LS to sell



Source(s): Authors' own creation

Figure 4. Decision-making sequence of scenario FLS

products to consumers through offline channel. The 3PL provides logistics service to the E-retailer and charge a transportation fee.

According to [Assumption 1](#), we express the demand function for the two channels as follows:

$$D_1^N = \psi X - \alpha p_1^N + \beta \theta_1 - \gamma \theta_3 \quad (1)$$

$$D_2^N = (1 - \psi)X - \alpha p_2^N + \beta \theta_3 - \gamma \theta_1 \quad (2)$$

The T-retailer's profit can be computed as the product sales in the offline channel subtracted by the costs of procurement, transportation and carbon emissions:

$$\pi_1^N(p_1^N) = (p_1^N - w - c_1)D_1^N - t e_1 D_1^N \quad (3)$$

The E-retailer's profit can be computed as the product sales in the online channel subtracted by the procurement cost and the transportation fee charged by 3PL:

$$\pi_2^N(p_2^N) = (p_2^N - w - f_3)D_2^N \quad (4)$$

The 3PL's profit can be computed as the transportation fee income subtracted by the carbon emission cost:

$$\pi_3^N(f_3) = (f_3 - c_3)D_2^N - t e_3 D_2^N \quad (5)$$

4.3 Model in Scenario FLS

In this case, the T-retailer shares her self-built FFL with the E-retailer and charges a transportation fee. According to [Assumption 1](#), we express the demand function for the two channels as follows:

$$D_1^S = \varphi X - \alpha p_1^S + \beta \theta_1 - \gamma \theta_1 \quad (6)$$

$$D_2^S = (1 - \varphi)X - \alpha p_2^S + \beta \theta_1 - \gamma \theta_1 \quad (7)$$

The T-retailer's profit can be computed as the product sales in the offline channel added with the transportation fee income subtracted by the cost of procurement, transportation and carbon emissions:

$$\pi_1^S(p_1^S, f_1) = (p_1^S - w - c_1)D_1^S + (f_1 - c_1)D_2^S - te_1(D_1^S + D_2^S) \quad (8)$$

The E-retailer's profit can be computed as the product sales in the online channel subtracted by the procurement cost and the transportation fee charged by the T-retailer:

$$\pi_2^S(p_2^S) = (p_2^S - w - f_1)D_2^S \quad (9)$$

Theorem 1. The optimal decisions and other outcomes in scenario N-FLS and scenario FLS are listed in [Table 3](#):

Comparing the results in scenario FLS with those in scenario N-FLS, we can find out the impacts of FLS on the supply chain and consumers.

Proposition 1. The impacts of consumer's sensitivities (i.e. price sensitivity and freshness sensitivity) on the supply chain are shown in [Table 4](#):

[Proposition 1](#) shows that as the price sensitivity decreases or the freshness sensitivity increases, the pricing as well as the profits of the firms increase. This is because, the more sensitive consumers are to freshness or the less sensitive they are to price, the higher the retail price and demand will be in each channel, which further helps the firms obtain more profits. [Proposition 1](#) suggests that the firms can benefit from the transition of consumers from price orientation to quality orientation. Therefore, in order to effectively exploit the dividends from consumer's preferences, firms should increase their promotional efforts and choose the target market wisely.

Proposition 2. The impacts of channel competition intensity on the supply chain are shown in [Table 5](#):

[Proposition 2](#) shows that as the channel competition intensity increases, the pricing and profits of firms as well as the demands decline. As the channel competition raises, the firms can only attract consumers by reducing prices in the short term, which makes it difficult to guarantee the freshness of products. The equilibrium demand falls naturally when consumers value product's quality more than its price. [Proposition 2](#) suggests that the channel competition is not economical, firms should focus on improving the stickiness of its own consumers rather than competing with others.

Proposition 3. The impacts of consumer's channel preference on firms' profits are shown as follows:

$$(1) \quad \frac{\partial \pi_1^N}{\partial \psi} > 0, \frac{\partial \pi_2^N}{\partial \psi} < 0, \frac{\partial \pi_2^S}{\partial \psi} < 0;$$

$$(2) \quad \frac{\partial \pi_1^S}{\partial \psi} \begin{cases} < 0 \left(0 < \psi < \frac{1}{3} \right) \\ > 0 \left(\psi > \frac{1}{3} \right) \end{cases} \quad \frac{\partial \pi_2^S}{\partial \psi} < 0.$$

[Proposition 3](#) indicates that without FLS, in one channel, the firm's profit is always proportional to the consumer's preference for that channel. However, after FLS, the profit of T-retailer is only proportional to the consumer's preference for offline channel (ψ) when $\psi > \frac{1}{3}$. This is because, when ψ is small, compared with the increase in sales caused by the increased ψ , it leads to a greater decrease in the transportation fee revenue, which damages the T-retailer's profit. [Proposition 3](#) suggests that firms can gain more profit by increasing the

