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Quality disclosure strategy with asymmetric demand information in food supply chains

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Abstract

The effects of food product quality disclosure on enhancing food quality transparency have drawn wide attention to food supply chain management. However, demand information asymmetry in the vertical direction of food supply chains hinders the supplier's quality disclosure due to the fact that the supplier is uncertain whether the profits brought by quality disclosure can offset the disclosure costs. To overcome this challenge, this paper analyzes the information interaction in food supply chains including one leading supplier who provides consumers food with uncertain quality information and two following retailers who own demand information privately; the supplier provides preservation service for the food to stimulate the demand and makes the quality disclosure decision based on the profit trade-off between disclosure and not disclosure. Our research shows that cost-effective preservation service can stimulate two retailers to share information. To avoid high information leakage, two retailers will face the prisoner's dilemma when they achieve the final equilibrium under certain conditions. If the supplier discloses information about food with high quality, it will deepen the information leakage. Higher preservation service efficiency can avoid the retailers' prisoner's dilemma, whereas information disclosure of high-quality products may make the prisoner's dilemma worse. The numerical example shows that more accurate information signals and more intense competition urge the supplier to disclose quality information. A subsidy mechanism is designed for the supplier to motivate the retailers to provide information, which enables supply chain members to gain more profits.

Keywords: Information sharing; Quality disclosure; Food supply chain; Competition; Preservation technology investment

1. Introduction

Some intrinsic attributes of food quality can only be evaluated after testing. Thus, customers often hold a perceived belief in food quality (Hussein et al., 2015). Perceived quality is the assessment from the perspective of consumers, and it is related to one's own and others' experiences (Azimian et al., 2016). The nature of food results in the quality information asymmetry between supply and consumption. In particular, where there are great food safety concerns with food borne diseases or contamination, such as COVID-19, Bovine Spongiform Encephalopathy, and Bird Flu, etc., consumers require ensured food safety and expect stakeholders to provide transparent food information along supply chains (Gallo et al., 2021).

Transparency can guarantee food quality and increase customers' trust (Trienekens et al., 2012; Kassahun et al., 2014). To ensure food safety, increase transaction transparency, and improve food quality (Li et al., 2023), quality information disclosure technologies such as intelligent sensors, camera systems, blockchains (Fore et al., 2018), and strategies such as food labels and quality certification are adopted widely across the world (Guo, 2009). The technologies increase information accessibility and availability, facilitate information sharing along the food chains (Stranieri et al., 2021), and improve social welfare (Dutta et al., 2020). Nestle, Walmart, Golden State Foods, Tyson Foods, and many other food enterprises have been employing blockchain technology in their supply chains[1]. For instance, Walmart employed blockchain technology on the Chinese pork supply chain to disclose information such as product origin, processing methods, expiration date, and storage temperature[2]. Some other food suppliers have also adopted the technical means to disclose food quality information. Princes has provided Napolina QR codes that consumers can scan to seek information about their products[3]. In other industries, blockchain is also widely used to enhance supply chain transparency (Chod et al., 2020).

The supplier may decide to disclose food quality information when the profit gained from quality disclosure can cover the disclosure costs. However, customer demands both before and after disclosure are uncertain in reality. For example, when the aforementioned businesses implement blockchain technology, the impact on demand differs in customers due to the fact that the functioning is difficult to understand (Contini et al., 2023); some customers are unfamiliar with blockchain technologies (Cao et al., 2021; Garaus and Treiblmaier, 2021), and even doubt the disclosed information (Zhou et al., 2023). For example, BeefChain employs blockchains in the beef industry to improve traceability and transparency; however, Shew et al. (2022) conducted a

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[1] https://news.coinsquare.com/blockchain/blockchain-food-industry/
[2] https://news.coinsquare.com/blockchain/blockchain-food-industry/
[3] https://www.newfoodmagazine.com/article/158504/the-new-era-of-transparency/

survey including 3560 cases in the United States to investigate the consumer valuation of blockchains for beef information, and they found that consumer knowledge of blockchain technology is limited.

Although the downstream retailers are closer to consumers and can effectively analyze a large amount of customer data due to the rapid development of information technology, the demand information in the upstream and downstream of the supply chain is asymmetric (Ha and Tong, 2008; Shen et al., 2019; Zheng et al., 2021). Meanwhile, the food industry faces intense competition, as the world's largest comprehensive meat products supplier, Tyson Foods has established close cooperative relations with McDonald, Yum Brands, Wal Mart, and other retailers, supplying bacon, chicken pieces, pig, etc[4]. In this context, this paper takes food retailers' competition into account and constructs a supply chain consisting of one leading supplier and two following retailers, and studies the impacts of competition intensity on optimal solutions and information decisions. Due to the perishable characteristics of food, the supplier provides preservation service for the food to stimulate the demand. For example, refrigeration slows the growth of unwanted microbes and the oxidation process[5]; gases such as nitrogen, oxygen, and carbon dioxide are used to extend shelf life[6]. The quality of the perishable foods is considered a function of alternative preservation technologies in this paper. We then consider the trade-off between the costs and extending the shelf-life. The following aspects constitute the contributions of this article. First, this paper studies quality disclosure strategy and preservation technology investment considering quality deterioration in the food supply chains. Second, we simultaneously consider quality and demand information asymmetry among members within the horizontal and vertical axis of the food supply chain. Third, we construct a strategy matrix about the supplier's quality disclosure and retailers' demand information sharing, and analyze the interaction between the above two information strategies. Finally, we analyze the impacts of the food quality deterioration coefficient, preservation technology investment cost coefficient, and retailers' competition intensity on decision making. Especially, this paper mainly solves the following problems.

(1) What is the optimal preservation technology investment under food supply chain members' different information strategies?

(2) What is the retailers' demand information sharing strategy in equilibrium? How does retailers' information sharing affect the preservation technology investment and the food supply chain members' pricing strategies?

(3) Under what conditions will the supplier choose to disclose quality information? What are the optimal information strategy combinations about the supplier's quality

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[4] http://crueltyfreeinvesting.org/tyson-foods/

[5] https://www.canr.msu.edu/news/preservatives-refrigeration

[6] https://www.foodmanufacturing.com/ingredients/article/21127521/naturally-preserving-food-with-gases

disclosure and retailers' demand information sharing strategy in equilibrium?

To solve the problems mentioned above, we construct a model of food supply chains comprised of one supplier and two retailers. Quality preservation technology options are available to the supplier to maximize the profit. The supplier will make the quality disclosure decision based on the profit difference before and after quality disclosure. Subsequently, with the privately owned uncertain demand information, two retailers will determine the information sharing strategy under competition.

Using backward induction, we first solve the retailers' information sharing strategy based on the equilibrium pricing and preservation technology investment decisions. We then construct the retailers' information sharing strategy combination and determine the supplier's quality disclosure strategy. We find that both preservation technology investment efficiency and competition in food retailing encourage cooperation in information sharing. Higher preservation technology investment efficiency and higher customers' quality preference make two retailers more quickly achieve (Sharing, Sharing) equilibrium. To avoid high information leakage, two retailers will fall into the prisoner's dilemma when they achieve the final equilibrium, whereas the disclosure of high-quality product information will deepen the information leakage. This paper finally forms the strategic combination of information disclosure and sharing. The numerical example shows that more accurate information signals and more intense competition urge the supplier to disclose quality information. To solve the prisoner's dilemma, this paper suggests that the supplier stimulates two retailers to share information by providing subsidies, and this incentive mechanism can avoid the two retailers' prisoner's dilemma, thus, two retailers and the supplier can realize a win-win-win situation.

This paper is organized as follows. Section 2 briefly reviews the related literature. Section 3 puts forward the model assumption and setting. Sections 4 and 5 derive the equilibrium solution and information strategy combination. Section 6 provides a subsidy from the perspective of the food supplier to make the supply chain members achieve a win-win-win situation. Finally, Section 7 concludes the whole study and puts forward future research.

2. Related Literature

This paper focuses on the supplier's quality disclosure strategy in the food supply chain consisting of one leading supplier and two following retailers with private demand information. This topic is related to the following three streams of existing research: quality transparency in food supply chains, quality information disclosure, and demand information sharing under competition.

2.1. Quality transparency in food supply chains

When studying quality transparency in food supply chains, many researchers study the importance of transparency. Transparency can guarantee food quality and product origin (Trienekens et al., 2012), and increase customers' trust (Kassahun et al., 2014). The measures to achieve transparency are also studied. Intensified information exchange and integrated information systems can make food properties more transparent and guarantee food safety (Trienekens et al., 2012). To ensure the implementation of meat supply chain transparency systems, Kassahun et al. (2014) put forward consumer and technological requirements. Donaldson (2022) thinks that digital devices employed to ensure food integrity and control the supply chains can ensure qualities of foodstuffs along the supply chain. Liu et al. (2022) analyze the effects of blockchains on imported fresh food supply chains, they find that the blockchain is more inclined to make the manufacturer and retailer better off when the blockchain cannot effectively mitigate consumers' concerns.

This paper also studies quality transparency decisions in food supply chains by means of quality disclosure. However, this paper combines quality and demand information asymmetry and studies the impact of the demand information asymmetry on the food supplier's quality disclosure decision in food supply chains. In particular, this paper builds the endogenous food quality function by taking the supplier's preservation technology investment into account.

