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Original Research

Research on the Impact of Information Scenarios on Retailers' Strategies for Purchasing Fresh Agricultural Products

Jing Liu[1], Shichun Du[2*], Qile He[3]

[1]School of Business, Ludong University, Yantai 264025, China
[2]School of Public Administration, Shandong Technology and Business University, Yantai 264005, China
[3]College of Business, Law and Social Sciences, University of Derby, Derby, UK

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Abstract

Controlling the social and environmental responsibility of extended supply chains has become one of the most challenging issues in modern management. This paper models retailers' optimal sourcing strategies for fresh agricultural products (FAPs) in order to understand sourcing activities of retailers more systematically under two scenarios – the symmetric information scenario and the asymmetric information scenario. In this paper, we suppose that to maximize profit, retailers can choose from two types of suppliers – suppliers with freshness-keeping efforts are costly but adhere to strict social and environmental responsibility standards, while risky suppliers without freshness-keeping efforts are less expensive but may experience responsibility violations. Hence, different sourcing strategies of retailers are modeled and simulated by numerical image analysis. The results show that the retailers' profit is concave because of the proportion of quality-sensitive consumers. Isolated consumer-oriented approaches may have a negative impact on the level of freshness in the supply chain. On the other hand, higher penalty levels and the exposure probability of food safety incidents will have a positive impact on the freshness level in the supply chain. However, simply relying on enhanced regulations will not be enough. Instead, a combined effort, enhancing regulations, monitoring the market, and raising consumer awareness will be needed to rationalize the market and to create a quality-sensitive market. Results offer regulators and various stakeholders new insights, helping them to understand how to encourage quality sourcing practices and maximize food quality and safety in the supply chain.

Keywords: social and environmental responsibility, supply chain management, fresh agricultural products, freshness-keeping effort, sourcing strategy

*e-mail: dschcau@sdtbu.edu.cn

Introduction

Nowadays, consumers' requirements for fresh agricultural products (FAPs) have grown significantly due to concerns about environment, food safety and healthier diets. FAPs, such as vegetables, fruit, seafood, meat, and eggs, have a limited lifetime and rely on specialized equipment and procedures for storage and transportation [1]. Loss of freshness will cause deterioration in nutritional value, flavor, texture, color, and other sensory properties of FAPs and is a major risk to food safety. It is one of the main causes of food waste [2]. Therefore, freshness-keeping efforts, through adequate techniques, equipment, and technology, are needed to ensure food quality and to reduce deterioration of FAPs [3]. However, investing in freshness-keeping efforts is costly [4]. The price premium resulting from freshness-keeping efforts may not be affordable to all consumers. Therefore, retailers have the dilemma of sourcing all, some, or none of their products from suppliers with adequate freshness-keeping efforts [5]. For this reason, retailers' sourcing strategies greatly affect the freshness and quality of FAPs in the entire supply chain [6]. Understanding of optimal sourcing strategies of retailers will help the industry and regulators to better facilitate quality sourcing behavior and to ensure better food safety in the supply chain.

An important issue surrounding effective FAPs supply chain management is the sourcing strategy of retailers which ideally balances profitability, food quality and safety, and the cost of logistics and supply chain management [7]. Earlier studies of FAPs sourcing models have largely focused on deteriorating inventory models and economic order quantity models [8]. Deteriorating inventory models based on shelf-life characteristics can be divided into three categories: models for inventory with a fixed lifetime, models for inventory with a random lifetime, and models for inventory that decays at a rate corresponding to the proportional inventory decrease in terms of its utility or physical quantity.

However, previous FAPs sourcing studies largely offered static Modelling of local inventory management or sourcing decisions without much comprehensive consideration of the dynamics between information availability to stakeholders and optimal sourcing decisions. Moreover, previous sourcing studies generally lacked any attempt to model the balance between the profit orientations of suppliers and retailers and the quality preferences of consumers.

Although limited in number, previous studies suggest that intrinsic factors for retailers, such as the perceived risk of management, corporate social responsibility, and the nature of contracts play important roles in the sourcing strategy of retailers. In addition, extrinsic institutional factors, such as regulations, monitoring, and inspection policies on the one hand, and the cost of violations, willingness-to-punish for violations, and willingness-to-pay for responsibility on the other hand are also highlighted [9]. However, these factors are largely fragmented in previous Modelling attempts. Moreover, none of these previous studies considered the level of freshness-keeping effort of suppliers which affects the quality assurance in FAPs supply chains as well as the cost structure of FAPs retailers.

Moreover, there could be trade-offs between various sourcing strategies of retailers (i.e., low-cost vs. high-cost and single-channel vs. multiple-channel) due to various factors that shape the cost-benefit structure of sourcing activities. Rational retailers will decide on the optimal sourcing strategy which will maximize returns from sourcing. Such an optimal sourcing strategy should be formed on the basis of whether sufficient information will be available to both retailers and customers [10]. For example, when suppliers, retailers, and consumers have equal access to production information due to proper transparent labeling or information sharing in the market, there will be a symmetric information scenario. On the other hand, when suppliers, retailers, and consumers have unequal access to information, there will be an asymmetric information scenario. Literature suggests that asymmetric information is a source of opportunistic behavior [11]. Therefore, in this paper, we advocate that information symmetry or otherwise between FAPs retailers, suppliers, and consumers will be an important dimension that will change the nature of trade-offs between various sourcing strategies of retailers. Hence, there will be different optimal sourcing strategies for retailers under either the symmetric or the asymmetric information scenario. As far as we are able to ascertain, previous studies have not incorporated conditions of information symmetry into Modelling the optimal sourcing strategies of FAPs retailers.

Therefore, this paper attempts to provide a more comprehensive model to include behavioral characteristics of suppliers and retailers, consumer preferences, market segmentation, regulatory penalties, and market monitoring that potentially shape the optimal sourcing strategy of FAPs retailers. Based on the extant literature, we focus on five important factors: 1) the level of freshness-keeping effort of suppliers. Suppliers with higher freshness-keeping efforts have higher costs but provide higher quality FAPs, whilst suppliers with no freshness-keeping effort are more cost-effective, but penalties due to food safety incidents may be received; 2) consumers' quality preference, which matters because some consumers are willing to pay a higher price for FAPs with better freshness-keeping effort; 3) potential price premium, which appeals to more wealthy consumers; 4) risk of food safety incidents, given by the probability of occurrence of food safety incidents and varies according to the level of freshness-keeping effort; 5) level of potential penalties for unsafe products, which is imposed on retailers as a consequence of supplying unsafe products. Moreover, this paper also attempts to model the level of information symmetry as an important model dimension. Hence, this paper will simulate the optimal sourcing strategy of FAPs retailers taking all these factors into account. In this vein, this paper attempts to determine the optimal sourcing strategies of FAPs either with freshness-keeping or without freshness-keeping efforts, and the subsequent freshness levels in the supply chain under these two scenarios through numerical Modelling. The sensitivities of optimal strategies to some key model parameters are analyzed and simulated by numerical image analysis using MATLAB.