Table 3. The optimal decisions and outcomes in scenario N-FLS and scenario FLS

Variables	Scenario N-FLS	Scenario FLS
Retail price in offline channel	$p_1^N = \frac{w\alpha + X\psi + \alpha c_1 + t\alpha e_1 + \beta\theta_1 - \gamma\theta_2}{2\alpha}$	$p_1^S = \frac{X\psi + w\alpha + \alpha c_1 + t\alpha e_1 + (\beta - \gamma)\theta_1}{2\alpha}$
Retail price in online channel	$p_2^N = \frac{3X + w\alpha - 3X\psi + \alpha c_3 + t\alpha e_3 - 3\gamma\theta_1 + 3\beta\theta_3}{4\alpha}$	$p_2^S = \frac{3(1 - \psi)X + w\alpha + \alpha c_1 + t\alpha e_1 + 3(\beta - \gamma)\theta_1}{4\alpha}$
Transportation fee	$f_3^N = \frac{X(1 - \psi) - w\alpha + \alpha c_3 + t\alpha e_3 - \gamma\theta_1 + \beta\theta_3}{2\alpha}$	$f_1^S = \frac{(1 - \psi)X - w\alpha + \alpha c_1 + t\alpha e_1 + (\beta - \gamma)\theta_1}{2\alpha}$
Demand of the T-retailer	$q_1^N = \frac{1}{2}(X\psi - w\alpha - \alpha(c_1 + t e_1) + \beta\theta_1 - \gamma\theta_3)$	$q_1^S = \frac{1}{2}(X\psi - w\alpha - \alpha(c_1 + t e_1) + (\beta - \gamma)\theta_1)$
Demand of the E-retailer	$q_2^N = \frac{1}{4}(X(1 - \psi) - w\alpha - \alpha(c_3 + t e_3) - \gamma\theta_1 + \beta\theta_3)$	$q_2^S = \frac{1}{4}(X(1 - \psi) - w\alpha - \alpha(c_1 + t e_1) + (\beta - \gamma)\theta_1)$
The T-retailer's profit	$\pi_1^N = \frac{(X\psi - w\alpha - \alpha c_1 - t\alpha e_1 + \beta\theta_1 - \gamma\theta_3)^2}{4\alpha}$	$\pi_1^S = \frac{1}{8\alpha} \left(3w^2\alpha^2 - 2wX\alpha(1 + \psi) + X^2(1 + \psi(-2 + 3\psi)) + (2(X - 3w\alpha + X\psi) - 3\alpha(c_1 + t e_1) + 3(\beta - \gamma)\theta_1)((\beta - \gamma)\theta_1 - t\alpha e_1 - \alpha c_1) \right)$
The E-retailer's profit	$\pi_2^N = \frac{(X(1 - \psi) - w\alpha - \alpha c_3 - t\alpha e_3 - \gamma\theta_1 + \beta\theta_3)^2}{16\alpha}$	$\pi_2^S = \frac{(w\alpha + X(-1 + \psi) + \alpha c_1 + t\alpha e_1 + (-\beta + \gamma)\theta_1)^2}{16\alpha}$
The 3PL's profit	$\pi_3^N = \frac{(X(1 - \psi) - w\alpha - \alpha c_3 - t\alpha e_3 - \gamma\theta_1 + \beta\theta_3)^2}{8\alpha}$	—
Consumer surplus in offline channel	$CS_1^N = \frac{(X\psi - w\alpha - \alpha c_1 - t\alpha e_1 + \beta\theta_1 - \gamma\theta_3)^2}{8\alpha}$	$CS_1^S = \frac{(X\psi - w\alpha - \alpha c_1 - t\alpha e_1 + (\beta - \gamma)\theta_1)^2}{8\alpha}$
Consumer surplus in online channel	$CS_2^N = \frac{(X(1 - \psi) - w\alpha - \alpha c_3 - t\alpha e_3 - \gamma\theta_1 + \beta\theta_3)^2}{32\alpha}$	$CS_2^S = \frac{(X(1 - \psi) - w\alpha - \alpha c_1 - t\alpha e_1 + (\beta - \gamma)\theta_1)^2}{32\alpha}$
Source(s): Authors' own creation		

Table 4. The impacts of consumer's sensitivity on the supply chain

$\alpha \uparrow / \beta \downarrow$	p_1	p_2	f_1/f_3	π_1	π_2	π_3
N-LSS	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$
LSS	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	$\uparrow$	—
Source(s): Authors' own creation						

Table 5. The impacts of channel competition intensity on the supply chain

$\gamma \uparrow$	p_1	p_2	f_1/f_3	π_1	π_2	π_3	q_1	q_2
N-LSS	$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$
LSS	$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$	—	$\downarrow$	$\downarrow$
Source(s): Authors' own creation								

consumer preference for the channel to which they belong. Notably, when FLS is applied, the T-retailer needs to consider the market share of offline channel to avoid a profit loss.

Proposition 4. The impacts of cost, freshness and carbon emissions of the carriers' transportation on the E-retailer are shown as follows:

$$(1) \frac{\partial \pi_2^N}{\partial c_3} < 0, \frac{\partial \pi_2^N}{\partial e_3} < 0, \frac{\partial \pi_2^N}{\partial \theta_3} > 0;$$

$$(2) \frac{\partial \pi_2^S}{\partial c_1} < 0, \frac{\partial \pi_2^S}{\partial e_1} < 0, \frac{\partial \pi_2^S}{\partial \theta_1} > 0.$$

[Proposition 4](#) shows that the profit of E-retailer is positively related to the carriers' freshness level, but negative related to the transportation cost and carbon emission level of the carrier (i.e. the T-retailer or the 3PL). This is because when the transportation cost and carbon tax cost increase, the carrier will raise the transportation fee, which indirectly decreases the E-retailer's profit. In contrast, a high freshness level of the carrier enables the E-retailer to set a higher retail price and get a higher profit from increased demand. [Proposition 4](#) suggests that the E-retailer has the willingness to reduce his carrier's transportation cost and carbon emission level and to improve the logistics freshness level.