2.2. Quality information disclosure

Quality disclosure strategies in different scenarios are also studied. For quality disclosure strategy considering consumer returns, Feng et al. (2020) find that the selection of information disclosure strategy relies on the returns rate of new products, quality information disclosure carried out by the retailer can be more specifically accompanied by the low returns rate of new products. For quality disclosure strategies of secondhand products, Dou et al. (2022) incorporate the manufacturer's channel decisions into the model and find that the retailer may withhold information even if the product quality is sufficiently high. Quality certification as one type of quality information disclosure is also studied. Bian et al. (2022) study the impacts of the government's information provision on the quality certification strategy of one farming cooperative; and find that the farming cooperative will suffer profit loss when the government provides free information, especially when the information precision rate is higher. Yu and He (2021) find that when the small-scale producer joins the farmers' organization to implement organic certification accompanied by a rational portion of revenue sharing, they can realize a win-win situation. When integrating quality disclosure strategies into technology licensing including the patentor and the licensee, Hong et al. (2021a) analyze the quality disclosure strategies of the patentor and the licensee in a duopoly model and compare different patterns of licensing. When employing blockchains to disclose information, Liu et al. (2023) compare the strategies of adopting blockchains and voluntary disclosure and find that the manufacturer and retail platform can benefit from price parity clauses. When considering cost heterogeneity, Guan and Chen (2015) find that when the product quality is sufficiently low, the ex-post payoff can be higher in the decentralized situation than in the integrated situation. By combining channel structure and the supplier's quality disclosure, Jiang et al. (2022) find that the supplier may choose to sell products directly accompanied by low product quality.

Some researchers study information acquisition and quality disclosure simultaneously. Guan and Chen (2017) investigate a scenario where the product quality information is privately owned by the manufacturer but the manufacturer lacks the related information about consumer preferences. They find that the manufacturer may not obtain more profits from free customer information. Guan et al. (2019) further compare the Upfront Market Research and Upfront Quality Advertising scenarios. Cao et al. (2020) show that mandatory disclosure can reduce the disclosure level of the products. When comparing voluntary disclosure and mandatory disclosure of green manufacturers, Hong et al. (2021b) find that mandatory information disclosure sometimes can make supply chain members obtain higher profits.

This study combining quality disclosure and demand information asymmetry simultaneously is limited. Guan and Chen (2017) and Guan et al. (2019) consider quality and demand information asymmetry, whereas they ignore the competition in the industry. Yu and He (2021) only consider the horizontal operation and ignore the information disclosure decisions between enterprises in vertical food supply chains, which is a common challenge to information sharing in supply chains. This paper fills this research gap by studying the food supplier's quality disclosure strategy in the supply chain with horizontal competition and vertical information asymmetry. This paper also builds an endogenous food quality function by taking the supplier's preservation technology investment into account due to the perishable characteristics of food quality.

2.3. Demand information sharing under competition

When studying demand information sharing, the competition between upstream enterprises is considered. Gumus (2014) investigates the setting where upstream enterprises are made up of two heterogeneous suppliers and finds that vertical information asymmetry in supply chains can increase the equilibrium prices between competing suppliers. Jain (2022) finds that a manufacturer can increase the wholesale price to share private information with the retailer.

The scenario including an upstream firm and multiple downstream firms with private demand information is also studied; among the rest, Li (2002) studies the impacts of vertical information sharing. Li and Zhang (2008) find that supply chain members are inclined to share information accompanied by intense retail competition. Jain et al. (2011) put forward that pricing strategies can incentivize all retailers to provide information. Xue et al. (2017) combine information sharing and selling strategies including advance sales or regular sales, and find that the increase in information precision may reduce retailers' profits under regular sales. Xing et al. (2020) study the supply chain where a supplier sells to downstream competing manufacturers who determine whether to purchase information or not and find that the downstream competition intensity can determine how many manufacturers will purchase the information. In particular, the supply chain structure typical of one supplier and two competitive retailers is widely studied. Lei et al. (2020) study the structure made up of one entrant retailer and one incumbent retailer and find that the incumbent retailer deflates its demand information when only the entrant retailer is informed. Li et al. (2020a) study the manufacturer's information acquisition and subsidization strategies and find that the manufacturer can gain demand information by means of information acquisition, which can reduce the expenditure of subsidization. Cao and Chen (2021) study the structure made up of one manufacturer and two retailers with different informativeness and find that the manufacturer's cost-reduction efficiency and the retailers' competition mode can distort the manufacturer's pricing decisions. Qiu et al. (2022) find that cooperation between retailers increases profits from information sharing.

Some researchers study bilateral information sharing. Hao et al. (2018) find that the supplier's vertical information acquisition can complement retailers' horizontal information sharing. Jain and Sohoni (2015) study information leakage by a third-party supplier in the outsourcing scenario, they find that the first mover may not benefit from concealing information, which relies on the second mover's informativeness and can be moderated by competition intensity. Wang et al. (2022) study the decisions of retailers' pricing and service efforts investment when the demand information is privately owned by the manufacturer.

Information sharing considering supply chain competition is also studied. Whether one supply chain may be better off due to information sharing depends on the types of competition, Ha et al. (2011) find that Cournot competition may make the supply chain that shares information worse off, whereas Bertrand competition will benefit the supply chain that shares information. One supply chain's information sharing can benefit itself (Guan et al., 2020), sometimes it can also make the rival supply chain better off (Bian et al., 2016).

Some researchers study information sharing in supply chains with more complex structures consisting of multiple agents. Jiang and Hao (2016) study horizontal information sharing and vertical information acquisition in two-tier supply chains and find that horizontal competition among retailers can facilitate information sharing, whereas vertical information acquisition can be excluded by suppliers' competition. Wu et al. (2019) study a setting comprised of multiple suppliers and two competing retailers with private demand signals and they find that the supplier correlation and the number of suppliers affect the suppliers' desire for more accurate information.

The above literature only considers one type of information asymmetry, either quality or demand information. However, the two types of information asymmetry can interactively affect supply chain performance. Furthermore, the impact of quality information disclosure obviously relates to food quality. The quality disclosure behavior therefore naturally relates to food quality management decisions in supply chain operations. It would be practically significant to understand how the business operations strategies for managing key endogenous attributes of food quality interact with the quality disclosure strategy.

Table 1. Summary of related literature.

	quality disclosure	information sharing	food supply chain	competition
Bian et al. (2016)		√		√
Bian et al. (2022)	√			
Cao et al. (2020)	√			
Cao and Chen (2021)		√		√
Donaldson (2022)	√		√	
Dou et al. (2022)	√			
Feng et al. (2020)	√			
Guan and Chen (2015)	√			
Guan and Chen (2017)	√	√		
Guan et al. (2019)	√	√		
Guan et al. (2020)		√		√
Gumus (2014)		√		√
Ha et al. (2011)		√		√
Hao et al. (2018)		√		√
Hong et al. (2021a)	√			√
Hong et al. (2021b)	√			
Jain et al. (2011)		√		√
Jain and Sohoni (2015)		√		√
Jain (2022)		√		√
Jiang and Hao (2016)		√		√
Jiang et al. (2022)	√			
Lei et al. (2020)		√		√
Li (2002)		√		√
Li and Zhang (2008)		√		√
Li et al. (2020a)		√		√
Liu et al. (2022)	√		√	
Liu et al. (2023)	√			
Qiu et al. (2022)		√		√
Trienekens et al. (2012)	√		√	

Wang et al. (2022)		√		√
Wu et al. (2019)		√		√
Xing et al. (2020)		√		√
Xue et al. (2017)		√		√
Yu and He (2021)	√	√		√
This paper	√	√	√	√

To sum up, this paper studies the quality disclosure behavior in food supply chains affected by endogenous food quality characteristics which is a function of the supplier's preservation technology investment. This is studied in the context of quality and demand information asymmetry among members within the horizontal and vertical axis of a food supply chain. The relationship between the supplier's quality disclosure and retailers' demand information sharing is also studied. Table 1 makes a summary of the related literature.

3. Model Description

We study the quality information disclosure problem in a perishable food supply chain comprised of one leading supplier and two following retailers. The supplier provides the food quality preservation technology at the investment τ and supplies the food for retailer i at the wholesale price w_i with unit production cost c. The retailer i sells food to consumers at the retail price p_i. Corresponding costs (F) for quality assurance is essential to make the decision on food quality information disclosure, e.g., product testing or third-party certifications. We assume that the demand forecast by retailers is privately owned, and the retailers will decide whether to provide information to the supplier. This paper assumes that quality disclosure and information sharing negotiation take place in the early stage due to the fact that information sharing and quality disclosure are long-term strategic decisions. As the case showed in the study of Shew et al. (2022) ~~shows~~, the quality disclosure strategy adopted~~made~~ by BeefChain is carried out before fully understanding customers' demand for blockchain technology.~~,~~ ~~b~~But after implementing the information disclosure strategy, it is discovered that customers have limited knowledge about ~~of~~ blockchain. This shows significance of studying the impact of the interaction between supply chain players on adoption of information discourse strategies. Since ~~the~~ food suppliers play a leading role ~~is the leader~~ in such business practice~~the game~~, we assume in this paper that the food supplier firstly discloses quality information, and then the retailer shares demand information. The food supply chain members then determine the pricing and preservation technology investment. The sequence of the whole event is shown in Fig. 1.

(1) The food supplier makes the quality disclosure decision.

(2) Each retailer decides whether to share his information with the supplier.

(3) Retailer i privately holds the demand signal Y_i and implements the information

sharing decision based on the predetermined information arrangement.

(4) The food supplier determines preservation technology investment τ and the wholesale price w_i.

(5) Retailer i decides the retail price p_i.

(6) The sales cycle begins and the corresponding demand appears.

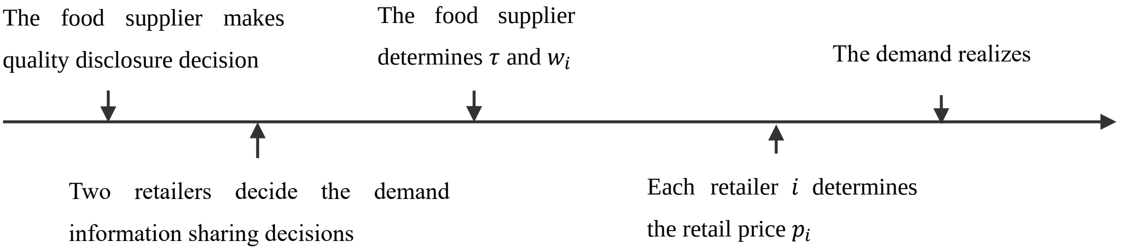

Fig. 1. The sequence of events in the game.