This research makes several contributions. Firstly, this paper identifies and examines some key factors affecting retailers' optimal sourcing strategy and, in particular, highlights the interaction of behavioral characteristics of retailers and suppliers, market segmentation, consumer preference, penalty of food safety incidents and monitoring in the market, that will determine the freshness levels in the FAPs supply chain. Secondly, the previous literature mainly examined sourcing strategies under a single symmetric information scenario [12]. This research extends the literature by Modelling the optimal sourcing strategies of retailers under two scenarios (i.e., symmetric information scenario and asymmetric information scenario). Thirdly, this research will provide a new Modelling approach to advance the understanding of the facilitators and hindrances of quality assurance of food supply chains under multiple scenarios, which was called for by the previous literature [13].

Material and Methods

Assumptions

In this paper, we take into account the freshness-keeping efforts of FAPs suppliers, single vs. multiple channel sourcing strategies, and the information symmetry between stakeholders as the main dimensions of Modelling. The following assumptions are imposed:

a) We consider a single supply chain of one retailer and two suppliers of different freshness-keeping efforts, one being a supplier with freshness-keeping efforts and the other being a supplier without freshness-keeping efforts. The two suppliers are the same in all respects except for the freshness-keeping efforts.
b) FAPs with freshness-keeping efforts will cost more than FAPs without freshness-keeping efforts, so that the supplier with freshness-keeping efforts has a higher cost per unit.
c) The retailer is rational and wants to maximize profit.
d) To focus our analysis, the two suppliers are set to two extreme cases: one with zero probability of food safety incidents and the other with a non-zero probability of food safety incidents.
e) The lead time is zero.
f) The overall FAPs demand is a known constant
g) Consumers have an equal willingness to purchase.
h) Consumers can be quality-sensitive or non-quality-sensitive. Quality-sensitive consumers prefer higher-quality FAPs and are willing to pay a price premium if they know the quality status of FAPs. Non-quality sensitive consumers are common consumers indifferent to quality and are unwilling to pay the price premium.

Information Scenarios

Based on these assumptions and the extant literature, possible sourcing strategies are examined. Firstly, information symmetry can be facilitated by transparent labeling and information sharing, hence consumers have access to important FAPs information, such as food origin, time of production, and level of freshness-keeping effort. As a result, consumers can more easily switch between different products. Based on the review of literature, there are four possible sourcing strategies under the symmetric information scenario [14] (see Table 1): 1) single channel low-cost sourcing (SCLC) – the retailer sources all FAPs from a low-cost supplier without freshness-keeping effort and sells FAPs to all consumers (including common consumers and quality-sensitive consumers) at the same price; 2) dual channel sourcing (DC) – the retailer sources from two types of suppliers simultaneously (i.e., low-cost supplier without freshness-keeping effort and high-cost supplier with freshness keeping effort) and sells FAPs to all consumers at different prices; 3) single channel high-cost sourcing (SCHC) – the retailer sources all FAPs from high-cost supplier with freshness-keeping effort and only sells FAPs to quality-sensitive consumers at a higher price;

Table 1. Types of sourcing strategies under the symmetric/asymmetric information scenario.

Supplier		Consumers	
		Quality-sensitive consumers	All consumers
Information symmetry	Low-cost	-	SCLC
	High-cost	SCHC	SCHCMM
	Low-cost and High-cost	-	DC
Information asymmetry	High-cost	-	HSDS
	Low-cost	-	LSDS

and 4) single channel high-cost mass-market sourcing (SCHCMM) – the retailer sources all FAPs from the high-cost supplier with freshness-keeping and sells FAPs to all consumers at the same, lower price.

Secondly, an asymmetric information scenario will result, due to a lack of information sharing between retailers and consumers. It is difficult for consumers to tell whether FAPs are supplied with freshness-keeping effort or not. Food packages, labeling, and description from the retailer will be the main source of information for consumers to tell the difference between FAPs [15-17]. Under this scenario there are two possible sourcing strategies (see Table 1): 1) high-cost sourcing and double-label selling (HSDS) – the retailer sources all FAPs from the high-cost supplier with freshness-keeping effort, but will have some products with freshness-keeping labeling and some products without such labeling; 2) low-cost sourcing and double-label selling (LSDS) – the retailer sources all FAPs from a low-cost supplier without freshness-keeping effort, but the retailer has some FAPs with freshness-keeping labeling to obtain a price premium (an opportunistic behavior). The optimal sourcing strategies under different scenarios are then modeled and simulated using numerical image analysis, as detailed in the sections below.

Methods

The following notations are used for developing the proposed model:

- D Market demand rate per unit time.
- S Shelf life.
- T Length of retailer order cycle, $T \leq S$
- α Freshness-keeping effort of suppliers, where $0 \leq \alpha \leq 1$.
- γ Proportion of quality-sensitive consumers, who are willing to pay a price premium.
- η Exposure probability of food safety incidents due to not having freshness-keeping effort, where $0 \leq \eta \leq 1$.
- ε Proportion of quality-sensitive consumers withdrawing from the market when food safety incidents occur due to not having freshness-keeping effort.
- κ Penalty per unit due to not having freshness-keeping effort.
- p Average retailer price per unit.
- p_r Potential price premium per unit.
- I_i Inventory level at time t, $0 \leq t \leq T$.
- λ_i (t) Deterioration rate of FAPs, where $0 \leq \lambda \leq 1$.
- h_i Retailer's inventory cost per unit.
- H_i Retailer's inventory cost for each order cycle.
- c_i Retailer's purchasing price per unit.
- q_i Retailer's order proportion for each order cycle.
- Q_i Retailer's order quantity for each order cycle.