Proposition 5. The impacts of FLS on the T-retailer are shown as follows:

$$(1) \Delta p_1 = p_1^S - p_1^N < 0; \Delta q_1 = q_1^S - q_1^N < 0;$$

$$\frac{\partial \Delta p}{\partial \theta_3} > 0, \frac{\partial \Delta q}{\partial \theta_3} > 0, \frac{\partial \Delta p}{\partial \theta_1} < 0, \frac{\partial \Delta q}{\partial \theta_1} < 0, \frac{\partial \Delta p}{\partial \gamma} < 0, \frac{\partial \Delta q}{\partial \gamma} < 0;$$

$$(2) \Delta\pi_1 = \pi_1^S - \pi_1^N \begin{cases} > 0 \begin{cases} 0 < \psi < \frac{1}{2} \\ \frac{1}{2} \leq \psi < 1 \text{ and } \alpha < \alpha'_1, w < w'_1, t < t'_1 \end{cases} \\ < 0 \begin{cases} \frac{1}{2} \leq \psi < 1 \text{ and } \alpha < \alpha'_1, w > w'_1 \\ \frac{1}{2} \leq \psi < 1 \text{ and } \alpha > \alpha'_1 \end{cases} \end{cases}$$

$$\alpha'_1 = \frac{1}{c_1} \left((1 - \psi)X + (\beta - 3\gamma)\theta_1 + 2\gamma\theta_3 - \sqrt{2\gamma(\theta_1 - \theta_3)((4\psi - 2)X + 3\gamma\theta_1 - 3\gamma\theta_3)} \right);$$

$$w'_1 = \frac{1}{\alpha} \left((1 - \psi)X + (\beta - 3\gamma)\theta_1 + 2\gamma\theta_3 - \alpha c_1 - \sqrt{2\gamma(\theta_1 - \theta_3)((4\psi - 2)X + 3\gamma\theta_1 - 3\gamma\theta_3)} \right);$$

$$t'_1 = \frac{1}{\alpha e_1} \left((1 - \psi)X - w\alpha - \alpha c_1 + (\beta - 3\gamma)\theta_1 + 2\gamma\theta_3 - \sqrt{2\gamma(\theta_1 - \theta_3)((4\psi - 2)X + 3\gamma\theta_1 - 3\gamma\theta_3)} \right).$$

Proposition 5 indicates that the pricing and market demand of the T-retailer decline after FLS, and the profit change is influenced by various factors, such as consumer's channel preference and price sensitivity, carbon tax etc. Furthermore, the decline in pricing and demand for the T-retailer increases when her relative logistics freshness and channel competition intensify. It should be noted that when consumers prefer online channel, FLS provides additional revenue for the T-retailer that can compensate for or even surpass the loss of her logistics freshness advantage, so she can benefit from FLS mode. On the contrary, if consumers prefer offline channel, the T-retailer can benefit from FLS mode only when the carbon tax rate and the wholesale price as well as the consumer's price sensitivity are low. **Proposition 5** suggests that the T-retailer's benefit from FLS mode depends on whether the transportation fee income can compensate for the loss of logistics superiority. Therefore, the T-retailer should focus on the relative size of offline market and her logistics cost when deciding on the logistics sharing. As new retail formats continue to spread, the consumer's preference for online channel is going to increase and the positive effect of FLS mode to the T-retailer would become more and more clearer.

Proposition 6. The impacts of FLS on the E-retailer are shown as follows:

$$(1) \Delta p_2 = p_2^S - p_2^N \begin{cases} > 0 \begin{cases} 0 < e_3 \leq e_1 \\ e_3 > e_1 \text{ and } 0 < t < t'_2 \end{cases} \\ < 0 (e_3 > e_1 \text{ and } t > t'_2) \end{cases}$$

$$(2) \Delta q_2 = q_2^S - q_2^N \left\{ \begin{array}{l} > 0 \left\{ \begin{array}{l} 0 < e_3 < e_1 \text{ and } 0 < \alpha < \alpha'_2, 0 < t < t'_2 \\ e_3 = e_1 \text{ and } 0 < \alpha < \alpha'_2 \\ e_3 > e_1 \left\{ \begin{array}{l} 0 < \alpha < \alpha'_2 \\ \alpha > \alpha'_2 \text{ and } t > t'_2 \end{array} \right. \end{array} \right. ; \\ < 0 \left\{ \begin{array}{l} 0 < e_3 < e_1 \left\{ \begin{array}{l} 0 < \alpha < \alpha'_2, t > t'_2 \\ \alpha > \alpha'_2 \end{array} \right. \\ e_3 = e_1 \text{ and } \alpha > \alpha'_2 \\ e_3 > e_1 \text{ and } \alpha > \alpha'_2 \text{ and } 0 < t < t'_2 \end{array} \right. \end{array} \right.$$

$$(3) \Delta f = f_1^S - f_3^N \left\{ \begin{array}{l} > 0 \left\{ \begin{array}{l} 0 < e_3 \leq e_1 \\ e_3 > e_1 \text{ and } 0 < t < t'_2 \end{array} \right. ; \\ < 0 (e_3 > e_1 \text{ and } t > t'_2) \end{array} \right.$$

$$(4) \Delta \pi_2 = \pi_2^S - \pi_2^N \left\{ \begin{array}{l} > 0 \left\{ \begin{array}{l} 0 < e_3 < e_1 \text{ and } 0 < \alpha < \alpha'_2, 0 < t < t'_2 \\ e_3 = e_1 \text{ and } 0 < \alpha < \alpha'_2 \\ e_3 > e_1 \left\{ \begin{array}{l} 0 < \alpha < \alpha'_2 \\ \alpha > \alpha'_2 \text{ and } t > t'_2 \end{array} \right. \end{array} \right. ; \\ < 0 \left\{ \begin{array}{l} 0 < e_3 < e_1 \left\{ \begin{array}{l} 0 < \alpha < \alpha'_2, t > t'_2 \\ \alpha > \alpha'_2 \end{array} \right. \\ e_3 = e_1 \text{ and } 0 < \alpha < \alpha'_2 \\ e_3 > e_1 \text{ and } \alpha > \alpha'_2, 0 < t < t'_2 \end{array} \right. \end{array} \right. .$$

$$\alpha'_2 = \frac{\beta(\theta_1 - \theta_3)}{c_1 - c_3}, t'_2 = \frac{ac_1 - ac_3 - \beta\theta_1 + \beta\theta_3}{-ae_1 + ae_3}.$$