Extension B shows the situation when two retailers first share demand information, and then the food supplier discloses quality information. In such a situation, two symmetric retailers do not necessarily adopt the same information strategies.

3.1. Function of perceived food quality with the impact of quality disclosure

Similar to previous studies (e.g., Wang and Li, 2012), we assume that $q_t = \widetilde{q_0}e^{-(\theta-\tau)t}$, $\widetilde{q_0}$ is the initial food perceived quality, and θ is the initial deterioration rate of fresh food, the actual deterioration rate of fresh food will be $\theta - \tau$ after investing in the preservation technology τ. However, as food quality information is asymmetric between production and consumption, customers will form subjective quality judgments. Following Guo (2009), this paper assumes that the initial and actual food quality q_0 follows a uniform distribution on the interval [0, 1], consumers form an expectation of food quality $\overline{q_0}$, without the quality information disclosed by the food supplier. While the food supplier discloses the quality information, consumers will have updated belief on quality with the knowledge of true quality q_0. The expectation on the quality satisfies:

$$\widetilde{q_0} = \begin{cases} q_0, & \text{if the supplier discloses information} \\ \overline{q_0}, & \text{if the supplier does not disclose information} \end{cases}.$$

We study the decision in the market life cycle T. Note 2 shows that $z = \frac{\int_o^T e^{-(\theta-\tau)t}dt}{T}$ is a monotone increasing function of τ, and the optimal preservation technology investment τ is an implicit function concerning various parameters, whereas z can be clearly represented through the formula. To simplify the exposition, we let $\widetilde{q_0}z$ represent the customers' perceived food quality in the whole sales cycle per unit time with the preservation technology investment. We have $z = \frac{\int_o^T e^{-(\theta-\tau)t}dt}{T} = \frac{1-e^{-(\theta-\tau)T}}{(\theta-\tau)T}$, and $z(\tau = 0) = A = \frac{1-e^{-\theta T}}{\theta T}$. Similar to prior studies (e.g., Tao et al., 2023), we assume that the preservation technology investment cost is $\frac{\lambda}{2}(z - A)^2$. λ is the preservation technology cost coefficient, and the cost function represents the diminishing performance of preservation technology investment (Li et al., 2020b). In this paper, we assume that $\frac{\lambda}{T} > \frac{\beta^2}{(2-r)(1-r)}$ to reflect the constraints of the positive marginal effect of the supplier's preservation technology investment on its profit increases.

3.2. Demand function under asymmetric information

Customer demand is correlated positively with the food quality and the competitor's retail price, and it is correlated negatively with the retail price. We use a linear function to describe the market demand at time t, this linear demand function is widely used in previous studies, such as Wang and Li (2012) and Chen et al. (2019). $d_{it} = a + \beta\widetilde{q_0}e^{-(\theta-\tau)t} - p_i + rp_{3-i} + \varepsilon, i = 1or2$, a is the initial market size, and parameter $\beta > 0$ is the influence coefficient of the perceived quality on demand. The consumers care more about food quality when β is higher. $r \in (0,1)$ denotes the two retailers' product substitutability performance. When r is higher, the substitutability of products is greater, and the retailers' competition becomes more intense. The demand uncertainty ε follows the distribution with a mean of zero and variance σ^2.

Each retailer i has a private signal Y_i about ε. Each Y_i is an unbiased estimator of ε, and the joint probability distribution of (ε, Y_1, Y_2) satisfies the following attributes: $Y_i = \varepsilon + \mu_i$, $E[Y_i|\varepsilon] = \varepsilon + E[\mu_i] = \varepsilon$. The noise term μ_i is independent of ε. μ_1 and μ_2 are independent and identically distributed random variables with mean zero and variance ${\sigma_\mu}^2$ (Li and Zhang, 2008). Similar to Li (1985), the demand signals satisfy $E[\varepsilon|Y_i] = E[Y_{3-i}|Y_i] = \frac{Y_i}{1+s}$, $E[\varepsilon|Y_1, Y_2] = \frac{(Y_1+Y_2)}{2+s}$, where s is the inaccuracy rate of the demand signal, $s = \frac{E[Var[Y_i|\varepsilon]]}{Var(\varepsilon)}$, $E[(Y_i)^2] = (1+s)\sigma^2$, $E(Y_iY_{3-i}) = \sigma^2$. Table 2 summarizes the notations.

Table 2. Notation and explanation.

Notation	Explanation
c	The unit production cost
a	The initial market size, which is assumed to be large enough to ensure the optimal decisions are greater than 0
β	The influence coefficient of food quality on demand, which reflects the customers' quality preference
ε	Demand uncertainty which obeys the distribution with mean zero and variance σ^2
s	The inaccuracy rate of demand signals
μ_i	The noise term which obeys the distribution with mean zero and variance ${\sigma_\mu}^2$, $i = 1or2$
Y_i	The private signal of retailer i, $i = 1or2$
r	Two retailers' product substitutability performance

q_0	The initial food quality which follows a uniform distribution on the interval [0, 1]
$\overline{q_0}$	Expected quality conditional on no disclosure
$\widehat{q_0}$	Quality disclosure threshold
$\widetilde{q_0}$	Updated belief on quality, $\widetilde{q_0} \in \{q_0, \overline{q_0}\}$
p_i	The retail price of product i, $i = 1 or 2$
w_i	The wholesale price of product i, $i = 1 or 2$
θ	The food quality deterioration rate
τ	Preservation technology investment
z	The performance of the preservation technology investment per unit time during the whole sales cycle
T	The length of sales cycle
λ	The increasing marginal cost of preservation technology investment
g	The increasing marginal cost of preservation technology investment per unit time which satisfies $g = \frac{\lambda}{T}$
F	Quality disclosure cost
G	The supplier's subsidy in motivating retailers to share information
d_{it}	Retailer i's customer demand at time t
D_i	Retailer i's customer demand during the whole sales cycle
Δ	One retailer's profit gain from information leakage in equilibrium
$E(\pi_{lM})$	The expected profit of each supply chain member in the M mode given the fixed quality disclosure strategy, $M = \{yy, yn, ny, nn\}$ and $l = \{R1, R2, S\}$
π_{lM}	The ex-ante profit of each supply chain member in the M mode given the fixed quality disclosure strategy, $M = \{yy, yn, ny, nn\}$ and $l = \{R1, R2, S\}$

To solve the game shown in Fig. 1, we first determine the equilibrium pricing and preservation technology investment decisions under retailers' different information sharing arrangements. We then derive the equilibrium outcomes of the information sharing decisions of two competing retailers and study the impacts of information sharing on the optimal decisions.

Using y and n to describe the sharing and non-sharing strategies of the two retailers respectively, there are four scenarios of the information sharing subgames (M): (y, y), (y, n), (n, y), and (n, n). Π_{RiM} and Π_{SM} ($M = yy$, nn, yn, ny) represent the ex-ante profit of retailer i or the supplier under different demand information sharing arrangements, respectively. We then derive the retailers' information sharing decisions in equilibrium when the supplier's quality disclosure strategy is fixed. We use d and nd to represent the supplier's quality disclosure and non-disclosure strategies, respectively; and then we determine whether the supplier should disclose quality information, and we finally construct the information strategy combination in Section 5.

4. Equilibrium analysis under different information sharing arrangements

In this section, we assume that the supplier's quality disclosure strategy is fixed, and its optimal decision is derived based on retailers' information sharing arrangements in Section 5. When retailer i shares information with the supplier, the food supplier determines z and w_i based on signal Y_i. After z^* and ${w_i}^*$ are announced, retailer j ($j = 3 - i$) learns Y_i through z^* and ${w_i}^*$. Similar to previous studies (Zhang, 2009), the retailer's information sharing has two types of effects. The effect of information sharing on the upstream supplier is called direct effect. When one retailer shares information with the supplier, the other retailer can speculate the demand information through the supplier's actions, which is called the leakage effect.

When two retailers both share the information with the supplier, two retailers can speculate the competitor's demand signal based on the supplier's decisions, so that the supplier and two retailers make decisions based on demand signals Y_1 and Y_2. When only retailer i shares the information with the supplier, the other retailer can speculate Y_i based on the supplier's decisions, and retailer i makes decisions based on signal Y_i, whereas retailer j makes decisions based on signal Y_i and signal Y_j. Due to the symmetry of the retailers, we mainly study three arrangements, namely, two retailers both share demand information with the supplier, only one retailer shares demand information with the supplier, and no retailers share demand information with the supplier.

4.1. Two retailers both share demand information ($M = yy$)

When two retailers both share information with the supplier, with both direct effect and leakage effect, the supplier and two retailers make decisions based on demand signals Y_1 and Y_2. The optimization problem of two retailers and the supplier under information strategy (yy) can be expressed as follows:

$$\max_{z_M,w_{1M},w_{2M}} E[\Pi_{SM}] = E[\int_0^T[(w_{1M}-c)(a+\beta\widetilde{q_0}e^{-(\theta-\tau_M)t}-p_{1M}+rp_{2M}+\varepsilon)$$

$$+(w_{2M}-c)(a+\beta\widetilde{q_0}e^{-(\theta-\tau_M)t}-p_{2M}+rp_{1M}+\varepsilon)]dt|Y_1,Y_2]-\frac{\lambda}{2}(z_M-A)^2$$

$$s.t.\begin{cases} p_{1M}^* \in arg\max_{p_{1M}} E[\Pi_{R1M}] = E[\int_0^T[(p_{1M}-w_{1M})(a+\beta\widetilde{q_0}e^{-(\theta-\tau_M)t} \\ \qquad -p_{1M}+rp_{2M}+\varepsilon)]dt|Y_1,Y_2] \\ p_{2M}^* \in arg\max_{p_{2M}} E[\Pi_{R2M}] = E[\int_0^T[(p_{2M}-w_{2M})(a+\beta\widetilde{q_0}e^{-(\theta-\tau_M)t} \\ \qquad -p_{2M}+rp_{1M}+\varepsilon)]dt|Y_1,Y_2] \\ \qquad z_M = \frac{1-e^{-(\theta-\tau_M)T}}{(\theta-\tau_M)T} \end{cases} . \quad (1)$$

The optimal decisions are summarized in Table 3.