Subscript $i = l$ represents low-cost / no freshness-keeping effort; Subscript $i = h$ represents high-cost / with freshness-keeping effort.

We consider a single-tier supply chain composed of a retailer and two suppliers. The suppliers decide on the level of freshness-keeping effort and the wholesale price, while the retailer determines the order quantity from the suppliers and the retail price to consumers. Based on the extant literature, a deterioration inventory model is applied to determine the order quantity of FAPs [18, 19]. The inventory level of the retailer is described by the following differential equation:

$$\frac{dI(t)}{dt} = -D - \lambda(t)I(t)\ (0 \leq t \leq T) \tag{1}$$

Because FAPs are necessities for living, in the absence of unexpected events, the demand rate D is relatively stable within the order cycle [20, 21], hence total market demand over the whole order cycle $Q = \int_0^T D\,dt = DT$.

All FAPs continuously deteriorate with time, and sales will stop beyond the shelf life S. The deterioration rate without freshness-keeping effort is $\lambda_l(t) = \frac{1}{1+S-t}$, $0 \leq t \leq T \leq S$ whilst the deterioration rate with freshness-keeping effort is $\lambda_h(t) = \frac{\alpha}{1+S-t}$, $0 \leq t \leq T \leq S$.

Hence, the inventory level at time t is: $\frac{dI_l(t)}{dt} = -D - \frac{1}{1+S-t} I(t)$.

With boundary condition $I_l(T) = 0$, we have $I_l(t) = D(1+S-t)ln\left(\frac{1+S-t}{1+S-T}\right)$, $0 \leq t \leq T$. Retailer's order quantity from the supplier without freshness-keeping effort in each cycle is:

$$Q_l = D(1+S)ln\left(\frac{1+S}{1+S-T}\right), 0 \leq t \leq T \tag{2}$$

Similar to the above derivation, we have the retailer's order quantity from the supplier with freshness-keeping effort in each cycle:

$$Q_h = \frac{D(1+S)^{\alpha}}{1-\alpha}\left((1+S)^{1-\alpha} - (1+S-T)^{1-\alpha}\right), \quad 0 \leq t \leq T \tag{3}$$

Inventory cost of the retailer during the order cycle T is $H_i = h_i \int_0^T I_i(t)\,dt$, $i = l, h$.

Based on these, optimal sourcing strategies under the symmetric information scenario and asymmetric information scenario are discussed below.

Results and Discussion

Symmetric Information Scenario

Sourcing Strategies under Symmetric Information Scenario

A supply chain with information symmetry is regarded as an important part of the overall food quality assurance system. The expected profits of each of the four sourcing strategies under the symmetric information scenario are discussed below.

Single Channel Low-cost (SCLC) Sourcing: Under this strategy, the retailer chooses to purchase all FAPs from the supplier without freshness-keeping effort. Therefore, $q_l = 1$, $q_h = 0$. Since there is only one retailer, all consumers can only buy FAPs without freshness-keeping efforts at price p. FAPs from this supplier are prone to spoilage and corruption due to the absence of freshness-keeping effort. The consumer's purchase of FAPs will have two possible consequences to the retailer: reduced purchase and/or penalty charge. The former consequence is due to consumers who experienced food safety incidents and stopped purchasing the product anymore. A proportion (ε) of consumers known as "quality-sensitive" will respond to the incidents by withdrawing from the retailer. The latter consequence is related to cost rising due to penalty charges (κ) from the food safety incidents. Therefore, the expected profit of the retailer under this sourcing strategy is:

$$\Sigma_1 = Q\gamma(1-\varepsilon\eta)(p-c_l) + Q(1-\gamma)(p-c_l) - Q\eta\kappa - c_l(Q_l - Q) - \mathrm{H}_l \quad (4)$$

In formula (4), the first part is the profit that the retailer obtains from quality-sensitive consumers. The second part is the profit from non-quality sensitive consumers. The other three parts are total penalty charges, over-purchase costs, and inventory costs, respectively.

Dual Channel (DC) Sourcing: The retailer may choose to source from two suppliers simultaneously (i.e., a low-cost supplier without freshness-keeping efforts and a high-cost supplier with freshness-keeping efforts). It is assumed that quality-sensitive consumers would certainly choose to purchase FAPs with freshness-keeping efforts. Hence, FAPs without freshness-keeping effort are only sold to ordinary consumers at price p, whilst high-cost FAPs are sold to quality-sensitive consumers at a higher price than p, so the retailer will obtain the premium (p_r). Therefore, $q_l = 1 - \gamma$, $q_h = \gamma$. Because a proportion of FAPs sold by the retailer has no freshness-keeping effort, food safety incidents may occur. Since all of the products come from the same retailer, although at different prices, it will inevitably induce some quality-sensitive consumers to withdraw from purchasing from the retailer. Thus, the expected profit of the retailer under this strategy is:

$$\Sigma_2 = Q\gamma(1-\varepsilon\eta)(p+p_r-c_h) + Q(1-\gamma)(p-c_l) - Q\eta\kappa - (1-\gamma)c_l(Q_l-Q) - \gamma c_h(Q_h-Q) - (1-\gamma)H_l - \gamma H_h \quad (5)$$

In the above formula (5), the first part is the profit that the retailer obtains from quality-sensitive consumers. The second part is the profit from other consumers. The third part is the total penalty charge. The rest of the formula represents the deterioration cost and inventory costs of two kinds of FAPs.

Single Channel High-cost (SCHC) Sourcing: In the above dual channel (DC) sourcing strategy, quality-sensitive consumers withdraw from purchasing due to the negative impact of food safety accidents, resulting in retailer's profit loss. An alternative strategy is for the retailer to give up the low-cost channel and adopt a single high-cost channel with freshness-keeping efforts. In this case, only quality-sensitive consumers will purchase from the retailer. Common consumers will not purchase at all due to the price premium. Therefore, $q_l = 0$, $q_h = \gamma$. The retailer is now able to gain profit from the price premium (p_r). Thus, the expected profit of the retailer is:

$$\Sigma_3 = Q\gamma(p+p_r-c_h) - \gamma c_h(Q_h-Q) - \gamma H_h \quad (6)$$

In this case, the expected profit is an augment function of γ.