Proposition 6 shows that, for the E-retailer, variations of his profit and pricing are affected by several factors (e.g. carbon tax etc.). Meanwhile, changes of his transportation fee and demand are influenced by the carbon tax rate along with the carriers' carbon emission levels. Only when the T-retailer has a low carbon emission level and the carbon tax rate is above the threshold, the E-retailer could receive a lower transportation fee after FLS. It is worth noting

that even the E-retailer raises his retail price, he can only earn an increased profit when the price sensitivity is low where consumers increase their purchases due to a higher freshness level. [Proposition 6](#) suggests that the benefit of E-retailer depends on the consumer's price sensitivity and the change in his transportation fee. Therefore, the E-retailer is likely to benefit from FLS because of the low price-elasticity feature of fresh food market, and the government can guide the development of FLS mode by regulating carbon tax rate.

Proposition 7. The impacts of FLS on consumers are shown as follows:

$$\begin{aligned}
 (1) \quad \Delta CS_1 = CS_1^S - CS_1^N &< 0; \\
 (2) \quad \Delta CS_2 = CS_2^S - CS_2^N &\left\{ \begin{array}{l} > 0 \left\{ \begin{array}{l} 0 < e_3 < e_1 \text{ and } 0 < \alpha < \alpha'_2, 0 < t < t'_2 \\ e_3 = e_1 \text{ and } 0 < \alpha < \alpha'_2 \\ e_3 > e_1 \left\{ \begin{array}{l} 0 < \alpha < \alpha'_2 \\ \alpha > \alpha'_2 \text{ and } t > t'_2 \end{array} \right. \end{array} \right. \\ < 0 \left\{ \begin{array}{l} 0 < e_3 < e_1 \left\{ \begin{array}{l} 0 < \alpha < \alpha'_2, t > t'_2 \\ \alpha > \alpha'_2 \end{array} \right. \\ e_3 = e_1 \text{ and } 0 < \alpha < \alpha'_2 \\ e_3 > e_1 \text{ and } \alpha > \alpha'_2, 0 < t < t'_2 \end{array} \right. \end{array} \right.
 \end{array}
 \right.
 \end{aligned}$$

$$\alpha'_2 = \frac{\beta(\theta_1 - \theta_3)}{c_1 - c_3}, t'_2 = \frac{ac_1 - ac_3 - \beta\theta_1 + \beta\theta_3}{-ae_1 + ae_3}.$$

[Proposition 7](#) indicates that FLS always reduces the margin of offline consumers, while its effects on online consumers influenced by factors like the consumer's price sensitivity etc. It needs to be noted that even the same good is sold at a lower price, consumer surplus in the offline channel still decreases because of the demand decline. While FLS has a positive impact on the online consumer when consumers can perceive more utility from a fresher product. [Proposition 7](#) suggests that under the effect of channel competition, FLS is more favorable to online consumers, but not to offline consumers, and a lower carbon tax rate can increase the profit possibility of online consumers.

5. Numerical studies

From theoretical analysis in [Section 4](#), there are many parameters that affect the benefit changes of the firms and consumers after FLS. Therefore, in this section, we further show the impacts of FLS on the firms and consumers through numerical studies. We primarily varied the parameters describing the external environment of the supply chain (e.g. carbon tax, consumer sensitivities to price and freshness, preference for channels, the carriers' carbon emission levels) to show the performance of FLS in various markets where have different carbon policies and consumer features. It should be noted that, we use the profit change of the firms (i.e. the T-retailer and the E-retailer) to reflect their sharing willingness, which further shows

the economic performance of FLS mode. Similarly, we use the consumer surplus change to reflect the mode's social performance.

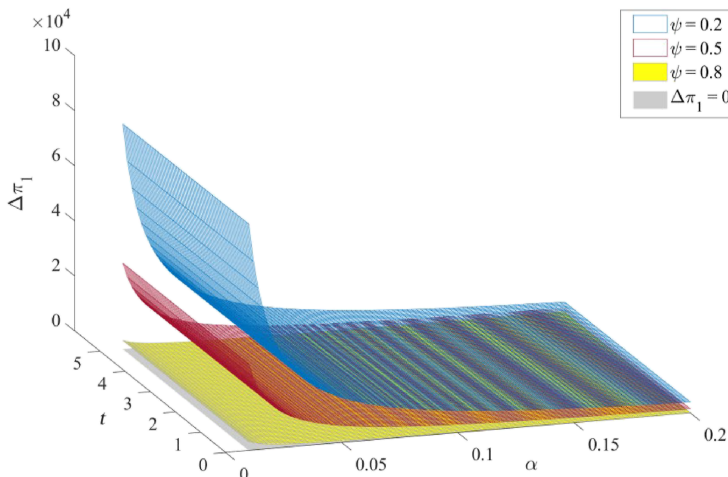
5.1 Sharing willingness analysis for the T-retailer

As shown in Proposition 5, the benefit of the T-retailer is affected by parameters like carbon tax rate etc. So we set the potential market demand, the freshness sensitivity, the wholesale price, the freshness and cost as well as carbon emissions of carriers as $X = 100, \beta = 0.5, w = 1, \theta_1 = 5, \theta_3 = 2, c_1 = 5, c_3 = 3, e_1 = 5, e_3 = 3$, respectively; let the carbon tax rate (t) increase from 0 to 5, the price sensitivity (α) increase from 0 to 0.2, make consumer's preference for offline channel (ψ) take the values of 0.2, 0.5, 0.8, respectively. From Figure 5, we can see that the T-retailer benefits from FLS under all the set circumstances, and the more the consumers prefer offline channel, the more her profit will grow.