4.2. Only one retailer shares demand information ($M = yn$)

In this scenario, we assume that retailer 1 shares information with the supplier, and retailer 2 does not. The supplier and retailer 1 make the corresponding decisions based on common conjectures of p_{2M} due to the lack of retailer 2's demand information. Retailer 2 will make decisions based on demand signals Y_1 and Y_2 due to the leakage effect. The optimization problem of two retailers and the supplier under information strategy (yn) can be expressed as follows:

$$\max_{z_M, w_{1M}, w_{2M}} E[\Pi_{SM}] = E[\int_0^T [(w_{1M} - c)(a + \beta\widetilde{q_0}e^{-(\theta-\tau_M)t} - p_{1M} + rp_{2M} + \varepsilon) + (w_{2M} - c)(a + \beta\widetilde{q_0}e^{-(\theta-\tau_M)t} - p_{2M} + rp_{1M} + \varepsilon)]dt|Y_1] - \frac{\lambda}{2}(z_M - A)^2$$

$$s.t.\begin{cases} p_{1M}^* \in arg\max_{p_{1M}} E[\Pi_{R1M}] = E[\int_0^T [(p_{1M} - w_{1M})(a + \beta\widetilde{q_0}e^{-(\theta-\tau_M)t} \\ \qquad -p_{1M} + rp_{2M} + \varepsilon)]dt|Y_1] \\ p_{2M}^* \in arg\max_{p_{2M}} E[\Pi_{R2M}] = E[\int_0^T [(p_{2M} - w_{2M})(a + \beta\widetilde{q_0}e^{-(\theta-\tau_M)t} \\ \qquad -p_{2M} + rp_{1M} + \varepsilon)]dt|Y_1, Y_2] \\ z_M = \frac{1-e^{-(\theta-\tau_M)T}}{(\theta-\tau_M)T} \end{cases}. \qquad (2)$$

Table 3 shows the optimal pricing and preservation technology investment decisions of the food supply chain members.

It can be seen that, when only retailer 1 shares information with the supplier, the supplier will determine the corresponding prices based on the demand signal Y_1. There is no price distortion in this paper, although the supplier lacks the information about product 2, he will set the same wholesale price for two retailers, this finding is consistent with previous studies, such as (Zhang, 2009).

Table 3. The optimal decisions under different information sharing arrangements.

	yy	yn	nn
w_1^*	$w_0^* + \frac{g(2-r)(Y_1+Y_2)}{2(2+s)F(\widetilde{q_0})}$	$w_0^* + \frac{g(2-r)Y_1}{2(1+s)F(\widetilde{q_0})}$	$w_0^* + \frac{g(2-r)Y_1}{2(1+s)F(\widetilde{q_0})}$
w_2^*	$w_0^* + \frac{g(2-r)(Y_1+Y_2)}{2(2+s)F(\widetilde{q_0})}$	$w_0^* + \frac{g(2-r)Y_1}{2(1+s)F(\widetilde{q_0})}$	$w_0^* + \frac{g(2-r)Y_1}{2(1+s)F(\widetilde{q_0})}$
p_1^*	$p_0^* + \frac{g(3-2r)(Y_1+Y_2)}{2(2+s)F(\widetilde{q_0})}$	$p_0^* + \frac{g(3-2r)Y_1}{2(1+s)F(\widetilde{q_0})}$	$p_0^* + \frac{g(3-2r)Y_1}{2(1+s)F(\widetilde{q_0})}$
p_2^*	$p_0^* + \frac{g(3-2r)(Y_1+Y_2)}{2(2+s)F(\widetilde{q_0})}$	$p_0^* + \frac{(g(4-r-r^2+3s-2rs)+\beta^2\widetilde{q_0}^2)Y_1}{2(1+s)(2+s)F(\widetilde{q_0})} + \frac{Y_2}{4+2s}$	$p_0^* + \frac{(g(4-r-r^2+3s-2rs)+\beta^2\widetilde{q_0}^2)Y_1}{2(1+s)(2+s)F(\widetilde{q_0})} + \frac{Y_2}{4+2s}$
z^*	$z_0^* + \frac{\beta\widetilde{q_0}(Y_1+Y_2)}{(2+s)F(\widetilde{q_0})}$	$z_0^* + \frac{\beta\widetilde{q_0}Y_1}{(1+s)F(\widetilde{q_0})}$	$z_0^* + \frac{\beta\widetilde{q_0}Y_1}{(1+s)F(\widetilde{q_0})}$
Π_S^*	$\Pi_{S0}^* + \frac{gT\sigma^2}{(2+s)F(\widetilde{q_0})}$	$\Pi_{S0}^* + \frac{gT\sigma^2}{2(1+s)F(\widetilde{q_0})}$	Π_{S0}^*
Π_{R1}^*	$\Pi_{R0}^* + \frac{g^2(1-r)^2T\sigma^2}{2(2+s)(F(\widetilde{q_0}))^2}$	$\Pi_{R0}^* + \frac{Tg^2(1-r)^2\sigma^2}{4(1+s)(F(\widetilde{q_0}))^2}$	$\Pi_{R0}^* + \frac{T(1+s)\sigma^2}{(r-2(1+s))^2}$
Π_{R2}^*	$\Pi_{R0}^* + \frac{g^2(1-r)^2T\sigma^2}{2(2+s)(F(\widetilde{q_0}))^2}$	$\Pi_{R0}^* + \frac{Ts\sigma^2}{4(1+s)(2+s)} + \frac{Tg^2(1-r)^2\sigma^2}{4(1+s)(F(\widetilde{q_0}))^2}$	$\Pi_{R0}^* + \frac{T(1+s)\sigma^2}{(r-2(1+s))^2}$

Note 1: $F(\widetilde{q_0}) = g(2-r)(1-r) - \beta^2\widetilde{q_0}^2$, $w_0^* = \frac{g(-2+r)(a+c-cr)+\beta\widetilde{q_0}(Ag(-2+r)+2c\beta\widetilde{q_0})}{-2F(\widetilde{q_0})}$, $p_0^* = \frac{g(3a+c-(2a+c)r)+\beta\widetilde{q_0}(Ag(3-2r)-2c\beta\widetilde{q_0})}{2F(\widetilde{q_0})}$, $z_0^* = \frac{Ag(2-r)(1-r)+\beta\widetilde{q_0}(a+c(-1+r))}{F(\widetilde{q_0})}$, $\Pi_{S0}^* = \frac{gT(a+c(-1+r)+A\beta\widetilde{q_0})^2}{2F(\widetilde{q_0})}$, $\Pi_{R0}^* = \frac{Tg^2(1-r)^2(a+c(-1+r)+A\beta\widetilde{q_0})^2}{4(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)^2}$.

Due to the symmetry of the model, the scenario that retailer 1 conceals information, and retailer 2 shares information is similar, thus we omit the relevant calculation.

4.3. They neither share demand information ($M = nn$)

In this scenario, retailer 1 makes decisions based on the common conjectures of p_{2M} due to the lack of retailer 2's demand information, so does retailer 2. The supplier determines the optimal wholesale price and preservation technology investment based on the common conjectures of p_{1M} and p_{2M} because of the lack of retailers' demand information. The optimization problem of two retailers and the supplier under information strategy (nn) can be expressed as follows:

$$\max_{z_M, w_{1M}, w_{2M}} E[\Pi_{SM}] = E[\int_0^T [(w_{1M} - c)(a + \beta \widetilde{q_0} e^{-(\theta-\tau_M)t} - p_{1M} + rp_{2M} + \varepsilon) + (w_{2M} - c)(a + \beta \widetilde{q_0} e^{-(\theta-\tau_M)t} - p_{2M} + rp_{1M} + \varepsilon)]dt] - \frac{\lambda}{2}(z_M - A)^2$$

$$s.t. \begin{cases} p_{1M}^* \in arg \max_{p_{1M}} E[\Pi_{R1M}] = E[\int_0^T [(p_{1M} - w_{1M})(a + \beta \widetilde{q_0} e^{-(\theta-\tau_M)t} \\ \qquad -p_{1M} + rp_{2M} + \varepsilon)]dt | Y_1] \\ p_{2M}^* \in arg \max_{p_{2M}} E[\Pi_{R2M}] = E[\int_0^T [(p_{2M} - w_{2M})(a + \beta \widetilde{q_0} e^{-(\theta-\tau_M)t} \\ \qquad -p_{2M} + rp_{1M} + \varepsilon)]dt | Y_2] \\ z_M = \frac{1 - e^{-(\theta-\tau_M)T}}{(\theta-\tau_M)T} \end{cases} . \quad (3)$$

The optimal solutions are summarized in Table 3.

To better understand the impacts of one retailer's information sharing on the optimal decisions under competition, Corollary 1 takes Scenario 2 as an example, namely, only retailer 1 shares information.

Corollary 1.