Single Channel High-cost Mass-market (SCHCMM) Sourcing: In order to maximize the market share, retailers may adopt the SCHCMM sourcing strategy, and so source only from a high-cost supplier with freshness-keeping effort and sell FAPs to all customers (quality-sensitive and non-quality-sensitive) without charging a price premium. Under this strategy, the order proportion is $q_l = 0$, $q_h = 1$, FAPs are charged at a single price p. There are no food safety risks under this strategy, because of the freshness-keeping effort for all FAPs. However, the retailer will not be able to obtain a price premium. In this case, the expected profit of the retailer is:

$$\Sigma_4 = Q(p-c_h) - c_h(Q_h-Q) - H_h \quad (7)$$

Based on formula (7), the expected profit is independent of γ. In addition, it can be derived from formulas (6) and (7) that, when $\gamma = 0$, the expected profit of SCHC is zero, which is less than SCHCMM, whilst when $\gamma = 1$, the expected profit of SCHC is greater than SCHCMM. According to formulae (4), (5), (6), and (7), the ordering proportions from different sources and the trend of profit changes when γ increases (while holding other parameters constant) can be derived (see Table 2), which will support our proposition development in the next section.

Table 2. Order quantity and trend of profit change when γ increases.

Sourcing strategy	q_l	q_g	Trend of profit change
SCLC	1	0	Decrease
DC	$1-\gamma$	γ	Increase or decrease
SCHC	0	γ	Increase
SCHCMM	0	1	Irrelevant

According to the above description of different sourcing strategies, it can be seen that the expected profit of the retailer is affected by the proportion of quality-sensitive consumers (γ), the proportion of market withdrawals due to quality safety incidents (ε) and the potential price premium (p_r), hence market segmentation and consumers' preference will be important factors. Moreover, the expected profit of the retailer will also be affected by the penalty (κ) for food safety accidents, hence government regulations will also play an important role. Furthermore, the expected profit of the retailer will also be affected by the exposure probability of food safety incidents (η), hence various stakeholders (such as trade associations, media, NGOs and consumer groups), which may affect the exposure of food safety incidents, will also play an important role. The increase of these variables (γ, ε, p_r, κ, η) also means the market with various stakeholders will favor better quality FAPs with proper freshness-keeping efforts.

Optimal Sourcing Strategies under Symmetric Information Scenario

Based on the four possible sourcing strategies discussed above, the conditions for optimal sourcing strategies can be determined. A key factor that determines such conditions is whether consumers are willing to pay more than the incremental cost of freshness-keeping effort, i.e., whether p_r is greater than $\omega = \frac{c_h(Q_h-Q)-c_l(Q_l-Q)+H_h-H_l}{Q(1-\varepsilon\eta)} + c_h - c_l$. Here, ω is the cost difference between the FAPs with freshness-keeping effort and the FAPs without freshness-keeping effort; $\frac{c_h(Q_h-Q)-c_l(Q_l-Q)}{Q(1-\varepsilon\eta)}$ is the difference in over-purchasing losses per unit between both types of FAPs, because there is a deterioration rate for any FAPs over time, so over-purchasing is needed for all FAPs to ensure consumer demand can be met; $\frac{H_h-H_l}{Q(1-\varepsilon\eta)}$ is the difference in inventory cost between both types of FAPs, because FAPs with freshness keeping effort will cost more for storage; $c_h - c_l$ is the difference in actual purchasing price of the retailer.

Because only quality-sensitive consumers are willing to pay for the price premium, the retailer must decide whether to source some or all FAPs from the freshness-keeping supplier and what the right price to charge consumers will be. Based on this, we want to examine the relationship between potential price premium p_r and the cost difference ω based on the retailer's aim to maximize profit.

First of all, we consider the case when the potential price premium is less than the incremental cost of freshness-keeping efforts ($p_r<\omega$). In this case, a dual channel sourcing strategy (DC) will never be optimal, because a greater profit can always be obtained from other sourcing strategies. Moreover, sourcing only from the supplier without freshness-keeping effort (i.e., SCLC) will occur if the incremental cost of freshness-keeping effort is greater than the loss in profit due to quality-sensitive consumer withdrawal and food safety penalty charges. Therefore,

Proposition 1. If the potential price premium is less than the incremental cost of freshness-keeping efforts ($p_r<\omega$):

(i) Single channel low-cost sourcing (SCLC) is optimal, if $Q_hc_h - Q_lc_l > Q\eta\kappa + Q\gamma\varepsilon\eta(p - c_l) + H_l - \gamma H_h + max\,[Q\gamma p_r - (1 - \gamma)(Qp - Q_hc_h - H_h), 0]$.

(ii) Single channel high-cost sourcing (SCHC) is optimal, if $p_r > \frac{1-\gamma}{Q\gamma}(Qp - Q_hc_h - H_h)$ and SCLC is not optimal.

(iii) Single channel high-cost mass-market sourcing (SCHCMM) is optimal, if $p_r < \frac{1-\gamma}{Q\gamma}(Qp - Q_hc_h - H_h)$ and SCLC is not optimal.

According to Proposition 1, it is foreseeable that the expected profit of SCLC will decrease with the increase of γ. To avoid profit losses, the retailer may switch its sourcing strategy to maximize profit. For the strategy switches from SCLC to SCHC and from SCLC to SCHCMM, the retailer's order quantity from the supplier without freshness-keeping efforts (q_l) will decrease with the increase of γ, while the order quantity from the supplier with freshness-keeping effort (q_h) will increase. This is in line with our intuitive understanding that the greater the quality preference of consumers, the lower the order quantity from the supplier without freshness-keeping effort.

However, when the optimal strategy switches from SCHCMM to SCHC, the retailer may reduce the order quantity from the supplier with freshness-keeping efforts (q_h), thus reducing the quality level of the whole supply chain. The reason is when γ is small, in order to occupy the market and to avoid the outbreak of food safety incidents which will result in penalties and withdrawal of quality-sensitive consumers from the market, the retailer will choose SCHCMM sourcing, since the expected profit of SCHCMM is greater than SCHC at this time. However, with the increase of γ, when the expected profit of SCHC exceeds SCHCMM, the high profit of SCHC will make the retailer give up the common consumers and adopt SCHC instead. The retailer will charge the price premium ($p + p_r$), which results in common consumers leaving the market and leads to the reduction of order quantity overall (in this case FAPs with freshness-keeping effort). Therefore,

Proposition 2. Optimal sourcing strategy will switch from single channel low-cost (SCLC) to either single channel high-cost (SCHC) or single channel high-cost mass-market (SCHCMM), if $p_r<\omega$ and $Q_hc_h - Q_lc_l < Q\eta\kappa + Q\gamma\varepsilon\eta(p - c_l) + H_l - \gamma H_h + max\,[Q\gamma p_r - (1 - \gamma)(Qp - Q_hc_h - H_h), 0]$ with the increase of γ.