From another perspective, Proposition 5 indicates that if consumers are sensitive to price, the wholesale price and the carbon tax rate are lower than the corresponding thresholds, the T-retailer's profit could rise. Thus, we simulate those thresholds to show the possibility to her benefit. Based on the parameter setting before (i.e. $X = 100, \beta = 0.5, w = 1, \theta_1 = 5, \theta_3 = 2, c_1 = 5, c_3 = 3, e_1 = 5, e_3 = 3$), we further set the price sensitivity $\alpha = 0.1$ to get Figure 6. Figure 6 demonstrates that as ψ keeps decreasing, i.e. the share of the online channel in the fresh market keeps enlarging, the condition (i.e. $\alpha < \bar{\alpha}_1, w < \bar{w}_1, t < \bar{t}_1$) for the T-retailer's profit growth in Proposition 5 is more likely to be satisfied, which further illustrates the certainty of her profit growth and willingness to FLS.

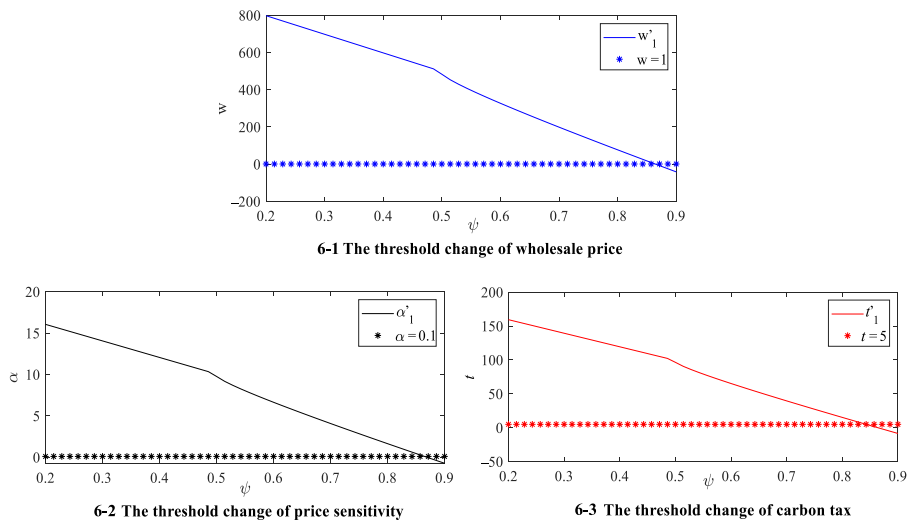
5.2 Sharing willingness analysis for the E-retailer

In order to investigate the E-retailer's profitability, we set $X = 100, \theta_1 = 5, c_1 = 5, c_3 = 3$, change the carbon tax rate (t) from 0 to 5 and the price sensitivity (α) from 0 to 0.2, respectively. Furthermore, for the robustness of our study, we make consumer's preference for offline-channel (ψ) take the values of 0.2, 0.5, 0.8, combining with different sets of the carrier's carbon emission levels (i.e. $e_1 = 3/5$) to form four figures, and we present three setting groups of parameters (i.e. $\beta = 0.5/0.8, \theta_3 = 2/4$) in each figure, as shown in Figure 7. Particularly,



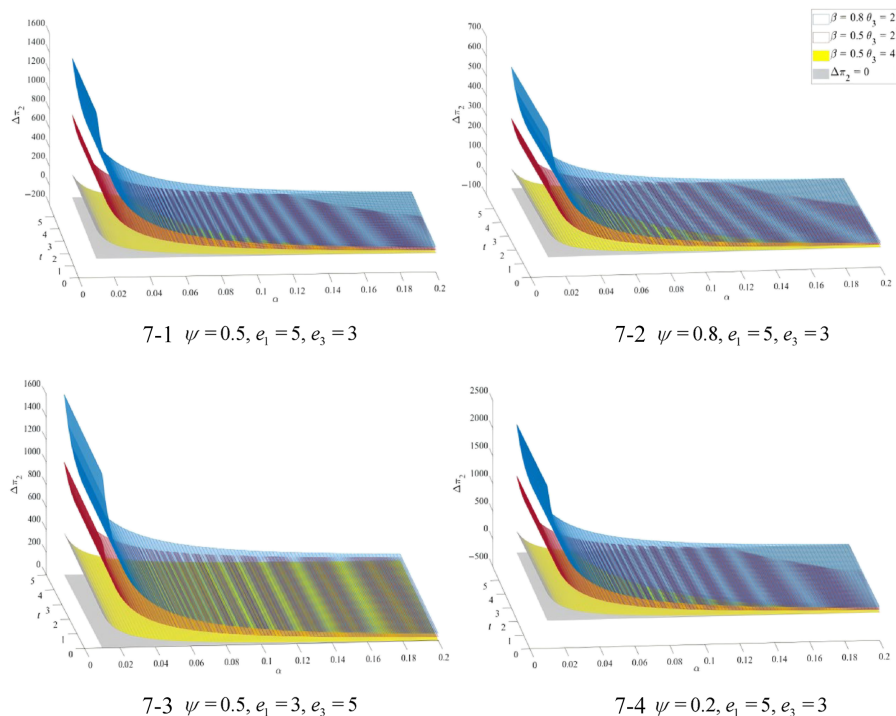
Source(s): Authors' own creation

Figure 5. The profit change of the T-retailer



Source(s): Authors' own creation

Figure 6. The variation of the threshold



Source(s): Authors' own creation

Figure 7. The profit change of the E-retailer

the gray area formed by the intersection of each surface and the gray plane indicates the profit damage interval of E-retailer, and the larger this area is, the E-retailer's profit is more likely to decrease.