(a) $\frac{\partial w_{1yn}^* - w_{1nn}^*}{\partial Y_1} = \frac{\partial w_{2yn}^* - w_{2nn}^*}{\partial Y_1} > 0$;

(b) $\frac{\partial p_{2yn}^* - p_{2nn}^*}{\partial Y_1} > 0$, $\frac{\partial p_{2yn}^* - p_{2nn}^*}{\partial Y_2} < 0$, $\frac{\partial p_{1yn}^* - p_{1nn}^*}{\partial Y_1} > 0$;

(c) $\frac{\partial z_{yn}^* - z_{nn}^*}{\partial Y_1} > 0$;

(d) if $\lambda \leq (>) \frac{2T(1+s)(\widetilde{q_0}\beta)^2}{(1-r)(2-r+2(1-r)s)}$, $\frac{\partial D_{1yn}^* - D_{1nn}^*}{\partial Y_1} \geq (<) 0$; $\frac{\partial D_{2yn}^* - D_{2nn}^*}{\partial Y_1} > 0$, $\frac{\partial D_{2yn}^* - D_{2nn}^*}{\partial Y_2} < 0$.

Corollary 1 illustrates the effects of one retailer's information sharing on pricing and preservation technology investment decisions. Retailer 1's information sharing can allow both pricing and preservation technology investment decisions to respond to the demand signal Y_1 positively, whereas it allows retailer 2 to negatively respond to the signal Y_2. Corollary 1(a) and Corollary 1(b) show that pricing strategies increase the double marginalization in the supply chain. Although the positive effects from preservation technology investment can compensate for the profit loss due to double marginal effects when the preservation technology investment is cost-effective enough, this positive tendency gradually begins to decline ($\frac{\partial^2 z_{1yn}^* - z_{1nn}^*}{\partial Y_1 \, \partial \lambda} < 0$) with the increase of λ. In this context, we find that when the preservation technology investment cost coefficient exceeds a threshold ($\lambda > \frac{2T(1+s)(\widetilde{q_0}\beta)^2}{(1-r)(2-r+2(1-r)s)}$), retailer 1's demand will respond to the demand signal Y_1 negatively.

Corollaries 1(a) and 1(c) show that the supplier with updated information can make the decisions of pricing and preservation technology investment better based on the demand fluctuations, which finally makes the supplier obtain more profits due to the retailer's information sharing (see Proposition 1(a)).

Proposition 1.

(a) The supplier can be better off from any retailer's information sharing;

(b) When retailer 2 shares information, $\Pi_{R1yy}^* \geq (<) \Pi_{R1ny}^*$ *if* $\lambda \leq (>) \frac{T(\widetilde{q_0}\beta)^2}{(1-r)^2}$; $\Pi_{R2yy}^* > \Pi_{R2ny}^*$;

(c) When retailer 2 does not share information, $\Pi_{R2yn}^* \leq (>) \Pi_{R2nn}^*$ *if* $\lambda \geq (<) \lambda^*$; $\Pi_{R1yn}^* \geq (<) \Pi_{R1nn}^*$ *if* $\lambda \leq (>) \frac{2T(1+s)(\widetilde{q_0}\beta)^2}{(1-r)(2-r+2(1-r)s)}$, *where* λ^* *satisfies* $\Pi_{R2yn}^* = \Pi_{R2nn}^*$.

Proposition 1(a) shows that the supplier can always be better off from the retailer's information sharing. Even though one of the downstream retailers (*e.g.,* retailer 2) conceals demand information, the supplier can still be better off from retailer 1's information sharing. However, the effects of one retailer's information sharing on two retailers are different. One retailer's information sharing may not always benefit the other retailer. To better reflect the value of one retailer's information sharing on the final decisions, we assume that retailer 2 shares information in Proposition 1(b) and does not share information in Proposition 1(c), respectively. Then, we find that retailer 1 will profit from sharing information when the preservation technology investment is relatively cost-effective regardless of the opponent's information sharing arrangement. This phenomenon can be explained as follows: Corollary 1 shows that when the preservation technology investment cost coefficient is less than a threshold, the positive impacts from improved preservation technology investment will dominate the negative effects from double marginalization of the supply chain, which can further lead to retailer 1's profit rise.

Interestingly, the impacts of retailer 1's information sharing on retailer 2 depend on retailer 2's information sharing decision. When retailer 2 shares information, as shown in Proposition 1(b), retailer 2 will always be better off from retailer 1's information sharing. When retailer 2 withholds information, as shown in Proposition 1(c), retailer 2 will obtain more profits through retailer 1's information sharing if the preservation technology investment is relatively cost-effective (*i.e.,* $\lambda < \lambda^*$). This can be explained as follows: in the information scenario yn, the demand and the marginal profit of retailer 2 respond to the demand signal Y_1 positively (*i.e.*, $\frac{\partial D^*_{2yn}-D^*_{2nn}}{\partial Y_1} > 0$, $\frac{\partial m^*_{2yn}-m^*_{2nn}}{\partial Y_1} > 0$), but respond to the demand signal Y_2 negatively (*i.e.*, $\frac{\partial D^*_{2yn}-D^*_{2nn}}{\partial Y_2} < 0$, $\frac{\partial m^*_{2yn}-m^*_{2nn}}{\partial Y_2} < 0$). Since $\frac{\partial^2 D^*_{2yn}-D^*_{2nn}}{\partial Y_1 \partial \lambda} < 0$ and $\frac{\partial^2 m^*_{2yn}-m^*_{2nn}}{\partial Y_1 \partial \lambda} < 0$, $\frac{\partial^2 D^*_{2yn}-D^*_{2nn}}{\partial Y_2 \partial \lambda} = 0$ and $\frac{\partial^2 m^*_{2yn}-m^*_{2nn}}{\partial Y_2 \partial \lambda} = 0$, when λ is relatively low, the demand and the marginal profit of retailer 2 become extremely and positively responsive to the demand signal Y_1, whereas retailer 2's response to the demand signal Y_2 is independent of λ. The positive change tendency of demand and the marginal profit from the demand signal Y_1 dominates the profit loss from demand signal Y_2. Thus, retailer 2 will be better off when the preservation technology investment is relatively cost-effective.

5. Equilibrium of information strategy combination

Using backward induction, this section firstly assumes that the supplier's quality disclosure strategy is fixed, and retailer i makes the final information sharing decisions based on the profits under different information subgames. Then, this paper determines the supplier's quality disclosure strategy based on the profit comparison before and after quality disclosure. Finally, the information strategy combination regarding quality disclosure and information sharing in equilibrium is derived.

To obtain the retailers' information decisions at equilibrium, we compare retailers' ex-ante profits under different information sharing arrangements, and then verify under what conditions information sharing is optimal for two retailers. Proposition 2 shows the optimal information sharing strategies.

Proposition 2. *When the supplier's quality disclosure strategy is fixed, the two retailers' information equilibrium is shown in Table 4.*

Table 4. Information sharing strategies in equilibrium.

s	r	λ	*Strategy combination*
$s \le \frac{1}{2}(1+\sqrt{7})$	$r \le 2+2s-\sqrt{2(1+s)(2+s)}$	$\lambda < \lambda_1$	*(y, y)*
		$\lambda \ge \lambda_1$	*(n, n)*
	$r > 2+2s-\sqrt{2(1+s)(2+s)}$	$\lambda \le \lambda_0$	*(y, y)*
		$\lambda > \lambda_0$	*(n, n)*
$s > \frac{1}{2}(1+\sqrt{7})$		$\lambda < \lambda_1$	*(y, y)*
		$\lambda \ge \lambda_1$	*(n, n)*

In the appendix, proof of Proposition 2 shows that when $\lambda \le \lambda_2$, information sharing is two retailers' dominant strategy; when $\lambda \ge \lambda_1$, information non-sharing is two retailers' dominant strategy; when $\lambda_2 < \lambda < \lambda_1$, two retailers have no dominant strategy and will adopt the same strategy. Proof indicates that two symmetric retailers will finally achieve the symmetric equilibrium, namely, (*y, y*) or (*n, n*). We further compare retailers' ex-ante profits in 4.1 and 4.3 and elaborate on the value of information sharing when two retailers reach equilibrium, and we finally obtain Proposition 2. When $r \geq \frac{6+2s(5+2s-\sqrt{2(1+s)(2+s)})}{3+2s(3+s)}$, we can get $\lambda_0 < 0$, two retailers can never profit from information sharing; which confirms that the competition weakens the benefits of information sharing.

From the perspective of the supplier, this effect will be contrary: when two retailers both share information with the supplier, the informed supplier can better capture the fluctuations of demand information and adjust the corresponding decisions with the increase of r, leading to the phenomenon that the supplier can be better off from the retailers' information sharing with the increasing competition. Although the equilibrium is not unique if $\lambda_2 < \lambda < \lambda_1$; after analyzing the value of information sharing, we confirm that if the preservation technology is cost-effective enough (*i.e.,* $\lambda \leq \min\{\lambda_0, \lambda_1\}$), two retailers will both share information. Since $\frac{\partial \lambda_1}{\partial r} > 0$ and $\frac{\partial \lambda_0}{\partial r} > 0$, higher competition intensity drives two retailers more easily to achieve (*y, y*) equilibrium. Higher customers' quality preference makes two retailers more quickly achieve (*y, y*) equilibrium due to the fact that $\frac{\partial \lambda_1}{\partial \beta} > 0$ and $\frac{\partial \lambda_0}{\partial \beta} > 0$.

The intuition behind Proposition 2 is as follows. To promote information sharing, it is recommended that retailers improve the efficiency of preservation technology investment while enhancing customers' preferences for food quality. In addition, due to the fact that higher competition intensity drives two retailers more easily to achieve (*y, y*) equilibrium, suppliers can provide products to highly competitive food retailers, which makes retailers in equilibrium provide information. After solving two retailers' information sharing strategy in equilibrium, this section determines the supplier's quality disclosure strategy by comparing the supplier's profit before and after quality disclosure. The equilibrium information strategy combination considering quality disclosure and demand information sharing is shown in Proposition 3.