Proposition 3. Order quantity from the supplier with freshness-keeping effort will decrease, if the optimal sourcing strategy is switched from SCHCMM to SCHC and γ increases from less than to greater than $\frac{Qp-Q_hc_h-H_h}{Qp_r+Qp-Q_hc_h-H_h}$.

From the above analysis, it can be seen that retailers' optimal sourcing strategies are determined by both the proportion of quality-sensitive consumers (γ) and the potential price premium (p_r), rather than by only one or the other. As γ and p_r increase, the premium obtained from quality-sensitive consumers will be more attractive to the retailer. Therefore, the optimal sourcing strategy will change from SCHCMM to SCHC. At this point, common consumers will be expelled from the market due to product unaffordability, causing the retailer to reduce the overall order quantity from the freshness-keeping supplier from Q to γQ.

We then consider the case when $p_r>\omega$, so that the potential price premium is greater than the incremental cost of freshness-keeping effort. In this case, dual channel sourcing (DC) can be optimal, if the retailer is profitable even if facing certain risks of penalty. Alternatively, single channel high-cost mass-market sourcing (SCHCMM) can be optimal, if the price premium (p_r) consumers are willing to pay is low and the retailer wants to avoid the severe penalty of sourcing from the non-freshness-keeping supplier. That is to say, DC is not optimal. Otherwise, single channel high-cost sourcing (SCHC) can be optimal, if consumers are willing to pay a higher potential premium (p_r) when DC is not optimal. Therefore,

Proposition 4. If the potential price premium is greater than the incremental cost of freshness-keeping efforts ($p_r>\omega$):

(i) Dual channel sourcing strategy (DC) is optimal, if

$$\gamma\varepsilon\eta(p+p_r-c_h)+\eta\kappa<\frac{1-\gamma}{Q}\min\left[(Qp-Q_lc_l-H_l),\ (Q_hc_h-Q_lc_l+H_h-H_l)+\frac{Q\gamma}{1-\gamma}p_r\right].$$

(ii) Single channel high-cost mass-market sourcing strategy (SCHCMM) is optimal if $p_r<\frac{1-\gamma}{Q\gamma}(Qp-Q_hc_h-H_h)$ and DC is not optimal.

(iii) Single channel high-cost sourcing strategy (SCHC) is optimal if $p_r>\frac{1-\gamma}{Q\gamma}(Qp-Q_hc_h-H_h)$ and DC is not optimal.

Therefore, in the case $p_r>\omega$, when the potential penalty is low, retailers will choose a dual channel (DC) strategy to maximize profit. However, when the potential penalty is high and consumers have a higher willingness to pay for a price premium, the retailer will consider sourcing more from the supplier with freshness-keeping efforts to reduce risks, hence SCHCMM or SCHC is the optimal strategy. There is also the possibility that when consumers' willingness to pay for price premiums increases, the retailers' purchase strategy will switch from SCHCMM to SCHC in order to obtain more profit, so the retailer will only target a relatively small number of quality-sensitive consumers and ignore common consumers. As a result, the retailer will reduce the overall order quantity of FAPs with a freshness-keeping effort, while not increasing the order quantity of FAPs without a freshness-keeping effort.

According to proposition 1 and proposition 4, it can be seen that with the increase of p_r, the retailer following an SCHCMM strategy either gives up common consumers (to follow SCHC) or sources partly from a non-freshness-keeping supplier and sells to common consumers (to follow DC). If the retailer finds that even if there are risks of penalties and the DC strategy is still profitable, this may lead to an increase in the quantity of FAPs without freshness-keeping effort in the market. Therefore, only encouraging quality-sensitive consumers to pay more for freshness-keeping products may eventually lead to a reduced order quantity of FAPs with freshness-keeping effort overall and an increase in the order quantity of FAPs without freshness-keeping effort, and thus lead to a reduced freshness level of the whole supply chain.

Next, we consider how the retailer's order quantity will be impacted by the cost of food safety incidents. According to Propositions 1 and 4, the penalty term (η, κ) and the proportion of quality-sensitive consumers withdrawing from the market due to food incidents (ε) only appears in the optimal sourcing strategies of single channel low-cost sourcing (SCLC) and dual channel sourcing (DC). In particular, if κ = 0, the retailer has the greatest incentive to source from the supplier without freshness-keeping effort. This suggests that the effort to increase the cost of food safety incidents – for example, by imposing penalties or increasing the chance of exposure to low-quality products — will result in a higher incentive for the retailer to follow sourcing strategies with freshness-keeping efforts (i.e., SCHCMM or SCHC). Therefore,

Proposition 5. The order quantity from the supplier with freshness-keeping efforts will increase with the exposure probability of food safety incidents due to not having freshness-keeping efforts (η), penalty per unit (κ), and the proportion of quality-sensitive consumers withdrawing from the market (ε); and the order quantity from the supplier without freshness-keeping effort will decrease with increasing η, κ and ε.

Proposition 5 suggests that increasing penalty levels or the intensity of disclosing violations will have a positive effect on the overall freshness level in the supply chain. Therefore, adequate regulatory and penalty measures, as well as improved traceability and accountability of retailers and suppliers can improve the food safety standards in the food supply chain.

From the perspective of the retailer's profit under optimal sourcing strategies, based on the above propositions, it can be derived that:

Proposition 6. Retailer's profit under optimal sourcing strategies will:

(i) decrease with the increase in the exposure probability of food safety incidents due to less freshness-keeping efforts (η), penalty per unit (κ), and the proportion of quality-sensitive consumers withdrawing from the market due to food safety incidents (ε).

(ii) increase with the increase in consumers' willingness to pay for the product (p) and the potential price premium (p_r).

(iii) be concave with the proportion of quality-sensitive consumers (γ).