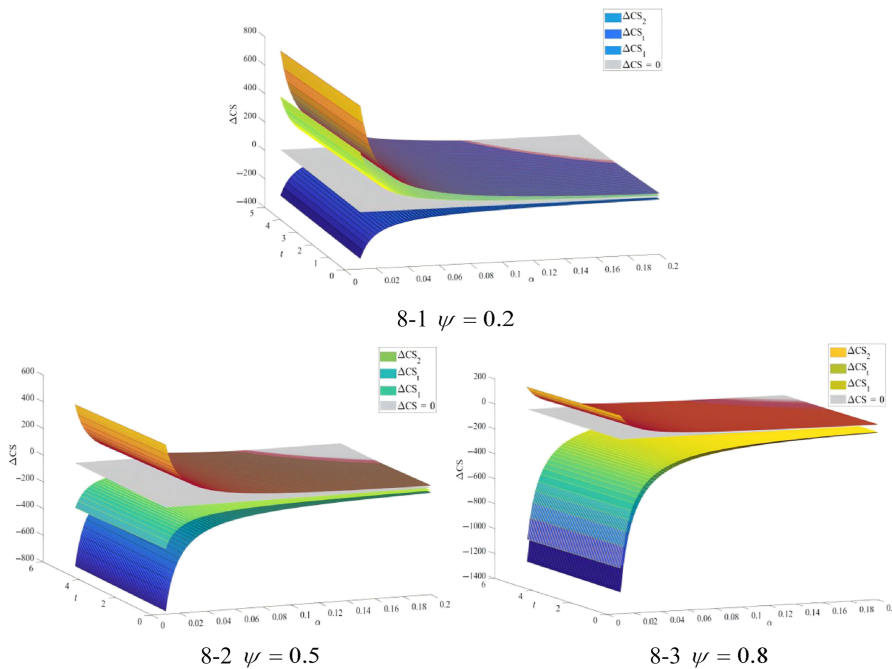
Comparing Figures 7-1, 7-2, and 7-4, we find that the profit growth of E-retailer is negatively related to the online channel's market share, but positively related to consumer's freshness sensitivity. Meanwhile, the greater the E-retailer's logistics freshness improves, the more likely his profits will rise, i.e. the blue surface is always higher than the red surface, and further higher than the yellow surface. In addition, with Figures 7-1 and 7-3, we verify the finding in Proposition 6 and further find that E-retailer is more likely to benefit from FLS when the T-retailer has carbon emission advantage, i.e. $e_1 < e_3$.

To sum up, the E-retailer is willing to participate in FLS, and this willingness rises with the market share of offline channel, the freshness sensitivity, as well as the T-retailer's relative advantages in terms of logistics freshness and carbon emissions.

5.3 The impacts of FLS on the consumers

As shown in Proposition 7, FLS mode damages the consumer surplus in offline channel. In order to investigate the impacts of FLS on the online consumers, further to show the consumer surplus change in the whole supply chain, we set $\beta = 100, \beta = 0.5, w = 1, \theta_1 = 5, \theta_3 = 2, c_1 = 5, c_3 = 3, e_1 = 5, e_3 = 3$ and make ψ take the values of 0.2, 0.5, 0.8 to get Figure 8.

The comparison between each surface in Figures 8.1–8.3 reveals that the impacts of FLS on consumers are largely influenced by consumer's channel preference and freshness sensitivity.



Source(s): Authors' own creation

Figure 8. The variation of consumer surplus

The online consumers are more likely to benefit from FLS, especially when they are less price-sensitive. However, consumer surplus in the offline channel tends to decline due to the decreased demand. Besides, there is a higher risk of damage to consumer surplus in the supply chain, and the consumer surplus can only increase when the majority consumers prefer online channel (e.g. [Figure 8-1](#)). Therefore, the government could reduce carbon tax rate to improve the consumer's benefit from FLS, since there is a negative to positive transfer in the consumer surplus change when the carbon tax rate decreases in [Figure 8](#).

6. Conclusion

At present, e-commerce continues to thrive in the fresh market, while the traditional offline channel encounters great threats. Even though many large-scale enterprises (e.g. Alibaba, Meituan etc.) have made huge efforts to explore fresh e-market, the quality and capacity of their FFL are mostly insufficient. Besides, the practices of new business models such as community group buying and front-end warehousing are not as applicable as expected. Therefore, in order to coordinate the competition between online channel and offline channel in fresh market, we propose a fresh FLS mode between E-retailers and T-retailers (i.e. FLS mode). Furthermore, FFL also causes considerable carbon emissions and food deterioration than common supply chains. Thus, we build Stackelberg models with and without FLS in the context of carbon tax policy and get the following conclusions:

Firstly, in both FLS scenario and N-FLS scenario, the price sensitivity and channel competition are in-conductive to the firms' profit, while consumer's freshness sensitivity is always beneficial to the firms. Particularly, for the E-retailer, the advantages of his carrier in terms of logistics costs and freshness have a greater positive impact on his profits.

Secondly, FLS unexpectedly reduce the retail price and demand in offline channels at the same time, which further detriments the consumer. Even though the T-retailer's benefit from FLS is uncertain, the numerical analysis shows that her profit has a great increase chance with the growth of fresh e-commerce. It is noteworthy that for the T-retailer, FLS changes the interaction between consumer's channel preference and her profit. If the offline market share is small, the profit of T-retailer may decrease with consumer's preference for offline channel in FLS scenario. But it is not applicable to the E-retailer, since his profit always increases with consumer's preference for online channel.

Last, with FLS mode, the E-retailer can get a substantial profit increment in a price-insensitive market with low carbon tax rate, and the profit increment rises with the online-market share. Furthermore, the consumer's freshness sensitivity and the carrier's logistics advantage also help the E-retailer to benefit more from FLS.

Based on those findings, we conclude that the firms should always enhance their consumer's stickiness. And FLS mode has great positive impacts on the firms and society when the fresh market has a low channel competition and a large online market share. We further summarize the following managerial insights in details.