Proposition 3. *Two retailers and the supplier will achieve the following equilibrium considering quality disclosure and demand information sharing, which is shown in Table 5.*

Table 5. Information decisions in equilibrium.

s	r	λ	q_o	*Strategy combination*
$s \leq \frac{1}{2}(1+\sqrt{7})$	$r \leq 2+2s-\sqrt{2(1+s)(2+s)}$	$\lambda < \lambda_1$	$q_0 \leq \widehat{q_{oyy}}$	*(d, y, y)*
			$q_0 > \widehat{q_{oyy}}$	*(nd, y, y)*
		$\lambda \geq \lambda_1$	$q_0 \leq \widehat{q_{onn}}$	*(d, n, n)*

			$q_0 > \widehat{q_{onn}}$	(nd, n, n)
	$r > 2 + 2s - \sqrt{2(1+s)(2+s)}$	$\lambda \leq \lambda_0$	$q_0 \leq \widehat{q_{oyy}}$	(d, y, y)
			$q_0 > \widehat{q_{oyy}}$	(nd, y, y)
		$\lambda > \lambda_0$	$q_0 \leq \widehat{q_{onn}}$	(d, n, n)
			$q_0 > \widehat{q_{onn}}$	(nd, n, n)
$s > \frac{1}{2}(1 + \sqrt{7})$		$\lambda < \lambda_1$	$q_0 \leq \widehat{q_{oyy}}$	(d, y, y)
			$q_0 > \widehat{q_{oyy}}$	(nd, y, y)
		$\lambda \geq \lambda_1$	$q_0 \leq \widehat{q_{onn}}$	(d, n, n)
			$q_0 > \widehat{q_{onn}}$	(nd, n, n)

Customers can easily have an incomplete understanding with regard to food quality, this paper suggests that the supplier providing food with high quality should increase food transparency. The supplier needs sufficient profit gain to make up for the expenditure of disclosure costs. Thus, the supplier discloses information of high-quality food to ensure that disclosure can bring sufficient market share. Moreover, disclosing low-quality product information may lead to a decrease in customer demand, which makes the supplier suffer profit loss. To better reflect the impact of key parameters on the supplier's quality disclosure decision, we assume $\sigma^2 = 1$, $a = 0.5$, $c = 0.2$, $T = 1$, $q_0 = 0.9$, $\theta = 0.1$, $\beta = 0.6$, $\lambda = 0.8$; in Fig. 2, we assume $r = 0.42$, $F = 0.1, 0.2, 0.3$, respectively; in Fig. 3, we assume $s = 0.5$, $F = 0.1, 0.15, 0.2$, respectively; in Fig. 4, we assume $s = 0.5, r = 0.42$, $F = 0.1, 0.2, 0.3$, respectively. Fig. 2 shows that as s increases, the quality disclosure threshold increases, which reflects that the supplier is less inclined to disclose quality information when the inaccuracy of information shared by the retailer is higher. However, as r changes, the quality disclosure threshold decreases, which means that higher competition intensity drives the supplier to disclose product information. When the food quality is fixed, the supplier's profit increases in r. Thus, when the value of r is small, the supplier may disclose information on high-quality food so that the profit gained from quality disclosure can offset disclosure costs. As r further increases, the supplier's profit will increase with actual quality due to the fact that the supplier can afford to disclose quality information. Consequently, Fig. 3 shows that the quality disclosure threshold decreases in r. Given fixed food quality, the quality disclosure threshold increases in s, as seen in Fig. 2. The reason behind this is consistent with that for Figs. 3-4. Figs. 2-4 show that the optimal quality disclosure threshold increases in F, which intuitionally shows that the supplier is less inclined to disclose information as disclosure costs increase. Fig. 4 shows that the optimal quality disclosure threshold increases with the preservation investment cost coefficient. This implies that the supplier is inclined to disclose product quality as preservation technology becomes more cost-effective.

Through numerical analysis in Fig. 3 and the discussions of Proposition 3, the intuition behind Proposition 3 is as follows. When simultaneously taking demand information sharing and product quality disclosure into account in a highly competitive environment, competition among food retailers will promote transparency in demand and product information. Meanwhile, higher efficiency in preservation technology investment will simultaneously promote the transparency of food quality and demand information.

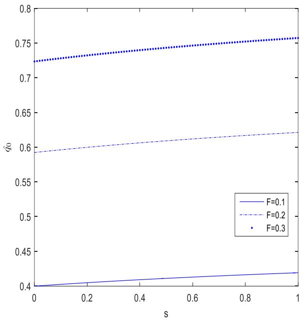

Fig. 2. The quality disclosure threshold as s changes.

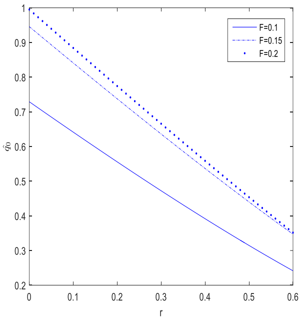

Fig. 3. The quality disclosure threshold as r changes.

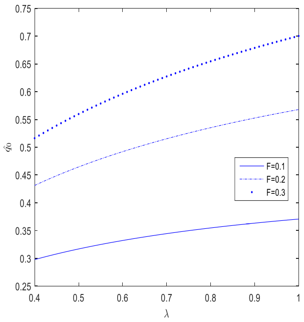

Fig. 4. The quality disclosure threshold as λ changes.

When supply chain members achieve the information decisions in equilibrium, the information leakage effect (Δ) is shown in Corollary 2.

Corollary 2. $\frac{\partial \Delta}{\partial s} > 0$ if $s < \sqrt{2}$, else, $\frac{\partial \Delta}{\partial s} < 0$; $\frac{\partial \Delta}{\partial r} > 0$; $\frac{\partial \Delta}{\partial \widehat{q_0}} > 0$.

As s increases, the accuracy of the demand information shared by the retailer decreases, and the retailer may try to reduce the leakage effect by transmitting incorrect demand information to the other retailer. Thus, Corollary 2 shows when $s > \sqrt{2}$, the information leakage effect decreases with s. However, as r increases, the price competition between two retailers becomes more intense, and the price fluctuations of the competitor can seriously affect customer demand. In this context, the retailer who speculates the demand information from the supplier's pricing decisions can better adjust selling prices based on demand fluctuations, and profit more from the other retailer's demand information as r increases. The supplier will disclose quality information when $q_0 > \widehat{q_{0yy}}$ or $q_0 > \widehat{q_{0nn}}$, meanwhile, Corollary 2 shows the leakage effect increases with customers' perceived quality. Thus, the supplier's disclosure of high-quality food increases the information leakage effect.

Proposition 4. *If* $s > \frac{1}{2}(1+\sqrt{7})$ *or* $s \le \frac{1}{2}(1+\sqrt{7}) \cap r \le 2 + 2s - \sqrt{2(1+s)(2+s)}$, *when* $\lambda_1 \le \lambda \le \lambda_0$, *two retailers will fall into the prisoner's dilemma.*

Proposition 2 shows that when $s > \frac{1}{2}(1+\sqrt{7})$ or $s \leq \frac{1}{2}(1+\sqrt{7}) \cap r \leq 2+2s-\sqrt{2(1+s)(2+s)}$, when $\lambda_1 \leq \lambda \leq \lambda_0$, two retailers will achieve (*n, n*) equilibrium. However, the proof in Proposition 2 shows that when $\lambda \leq \lambda_0$, the retailers would share information. Thus, this phenomenon confirms the existence of the prisoner's dilemma, namely, the individual's best choice is not the collective best choice.

According to Corollary 2, the leakage effect decreases in s when $s > \sqrt{2}$ and increases in r. Thus, the leakage effect in Proposition 4 is low. When two retailers share information, the leakage effects discourage the retailers from sharing their demand information (Li, 1985). Two retailers finally adopt to conceal information in equilibrium, so that they can avoid significant information leakage. However, this action drives two retailers to make decisions deviating from the collective optimum. For each retailer, the best strategy is sharing information simultaneously rather than concealing information simultaneously, which reflects that the individual's best choice is not the collective best choice in equilibrium. Since the information leakage effect increases in $\widetilde{q_0}$, the supplier's disclosure of the information on high-quality products may drive two retailers to conceal information in equilibrium. This finding is in accordance with the fact that the interval where two retailers are trapped in a prisoner's dilemma $(\lambda_0 - \lambda_1)$ increases in $\widetilde{q_0}$.

However, if the preservation technology investment is cost-effective enough, *i.e.,* $\lambda \leq \min\{\lambda_0, \lambda_1\}$, it can avoid the prisoner's dilemma, and motivate two retailers to share information. This eventually makes retailers and supplier realize a win-win-win situation. We assume that the supplier discloses quality information, and $q_0 = 1$, $\beta = 0.6$, $r = 0.8$ in Fig. 5. Fig. 5 shows that keeping λ fixed, with the increase of information inaccuracy, two retailers are easier to fall into the prisoner's dilemma. Furthermore, when s is fixed, with the increase of preservation cost coefficient, two retailers are also inclined to fall into the prisoner's dilemma.

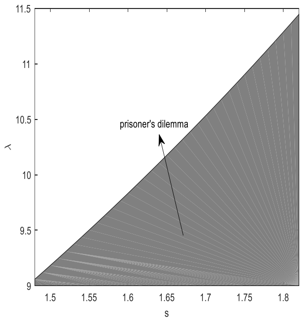

Fig. 5. The prisoner's dilemma of competing retailers.

Since two retailers finally achieve (*y, y*) or (*n, n*) equilibrium, Proposition 5 emphasizes the effects of information sharing by taking strategies (*y, y*) or (*n, n*) as examples.

Proposition 5.