Parts (i) and (ii) of Proposition 6 are intuitive. However, part (iii) shows that the retailer gains the highest profit when there is either a very small or very large proportion of quality-sensitive consumers (γ). On the other hand, intermediate proportions of quality-sensitive consumers will result in lower levels of profit under the optimal sourcing strategy. Hence, a rational retailer will prefer to either sell only to common consumers (non-quality-sensitive) or to quality-sensitive consumers. This implies that the retailer can be indifferent to initial efforts of converting consumers to be quality-sensitive, as the retailer's profit will decrease when γ increases from zero. However, as the proportion of quality-sensitive consumers reaches a critical level, the retailer will prefer to focus on a quality-sensitive customer market in order to generate higher profit.

Asymmetric Information Scenario

Sourcing Strategies under Asymmetric Information Scenario

Information asymmetry in a supply chain can be caused by complex supply chain structure, imperfect regulation, and lack of information sharing and monitoring. If needed, the retailer can hide important FAPs information deliberately (opportunistic behavior). The expected profits of each of the two sourcing strategies under the information asymmetry scenario are discussed below.

High-cost Sourcing and Double-label Selling (HSDS) Strategy: Under this sourcing strategy, the retailer sources from the supplier with freshness-keeping efforts but labels some of the products with freshness-keeping logos and the rest of the products without such logos. The retailer sells the FAPs with freshness-keeping logos at a higher price which appeals to quality-sensitive consumers. Hence, the expected profit of the retailer is:

$$\Sigma_5 = Q[\gamma(p + p_r) + (1-\gamma)p - c_h] - (Q_h - Q)c_h - H_h \tag{8}$$

However, if quality-sensitive consumers are sophisticated enough to Fig. out that FAPs with or without freshness-keeping logos actually have the same quality, they may then switch to purchasing FAPs without freshness-keeping logos at a lower price.

Low-cost Sourcing and Double-label Selling (LSDS) Strategy: Under this strategy, opportunistic behavior is possible. The retailer will source all FAPs from the supplier without freshness-keeping effort. However, the retailer may label some FAPs with freshness-keeping logos (counterfeit) to capture the price premium. Thus, the expected profit of the retailer is as follows:

$$\Sigma_6 = Q\gamma(1-\varepsilon\eta)(p + p_r - c_l) + Q(1-\gamma)(p - c_l) - Q\eta\kappa - (Q_l - Q)c_l - H_l \tag{9}$$

Optimal Sourcing Strategies under Asymmetric Information Scenario

According to formulae (8) and (9), the retailer's optimal sourcing strategy depends on the difference between the incremental sourcing cost of the retailer and the expected losses of low-cost sourcing. Suppose $Q_h c_h - Q_l c_l$ is the difference of sourcing costs between HSDS and LSDS; $Q\gamma\varepsilon\eta\ (p + p_r - c_l)$ is the expected loss of consumer withdrawing due to consumers' complaints about the food quality in the case of LSDS; $Q\eta\kappa$ is the amount of penalty; and $H_l - H_h$ is the difference of inventory costs between the two sourcing strategies. Therefore,

Proposition 7a. High-cost sourcing and double-label selling strategy (HSDS) is optimal, if $Q_h c_h - Q_l c_l < Q\gamma\varepsilon\eta(p + p_r - c_l) + Q\eta\kappa + H_l - H_h$;

Proposition 7b. Low-cost sourcing and double-label selling strategy (LSDS) is optimal, if $Q_h c_h - Q_l c_l > Q\gamma\varepsilon\eta(p + p_r - c_l) + Q\eta\kappa + H_l - H_h$.

Proposition 7 suggests that if $Q_h c_h - Q_l c_l$ is smaller than the expected losses of low-cost sourcing, the HSDS strategy is optimal, and if $Q_h c_h - Q_l c_l$ is larger than the expected losses of low-cost sourcing, the LSDS strategy is optimal. In this vein, the more severe the penalty and the higher the expected withdrawal of consumers due to food safety incidents, the more likely the retailer will choose HSDS as the optimal strategy.

Numerical Simulation

In this section, numerical examples are developed to analyze the sensitivities of optimal sourcing strategies on key model parameters. The results are simulated by numerical image analysis using MATLAB.

The Influence of γ and p_r on Sourcing Strategy

Sensitivities of optimal strategies to two key parameters related to consumers' preference (γ and p_r) are evaluated, so that γ and p_r are variable while holding other parameters fixed. We consider the following data set: $D = 1$; $T = 10$; $S = 15$; $c_l = 0.2$; $c_h = 0.5$; $h_l = 0.1$; $h_h = 0.015$; $p = 1.5$; $\kappa = 3.2$; $\eta = 0.1$; $\alpha = 0.8$; $\theta = 0.95$; $\varepsilon = 0.2$. Fig. 1 shows graphically the retailer's optimal sourcing strategy based on Propositions 1-7 as a function of proportion of quality-sensitive consumers (γ) and potential price premium (p_r).

Fig. 1a) reveals the optimal sourcing strategies and the possible switches between these strategies at different levels of γ and p_r under the symmetric information scenario. Firstly, when γ and p_r are small, the optimal sourcing strategy is SCLC, as shown in Fig. 1a).

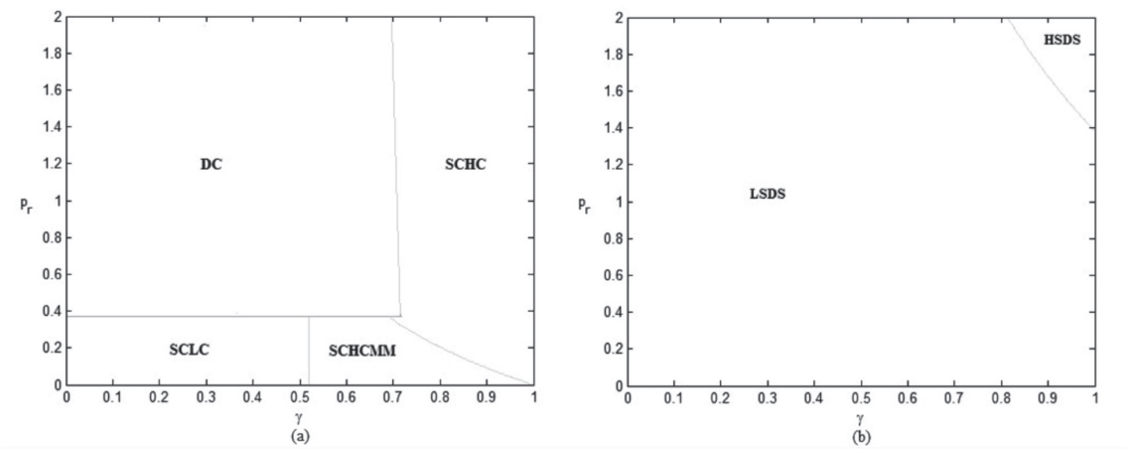

Fig. 1. γ vs. p_r was presented at the end of the paper according to the template.