Since the firms can benefit from the transition of consumers from price orientation to quality orientation, firms should increase their promotional efforts and choose the target market wisely to exploit the dividends from consumer's preferences effectively. Furthermore, the inter-competition between channels is inefficient and the firms can gain more profits from consumer's higher preference for the channel they belong, and firms should focus on improving the stickiness of their own consumers. Furthermore, as price sensitivity and freshness sensitivity of consumers have certain impacts on the firms' profit changes after the implementation of FLS. In the practice process of FLS mode, first and second-tier cities should be prioritized for pilot due to the high consumption level and quality pursuit of their residents.

For the E-retailer, it has strategic significance in the long term to work with his carrier to improve its logistics. Regarding to the FLS decision, he needs to combine various factors, such as the transportation fee, consumer's price sensitivity etc. However, given the characteristics of fresh market, FLS could be a direction worth exploring for the E-retailer to get the potential

purchasing power in online channel. Meanwhile, with the constant development of fresh e-commerce, the T-retailer should also value the application of FLS mode to seize the opportunity in crisis. Furthermore, due to channel competition, the consumer surplus in offline channel is more likely to be jeopardized than in online channel. Therefore, the government should play a regulatory role to implement the FLS mode in fresh food markets where channel competition is low and online market share is high, in order to realize its higher economic and social benefits.

In the future, FLS mode can be investigated from the following directions. First, the quantity loss in FFL can be taken into account as we only consider the quality loss. Second, the decision of logistics freshness level is not considered in our models, so it is also valuable to discuss the FFL construction decision from a long-term perspective (Zhang *et al.*, 2023). Third, more individualized results may be derived in the considerations of 3PL's gambling, or in the contexts of different carbon regulations and supply chain power structures (Xu and Yue, 2021). For example, E-retailers could use T-retailers' logistics sharing as a strategic weapon to force 3PLs to improve their logistics service quality, or where E-retailers could use 3PLs' service to force T-retailers to reduce the logistics service fee.

References

- An, H., Razzaq, A., Nawaz, A., Noman, S.M. and Khan, S.A.R. (2021), "Nexus between green logistic operations and triple bottom line: evidence from infrastructure-led Chinese outward foreign direct investment in Belt and Road host countries", *Environmental Science and Pollution Research International*, Vol. 28 No. 37, pp. 51022-51045, doi: [10.1007/s11356-021-12470-3](https://doi.org/10.1007/s11356-021-12470-3).
- Cao, K.Y., Xu, B., He, Y. and Xu, Q.Y. (2020), "Optimal carbon reduction level and ordering quantity under financial constraints", *International Transactions in Operational Research*, Vol. 27 No. 5, pp. 2270-2293, doi: [10.1111/itor.12606](https://doi.org/10.1111/itor.12606).
- Han, J.W., Zuo, M., Zuo, W.Y., Zuo, J.H., Lu, E.L. and Yang, X.T. (2021), "A comprehensive review of cold chain logistics for fresh agricultural products: current status, challenges, and future trends", *Trends in Food Science and Technology*, Vol. 109, pp. 536-551, doi: [10.1016/j.tifs.2021.01.066](https://doi.org/10.1016/j.tifs.2021.01.066).
- He, P. and Sun, Y.J. (2024), "The impacts of retailer's carbon tax on the price and carbon reduction decisions in supply chain", *Computers and Industrial Engineering*, Vol. 190, 110034, doi: [10.1016/j.cie.2024.110034](https://doi.org/10.1016/j.cie.2024.110034).
- He, P., Zhang, S.S. and He, C. (2019), "Impacts of logistics resource sharing on B2C E-commerce companies and customers", *Electronic Commerce Research and Applications*, Vol. 34, 100820, doi: [10.1016/j.elerap.2018.100820](https://doi.org/10.1016/j.elerap.2018.100820).
- He, P., Wen, J.Y., Ye, S. and Li, Z.Q. (2020), "Logistics service sharing and competition in a dual-channel e-commerce supply chain", *Computers and Industrial Engineering*, Vol. 149, 106849, doi: [10.1016/j.cie.2020.106849](https://doi.org/10.1016/j.cie.2020.106849).
- He, P., Wang, Z., Shi, V. and Liao, Y. (2021), "The direct and cross effects in a supply chain with consumers sensitive to both carbon emissions and delivery time", *European Journal of Operational Research*, Vol. 292 No. 1, pp. 172-183, doi: [10.1016/j.ejor.2020.10.031](https://doi.org/10.1016/j.ejor.2020.10.031).
- Jiang, J.H., Zhang, D.Z., Li, S.Y. and Liu, Y.J. (2019), "Multimodal green logistics network design of urban agglomeration with stochastic demand", *Journal of Advanced Transportation*, Vol. 2019, 4165942, doi: [10.1155/2019/4165942](https://doi.org/10.1155/2019/4165942).
- Li, B., Geng, Y., Xia, X.Q. and Qiao, D. (2021), "The impact of government subsidies on the low-carbon supply chain based on carbon emission reduction level", *International Journal of Environmental Research and Public Health*, Vol. 18 No. 14, p. 7603, doi: [10.3390/ijerph18147603](https://doi.org/10.3390/ijerph18147603).
- Lin, Q., Ma, Y.X. and Fu, W.H. (2021), "Sales mode selection of fresh E-commerce considering farmers' adulteration behavior (in Chinese)", *Operations Research and Management Science*, Vol. 30 No. 12, pp. 232-239.