(a) $\frac{\partial w_{iyy}^{*}-w_{inn}^{*}}{\partial Y_i} > 0$*;* $\frac{\partial w_{iyy}^{*}-w_{inn}^{*}}{\partial Y_{3-i}} > 0$*;* $\frac{\partial z_{yy}^{*}-z_{nn}^{*}}{\partial Y_i} > 0$, $\frac{\partial z_{yy}^{*}-z_{nn}^{*}}{\partial Y_{3-i}} > 0$*;*

(b) If $\lambda < (\geq) \frac{2T\beta^2\widetilde{q_0}^2(2+s)}{2-2s+r(-5-2s+2r(1+s))}$, $\frac{\partial p_{iyy}^{*}-p_{inn}^{*}}{\partial Y_i} > (\leq) 0$*;* $\frac{\partial p_{iyy}^{*}-p_{inn}^{*}}{\partial Y_{3-i}} > 0$*;*

(c) If $\lambda \geq (<) \frac{2T(2+s)\beta^2\widetilde{q_0}^2}{(1-r)(2(3+s)-r(3+2s))}$, $\frac{\partial D_{iyy}^{*}-D_{inn}^{*}}{\partial Y_i} \leq (>) 0$*;* $\frac{\partial D_{iyy}^{*}-D_{inn}^{*}}{\partial Y_{3-i}} > 0$*;*

(d) $\Pi_{Syy}^{*} > \Pi_{Snn}^{*}$*; where* $i = 1 or 2$.

Some interesting phenomena can be obtained from Proposition 5. In the final equilibrium, the supplier can always obtain more profits because of the retailers' information sharing. However, the impacts of information sharing on two retailers are not always positive. Retailers' information sharing makes them price positively to the competitor's demand signal, whereas they will price negatively to their own demand signal accompanied by the low preservation technology efficiency. The effects of information sharing on the demand are in line with this trend. Therefore, a retailer will be worse off due to sharing information under competition accompanied by a costly preservation technology investment.

We further analyze the effects of different parameters on the optimal preservation technology investment and emphasize the effect of deterioration rate and preservation technology investment cost coefficient on the optimal solutions, which are shown in Proposition 6.

Proposition 6.

(a) $\frac{\partial z_{M}^{*}}{\partial \beta} > 0$, $\frac{\partial z_{M}^{*}}{\partial \lambda} < 0$, $\frac{\partial z_{M}^{*}}{\partial \theta} < 0$, $\frac{\partial z_{yy}^{*}}{\partial s} < (\geq) 0$ *if* $Y_1 + Y_2 > (\leq) 0$*;*

(b) $\frac{\partial p_{iM}^{*}}{\partial \theta} < 0$, $\frac{\partial p_{iM}^{*}}{\partial \lambda} < 0$*;*

(c) $\frac{\partial w_{iM}^{*}}{\partial \theta} < 0$, $\frac{\partial m_{iM}^{*}}{\partial \theta} < 0$, $\frac{\partial D_{iM}^{*}}{\partial \theta} < 0$, $\frac{\partial w_{iM}^{*}}{\partial \lambda} < 0$, $\frac{\partial m_{iM}^{*}}{\partial \lambda} < 0$, $\frac{\partial D_{iM}^{*}}{\partial \lambda} < 0$*;*

(d) $\frac{\partial \Pi_{SM}^{*}}{\partial \theta} < 0$, $\frac{\partial \Pi_{RiM}^{*}}{\partial \theta} < 0$, $\frac{\partial \Pi_{SM}^{*}}{\partial \lambda} < 0$, $\frac{\partial \Pi_{RiM}^{*}}{\partial \lambda} < 0$*; where* $M = yy or nn$, $i = 1 or 2$.

Proposition 6(a) shows that the lower deterioration rate and preservation cost coefficient lead to a higher preservation technology investment. When the customers are more concerned about food quality, the food supplier is supposed to increase preservation technology investment. Interestingly, when the signal reflects low demand, (*i.e.,* $Y_1 + Y_2 \leq 0$), the optimal preservation technology investment increases in demand information inaccuracy. This would be explained as follows: in such instances, when the demand signal becomes more inaccurate, the signal reflecting low demand is less likely to come true. This means that the greater the possibility of high demand, the more preservation technology investment the supplier likes to implement. Proposition 6 shows that as θ or λ increases, the demand decreases, and the marginal profit and the wholesale price decline, which hurts the retailers' and the supplier's profits.

6. The supplier's subsidy in motivating information sharing

The above discussions demonstrate that the supplier always benefits from retailers' information sharing, but retailers sometimes suffer profit losses. Therefore, this section assumes that the supplier provides subsidies to motivate retailers to share demand information, thereby achieving a win-win situation for members of the food supply chain.

Proposition 7. *When the supplier offers a subsidy satisfying* $\frac{T(1+s)\sigma^2}{\left(r-2(1+s)\right)^2} - \frac{Tg^2(1-r)^2\sigma^2}{2(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)^2} \le G \le \frac{Tg\sigma^2}{2(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)}$, *two retailers can achieve (y, y) equilibrium and avoid the prisoner's dilemma.*

This section assumes that the supplier offers the subsidy at a fixed value G. When $\Pi_{Riyy}^* + G \ge \Pi_{Rinn}^*$ holds, two retailers share their information, and when $\Pi_{Syy}^* - 2G \ge \Pi_{Snn}^*$, the supplier can profit from retailers' information sharing. Thus, if the supplier offers a subsidy G which satisfies $\frac{T(1+s)\sigma^2}{\left(r-2(1+s)\right)^2} - \frac{Tg^2(1-r)^2\sigma^2}{2(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)^2} \le G \le \frac{Tg\sigma^2}{2(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)}$ to the two retailers, two retailers and the supplier will realize a win-win-win situation. The specific subsidy can be any numerical value that satisfies the interval shown in Proposition 7, which depends on the bargaining power of the supplier and retailers. The situation when considering the retailers' bargaining power is shown in Extension A. When the power of the supplier is extremely strong, the supplier maximizes his profit, the subsidy will be set at the minimum value $\frac{T(1+s)\sigma^2}{(r-2(1+s))^2} - \frac{Tg^2(1-r)^2\sigma^2}{2(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)^2}$, leading to two retailers making no difference in decisions regarding information sharing. Proposition 7 shows that the successful execution of the supplier's information incentive mechanism can avoid retailers' prisoner's dilemma as shown in Proposition 4.

7. Conclusions and managerial insights

The food quality information is asymmetric between production and consumption, and customers find it difficult to judge their true quality even after consuming the products. Food labels, quality certification, blockchain, and other information technologies are employed to disclose food quality information. However, the implementation of quality disclosure depends on the profit trade-off before and after disclosure. Demand information is asymmetric between upstream and downstream in the supply chain. When downstream retailers have private demand information, the retailers' information sharing strategies will affect the food supplier's quality disclosure strategy. In this paper, we consider that the food supplier provides preservation service to stimulate demand and the product information is asymmetric between production and consumption. Our study investigates the information sharing game of retailers with private demand information and the supplier's quality disclosure decision when the food quality can be improved by the preservation technology investment. We find that higher preservation technology efficiency and competition intensity make two retailers more quickly achieve (Sharing, Sharing) equilibrium. The supplier always benefits from retailers' information sharing, whereas two retailers will be better off from information sharing with cost effective preservation technology investment. Two retailers will fall into the prisoner's dilemma to avoid a high information leakage effect under some conditions. However, information disclosure of high-quality products deepens the information leakage. Numerical examples show that more accurate information signals and more intense competition encourage the supplier to disclose quality information. To solve the prisoner's dilemma, the finding suggests that the supplier stimulates two retailers to share information by providing subsidies so that the two retailers and the supplier can realize a win-win-win situation.

The above research findings provide significant managerial insights into the effective implementation of co-petition strategies in supply chains through informed information strategies.

For suppliers, supply chain partners have great opportunities to be all better off in a food supply chain by improving the efficiency of the quality preservation technology investment by suppliers. Such opportunities can also be achieved by providing a subsidy as the incentive for retailers to share demand information. When suppliers provide food to highly competitive retailers, they should increase transparency in food quality. As an example of facilitating information transparency by adopting emerging technologies~~In reality~~, Tyson food collaborates with many retailers, and has been using blockchain platforms since 2018 to ensure high-quality food supply[7]. For retailers, retailers should improve the accuracy of information prediction, and such an effort would further motivate suppliers to disclose food quality information. Although the

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[7] https://builtin.com/blockchain/food-safety-supply-chain

information leakage effect can increase with the accuracy of demand information, the retailers are suggested to share information accompanied by suppliers' efficient quality preservation service to achieve the collaboration benefits to all partners. If retailers with private information selfishly pursue low information leakage, they will fall into a prisoner's dilemma, which leads to economic loss for themselves and the supply chain.

Despite the above discussion (e.g., Propositions 2-3) showing that retailers' competition will promote the transparency of quality and demand information, the disclosure of quality information by suppliers for high-quality food can lead to high information spillover among retailers, making retailers more susceptible to falling into a prisoner's dilemma. Therefore, intensifying competition among retailers is not an effective means to promote information transparency. According to the discussions after Fig. 4 and Proposition 4, improving the efficiency of investment in preservation technologies is an effective way to promote quality and demand information transparency in the food supply chain, which can even avoid the prisoner's dilemma. This finding is consistent with Guan et al., (2020), which finds that manufacturers can incentivize the retailers to share demand information by improving service investment efficiency. Due to the fact that this paper uses a specific effort function to reflect the performance of preservation technology investment over a certain period, the conclusions of this paper are also applicable to other industries when considering the supplier's effort investment, quality disclosure, and the retailers' information sharing strategies.

Several extensions of our model merit further investigation. Retailers with different brand perceptions may have different information sharing strategies. It would be meaningful to investigate how heterogeneous elements between retailers would impact the information decisions. Furthermore, some observations about the effect of information sharing on quality disclosure are derived from the numerical examples. Further insights into the interplay between quality disclosure and demand information sharing may be explored to inform the information strategies.