Secondly, as γ increases to 1 while p_r remains small, the optimal sourcing strategy will gradually change into single channel high-cost mass-market (SCHCMM) and finally to single channel high-cost (SCHC). In this sense, we found that the retailer may source from the supplier with freshness-keeping efforts at a higher cost even if the potential price premium is low, but the proportion of quality-sensitive consumers must be high. Thus, converting non-quality-sensitive consumers to becoming quality-sensitive (i.e., increase γ) will lead to more quality sourcing and better overall freshness in the supply chain.

Thirdly, when p_r is at a higher level, but γ remains small, the optimal sourcing strategy can be a dual channel (DC), so that the retailer will source from both suppliers. Hence, it is possible for the retailer to source more from the supplier without freshness-keeping effort even if a small proportion of quality-sensitive customers are willing to pay more for freshness-keeping efforts (p_r). This suggests that solely increasing the potential price premium may not improve the overall freshness level of the supply chain.

Fourthly, single channel high-cost (SCHC) will be the optimal strategy when p_r and γ are both high. Hence, when there is a high proportion of quality-sensitive consumers willing to pay more for freshness effort, the overall supply chain freshness level will be the highest which is the most favorable situation.

Fig. 1b) reveals the optimal sourcing strategies and the possible switches between these strategies at different levels of γ and p_r under the asymmetric information scenario. The low-cost sourcing and double-label selling strategy (LSDS) will be optimal when γ and p_r are not high enough, so that retailer opportunistic behavior will be prominent. However, the optimal sourcing strategy may switch from LSDS to high-cost sourcing and double-label selling (HSDS) when γ and p_r are sufficiently high. This will be more favorable as the freshness level of the whole supply chain will be high. The retailer will only source from the supplier with freshness-keeping efforts.

Simulation of both scenarios shows that regulators and stakeholders can improve the freshness level of the supply chain by educating consumers about the quality and safety of FAPs (i.e., increasing γ), and improving affordability and willingness of consumers to pay more for freshness keeping effort (i.e., increasing p_r). Therefore, the overall freshness level of the supply chain will be the highest, when both γ and p_r are kept high.

The Influence of ε and η on Sourcing Strategy

Sensitivities of optimal strategies to two key parameters related to potential losses due to low freshness-keeping effort (ε and η) are evaluated, so that ε and η are variable while holding other parameters fixed. We consider the following data set (Wang and Dan, 2015): $D = 1$; $T = 10$; $S = 15$; $c_l = 0.2$; $c_h = 0.5$; $h_l = 0.1$; $h_h = 0.015$; $p = 1.5$; $\alpha = 0.8$; $\theta = 0.95$; $\gamma = 0.3$; $P_r = 0.38$; $\kappa = 0.3$ and 2.3. Fig. 2 shows graphically the retailer's optimal sourcing strategy based on Propositions 1-7 as a function of the proportion of quality-sensitive consumers withdrawing from the market when food safety incidents occur (ε) and exposure probability of food safety incidents (η) under symmetric and asymmetric information scenarios. Moreover, different penalty levels ($\kappa = 0.3$ and 2.3) are also considered.

Fig. 2a) and 2b) reveal optimal sourcing strategies and possible switches between these strategies at different levels of ε and η under the symmetric information scenario. First, when ε and η are small, the optimal sourcing strategy is dual channel (DC). In this case, quality-sensitive consumers and common consumers can choose to purchase FAPs according to their preferences and affordability. For example, quality-sensitive consumers can purchase FAPs with freshness keeping effort with a price premium and common consumers can purchase other FAPs.

Second, when ε and η increase, for example, due to the improvement of consumers' quality awareness, quality-sensitive consumers are more likely to withdraw from the market when food incidents happen. Therefore,