- Liu, Z., Guo, H.X., Zhao, Y.J., Hu, B., Shi, L.H., Lang, L.L. and Huang, B.T. (2021), "Research on the optimized route of cold chain logistics transportation of fresh products in context of energy-saving and emission reduction", *Mathematical Biosciences and Engineering*, Vol. 18 No. 2, pp. 1926-1940, doi: [10.3934/mbe.2021100](https://doi.org/10.3934/mbe.2021100).
- Luo, Y., Wei, Q., Gou, X.Y., Dai, D. and Zhou, Y.R. (2021), "Sharing logistics service supply chain with revenue-sharing vs cost-sharing contracts", *Mathematical Problems in Engineering*, Vol. 2021, 8841536, doi: [10.1155/2021/8841536](https://doi.org/10.1155/2021/8841536).
- Ma, P. and Lu, Y.J. (2023), "Operational decisions of low-carbon supply chains with triple bottom line under carbon tax policy", *Kybernetes*, Vol. 53 No. 5, pp. 1888-1919, doi: [10.1108/K-07-2022-1055](https://doi.org/10.1108/K-07-2022-1055).
- Macheka, L., Spelt, E., van der Vorst, J.G. and Luning, P.A. (2017), "Exploration of logistics and quality control activities in view of context characteristics and postharvest losses in fresh produce chains: a case study for tomatoes", *Food Control*, Vol. 77, pp. 221-234, doi: [10.1016/j.foodcont.2017.02.037](https://doi.org/10.1016/j.foodcont.2017.02.037).
- Mahmoodi, A. (2020), "Pricing and inventory decisions in a manufacturer-Stackelberg supply chain with deteriorating items", *Kybernetes*, Vol. 50 No. 8, pp. 2347-2366, doi: [10.1108/k-03-2020-0149](https://doi.org/10.1108/k-03-2020-0149).
- Pal, A. and Kant, K. (2020), "Smart sensing, communication, and control in perishable food supply chain", *ACM Transactions on Sensor Networks*, Vol. 16 No. 1, pp. 12-41, doi: [10.1145/3360726](https://doi.org/10.1145/3360726).
- Pan, F., Fan, T.J., Qi, X.Y., Chen, J.Y. and Zhang, C. (2021), "Truck scheduling for cross-docking of fresh produce with repeated loading", *Mathematical Problems in Engineering*, Vol. 2021, 5592122, doi: [10.1155/2021/5592122](https://doi.org/10.1155/2021/5592122).
- Qin, X.L., Liu, Z.X. and Tian, L. (2020), "The strategic analysis of logistics service sharing in an e-commerce platform", *Omega*, Vol. 92, 102153, doi: [10.1016/j.omega.2019.102153](https://doi.org/10.1016/j.omega.2019.102153).
- Shang, Y.C. (2021), "Research on the construction of modern circulation system of fresh agricultural products under the concept of community group purchase (in Chinese)", *Journal of Commercial Economics*, Vol. 2021 No. 19, pp. 150-153.
- Tang, Z.M., Liu, X.X. and Wang, Y. (2020), "Integrated optimization of sustainable transportation and inventory with multiplayer dynamic game under carbon tax policy", *Mathematical Problems in Engineering*, Vol. 2020, 4948383, doi: [10.1155/2020/4948383](https://doi.org/10.1155/2020/4948383).
- Wang, C., Peng, Q. and Xu, L. (2021), "Decision and coordination of a low-carbon supply chain considering environmental tax policy on consumers", *Kybernetes*, Vol. 50 No. 8, pp. 2318-2346.
- Xi, C.B. (2021), "Development and opportunity of community group buying logistics construction (in Chinese)", *Logistics and Material Handling*, Vol. 26 No. 8, pp. 66-69.
- Xu, G. and Yue, D.Q. (2021), "Pricing decisions in a supply chain consisting of one manufacturer and two retailers under a carbon tax policy", *Digital Object Identifier*, Vol. 9, pp. 18935-18947, doi: [10.1109/access.2021.3054776](https://doi.org/10.1109/access.2021.3054776).
- Yu, M., Cruz, J.M. and Li, D. (2019), "The sustainable supply chain network competition with environmental tax policies", *International Journal of Production Economics*, Vol. 217, pp. 218-231, doi: [10.1016/j.ijpe.2018.08.005](https://doi.org/10.1016/j.ijpe.2018.08.005).
- Zhang, L.Y., Tseng, M.L., Wang, C.H., Xiao, C. and Fei, T. (2019), "Low-carbon cold chain logistics using ribonucleic acid-ant colony optimization algorithm", *Journal of Cleaner Production*, Vol. 233, pp. 169-180, doi: [10.1016/j.jclepro.2019.05.306](https://doi.org/10.1016/j.jclepro.2019.05.306).
- Zhang, Q.Y., Cao, W. and Zhang, Z.C. (2023), "Operational decisions and game analysis in the agricultural supply chain: invest or not?", *Kybernetes*, Vol. 52 No. 4, pp. 1190-1222, doi: [10.1108/k-07-2021-0585](https://doi.org/10.1108/k-07-2021-0585).

Further reading

Ameknassi, L., Ait-Kadi, D. and Rezg, N. (2016), "Integration of logistics outsourcing decisions in a green supply chain design: a stochastic multi-objective multi-period multi-product programming model", *International Journal of Production Economics*, Vol. 182, pp. 165-184, doi: [10.1016/j.ijpe.2016.08.031](https://doi.org/10.1016/j.ijpe.2016.08.031).

Wei, J.Y., Liu, Y.X., Zhao, X.Y. and Yang, X. (2020), "Joint optimization of pricing and inventory strategy for perishable product with the quality and quantity loss", *Journal of Industrial and Production Engineering*, Vol. 37 No. 1, pp. 23-32, doi: [10.1080/21681015.2020.1719222](https://doi.org/10.1080/21681015.2020.1719222).

Supplementary material

The supplementary material for this article can be found online.

Corresponding author

Yujia Sun can be contacted at: syj991021@163.com