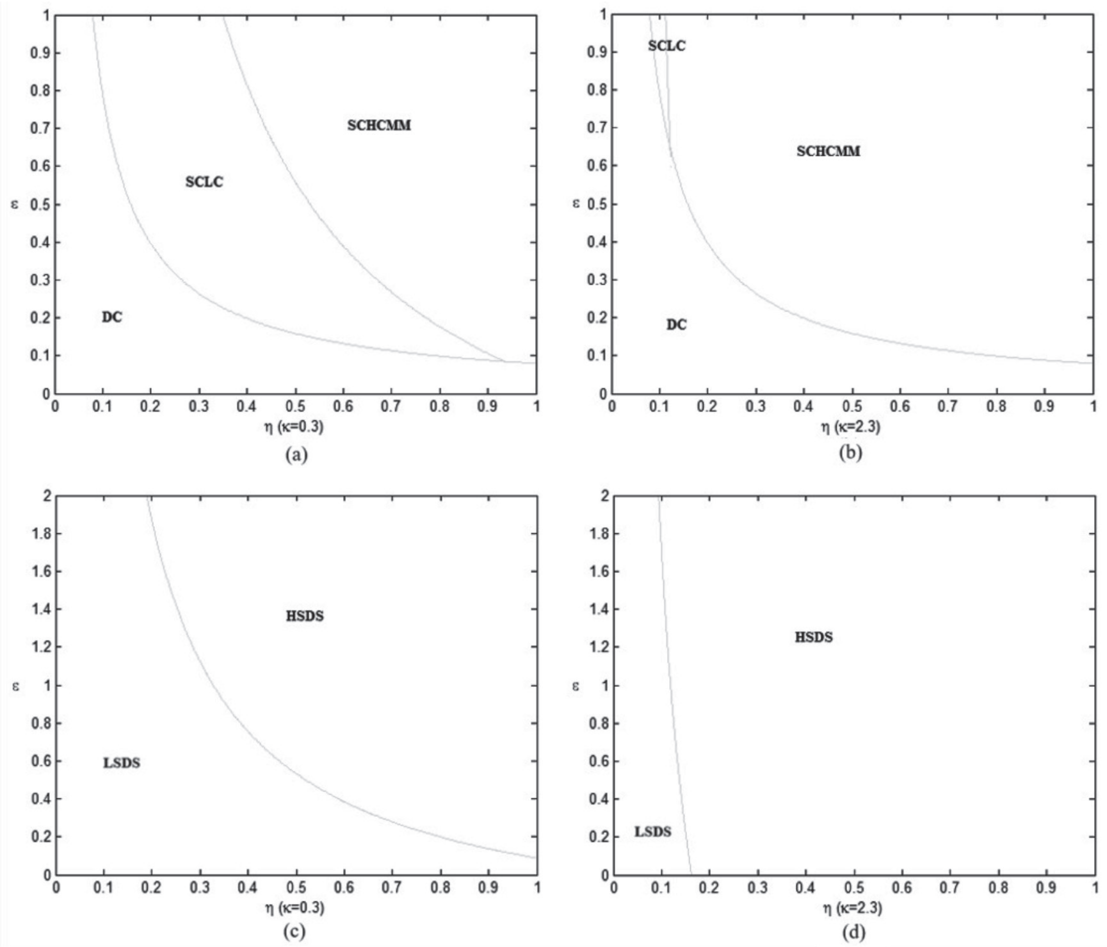

Fig. 2. ε vs.η was presented at the end of the paper according to the template.

the retailer will face a higher risk of losing profit from quality-sensitive consumers. Instead, they will benefit from focusing on common consumers only, so single channel low-cost (SCLC) will be the more optimal strategy.

Third, as ε and η continue to increase to a high level, the losses from consumer withdrawal and penalties from food incidents will make single channel high-cost mass-market (SCHCMM) the optimal strategy.

Fourth, as shown in Fig. 2a) and 2b), the heavier the penalty level (κ), the less chance the retailer will follow SCLC (smaller areas in Fig. 2), which is less favorable from the perspective of overall freshness in the supply chain.

In the case of the asymmetric information scenario (Fig. 2c) and 2d)), with the increase in ε and η, the optimal sourcing changes from LSDS to HSDS, reducing the retailer opportunistic behavior. This is because, as ε and η increase, the retailer's benefits from the opportunistic LSDS strategy cannot offset the losses from penalties and consumer withdrawal. Moreover, the higher the penalty level (κ), the quicker the retailer will switch to the HSDS strategy when ε and η increase.

Simulation of both scenarios shows that with the increase of ε and η, the retailer will gradually switch to quality sourcing as the optimal strategy (SCHCMM and HSDS). Moreover, higher penalty levels (κ) will speed up such change and encourage the retailer to adopt sourcing strategies with more freshness-keeping efforts (SCHCMM and HSDS). However, under the symmetric information scenario, such increase in ε and η has to be high enough to make sure losses from low-quality sourcing will offset any gains.

Conclusions

This paper examines the optimal sourcing strategies of FAPs retailers to understand the factors that will affect the overall freshness of food supply chains. We modeled various possible sourcing strategies under symmetric and asymmetric information scenarios to better understand the influence of factors such as behavioral characteristics of retailers and suppliers, market segmentation, consumer preference, penalty of food safety incidents, and monitoring in the market. We advocate that an ideal market should have the maximum order quantity of FAPs affordable to all consumers while maximizing the profit of the retailer. By proposing and simulating the optimal sourcing strategies of a FAPs retailer in a simple supply chain, this paper advances the understanding of the facilitators of and hindrances to quality assurance of food supply chains.

Firstly, in order to improve the overall order quantity of freshness-keeping FAPs in the supply chain, a sufficiently large proportion of quality-sensitive consumers is needed, which involves education, publicity, regulations, and other aspects. Through various means such as school education, community activities, and media promotion, we aim to popularize food safety knowledge to consumers, including the interpretation of food labels, correct methods for food storage and processing, and the impact of food additives and pesticide residues. Encourage food production and sales enterprises to disclose information on food sources, ingredients, processing processes, etc., so that consumers can understand the full picture of food and make wiser choices.

Secondly, higher penalty levels and a higher exposure probability of food safety incidents will lead to increased order quantities of FAPs with freshness-keeping effort, and hence higher freshness level in the supply chain. In this vein, regulators should make more effort to enhance the implementation of regulations for unsafe sourcing practices and penalty levels. Regulators or stakeholders may increase the exposure probability of violations, for example, by more frequent inspection of FAPs quality and more intensive media coverage. However, it is important to note that simply relying on enhanced regulations or penalties may not address the root cause of the problem. It is often difficult to achieve the optimal freshness level only by coercive forces imposed on the retailer. Instead, to improve the freshness level in the supply chain, regulators should focus on rationalizing the market and creating a quality-sensitive market, so that retailers' profitability will be in line with the preferred freshness expectations of the market. We suggest that this can be achieved by the combined effort of enhancing regulation, market monitoring, and consumer awareness raising.

Thirdly, isolated consumer-oriented approaches (i.e., focusing on either increasing the proportion of quality-sensitive consumers or increasing the potential price premium) rather than integrated approaches (i.e., increasing the proportion of quality-sensitive consumers while improving affordability), may have a negative impact on the retailer's order quantity of FAPs with freshness-keeping effort, and hence reduce the level of freshness in the supply chain. In short, improving consumer awareness of food safety consumption requires the joint efforts of the whole society. By strengthening education, improving information transparency, strengthening regulation and law enforcement, encouraging consumer participation, and advocating for healthy eating, we can jointly promote the improvement of food safety levels and ensure the physical health and life safety of the people.

Overall, this paper will help regulators, government, and various stakeholders to better understand the behavioral characteristics of FAPs retailers and suppliers, so that more targeted policies can be developed to reduce opportunistic behavior in the market and to enhance the overall freshness level of the supply chain. This paper only provides an illustration of a single supply chain consisting of one retailer and two suppliers, which is far from representing a real supply chain. However, this paper proposes a simplified model of what is making quality (freshness-keeping) sourcing a more viable strategy for FAPs retailers, given that there are heterogeneous suppliers in the supply chain. In this paper, although we only focused on the freshness-keeping effort as the main consideration for food quality, the approach of this paper, of modeling under multiple scenarios, can be employed by future researchers to evaluate other food quality considerations, such as buying organic and fair-trade products.

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Conflict of Interest

The authors declare no conflict of interest.

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