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Appendix A

Note 2.

$z = \frac{\int_o^T e^{-(\theta-\tau)t}dt}{T} = \frac{1-e^{-(\theta-\tau)T}}{(\theta-\tau)T}$, $\frac{\partial z}{\partial \tau} = \frac{F(\theta)}{T(\theta-\tau)^2}$, $F(\theta) = -Te^{-(\theta-\tau)T}(\theta-\tau) + (1 - e^{-(\theta-\tau)T})$, $\frac{\partial F(\theta)}{\partial \theta} = T^2 e^{-(\theta-\tau)T}(\theta-\tau) > 0$. Since $\theta - \tau > 0$, we can get $F(\theta) > 0$, thus, we can get $\frac{\partial z}{\partial \tau} > 0$.

Proofs for Section 4.1

The proofs of optimal results in Sections 4.1-4.3 are similar, we take the scenario yn as an example here. In the scenario yn, retailer 1 shares the demand signal Y_1 with the supplier, the supplier will make the pricing and preservation technology investment decisions. Retailer 2 can speculate signal Y_1 based on the supplier's decisions, thus, retailer 2 can make decisions based on signals Y_1 and Y_2 due to the own private information, whereas retailer 1 and the supplier can only make decisions based on signal Y_1 due to the lack of Y_2. Based on the above analysis, we assume that $p_{2yn} = A_1 Y_1 +$

$B_1 + A_2 Y_2$, where A_1, A_2, B_1 are the undetermined coefficients.

$$E[\Pi_{R1yn}] = E[\int_0^T [(p_{1yn} - w_{1yn})(a + \beta\widetilde{q_0}e^{-(\theta-\tau_{yn})t} - p_{1yn} + rp_{2yn} + \varepsilon)]dt|Y_1]$$

$$= T(p_{1yn} - w_{1yn})(a + \beta z_{yn}\widetilde{q_0} - p_{1yn} + r(A_1 Y_1 + B_1 + A_2\tfrac{Y_1}{1+s}) + \tfrac{Y_1}{1+s}).$$

$$E[\Pi_{R2yn}] = E[\int_0^T [(p_{2yn} - w_{2yn})(a + \beta\widetilde{q_0}e^{-(\theta-\tau_{yn})t} - p_{2yn} + rp_{1yn} +$$

$$\varepsilon)]dt\,|Y_1, Y_2] = T(p_{2yn} - w_{2yn})(a + \beta z_{yn}\widetilde{q_0} - p_{2yn} + rp_{1yn} + \tfrac{(Y_1+Y_2)}{2+s}).$$

It is obvious that $E\left[\Pi_{R1yn}\right]$ is concave in p_{1yn} and $E\left[\Pi_{R2yn}\right]$ is concave in p_{2yn}, making $\frac{\partial E\left[\Pi_{R1yn}\right]}{\partial p_{1yn}} = \frac{\partial E\left[\Pi_{R2yn}\right]}{\partial p_{2yn}} = 0$, we then get $A_1 = \frac{2+r+2s}{2(2-r)(1+s)(2+s)}$, $A_2 = \frac{1}{4+2s}$, $B_1 = \frac{(2+r)\left(a+\widetilde{q_0}z_{yn}\beta\right)+rw_{1yn}+2w_{2yn}}{4-r^2}$; $p_{1yn} = \frac{Y_1}{(2-r)(1+s)} + \frac{(2+r)\left(a+\widetilde{q_0}z_{yn}\beta\right)+2w_{1yn}+rw_{2yn}}{4-r^2}$, $p_{2yn} = \frac{2+r+2s}{2(2-r)(1+s)(2+s)}Y_1 + \frac{(2+r)\left(a+\widetilde{q_0}z_{yn}\beta\right)+rw_{1yn}+2w_{2yn}}{4-r^2} + \frac{Y_2}{4+2s}$. We then substitute p_{1yn} and p_{2yn} into $E\left[\Pi_{Syn}\right]$.

$$E[\Pi_{Syn}] = E[\int_0^T [(w_{1yn} - c)(a + \beta\widetilde{q_0}e^{-(\theta-\tau_{yn})t} - p_{1yn} + rp_{2yn} + \varepsilon)]\,dt|Y_1] +$$

$$E[\int_0^T [(w_{2yn} - c)(a + \beta\widetilde{q_0}e^{-(\theta-\tau_{yn})t} - p_{2yn} + rp_{1yn} + \varepsilon)]dt|Y_1] - \tfrac{\lambda}{2}(z_{yn} - A)^2\,.$$

The second order conditions satisfy: $\frac{\partial^2 E[\Pi_{Syn}]}{\partial {w_{1yn}}^2} = -\frac{2(2-r^2)T}{4-r^2}$, $\frac{\partial^2 E[\Pi_{Syn}]}{\partial w_{1yn}\partial w_{2yn}} = \frac{\partial^2 E[\Pi_{Syn}]}{\partial w_{2yn}\partial w_{1yn}} = \frac{2rT}{4-r^2}$, $\frac{\partial^2 E[\Pi_{Syn}]}{\partial w_{1yn}\partial z_{yn}} = \frac{\partial^2 E[\Pi_{Syn}]}{\partial z_{yn}\partial w_{1yn}} = \frac{T\beta\widetilde{q_0}}{2-r}$, $\frac{\partial^2 E[\Pi_{Syn}]}{\partial {w_{2yn}}^2} = -\frac{2(2-r^2)T}{4-r^2}$, $\frac{\partial^2 E[\Pi_{Syn}]}{\partial w_{2yn}\partial z_{yn}} = \frac{\partial^2 E[\Pi_{Syn}]}{\partial z_{yn}\partial w_{2yn}} = \frac{T\beta\widetilde{q_0}}{2-r}$, $\frac{\partial^2 E[\Pi_{Syn}]}{\partial {z_{yn}}^2} = -gT < 0$. So the Hessian matrix is $\begin{vmatrix} \frac{2(r^2-2)T}{4-r^2} & \frac{2rT}{4-r^2} & \frac{T\beta\widetilde{q_0}}{2-r} \\ \frac{2rT}{4-r^2} & -\frac{2(2-r^2)T}{4-r^2} & \frac{T\beta\widetilde{q_0}}{2-r} \\ \frac{T\beta\widetilde{q_0}}{2-r} & \frac{T\beta\widetilde{q_0}}{2-r} & -gT \end{vmatrix}$, the first order leading principal minor is less than 0, the second order leading principal minor is more than 0; the third order leading principal minor $-\frac{4(1+r)T^3(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)}{(2-r)^2(2+r)}$ is less than 0 with the assumption of $g > \frac{(\widetilde{q_0}\beta)^2}{(2-r)(1-r)}$. Therefore, $E[\Pi_{Syn}]$ is jointly concave in w_{1yn}, w_{2yn} and z_{yn} if $g > \frac{(\widetilde{q_0}\beta)^2}{(2-r)(1-r)}$. According to Guan et al. (2020), we assume that $g > \frac{\beta^2}{(2-r)(1-r)}$, then, making $\frac{\partial E[\Pi_{Syn}]}{\partial w_{1yn}} = \frac{\partial E[\Pi_{Syn}]}{\partial w_{2yn}} = \frac{\partial E[\Pi_{Syn}]}{\partial z_{yn}} = 0$, we derive that the best decisions of the supplier and the retailers are:

$$w^*_{1yn} = w^*_{2yn} = -\frac{g(-2+r)(a+c-cr)+\beta\widetilde{q_0}(Ag(-2+r)+2c\beta\widetilde{q_0})}{2g(2-r)(1-r)-2\beta^2\widetilde{q_0}^2} + \frac{g(2-r)Y_1}{2(1+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)},$$

$$z^*_{yn} = \frac{Ag(2-r)(1-r)(1+s)+\beta\widetilde{q_0}((a-c(1-r))(1+s)+Y_1)}{(1+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)},$$

$$p^*_{1yn} = \frac{g(3a+c-(2a+c)r)+\beta\widetilde{q_0}(Ag(3-2r)-2c\beta\widetilde{q_0})}{2g(2-r)(1-r)-2\beta^2\widetilde{q_0}^2} + \frac{g(3-2r)Y_1}{2(1+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)},$$

$$p^*_{2yn} = \frac{g(3a+c-(2a+c)r)+\beta\widetilde{q_0}(Ag(3-2r)-2c\beta\widetilde{q_0})}{2g(2-r)(1-r)-2\beta^2\widetilde{q_0}^2} + \frac{(g(4-r-r^2+3s-2rs)+\beta^2\widetilde{q_0}^2)Y_1}{2(1+s)(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)} + \frac{Y_2}{4+2s}.$$

When the supplier's quality disclosure strategy is fixed, the ex-ante demand of retailers 1 and 2 can be denoted by:

$$D^*_{1yn} = \frac{gT(1-r)((1+s)(a-c(1-r)+A\beta\widetilde{q_0})+Y_1)}{2(1+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)},$$

$$D^*_{2yn} = \frac{gT(1-r)(a-c(1-r)+A\beta\widetilde{q_0})}{2g(2-r)(1-r)-2\beta^2\widetilde{q_0}^2} + \frac{g(1-r)(r+s)+\beta^2\widetilde{q_0}^2}{2(1+s)(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)}TY_1 + \frac{TY_2}{4+2s}.$$

Through substituting w^*_{1yn}, w^*_{2yn}, p^*_{1yn}, p^*_{2yn} and z^*_{yn} into $E[\Pi_{Syn}]$, $E[\Pi_{R1yn}]$ and $E[\Pi_{R2yn}]$, the ex-ante profits of the supplier and the retailers given the fixed quality disclosure strategy can be denoted by:

$$\Pi^*_{R1yn} = \frac{Tg^2(1-r)^2(a-c(1-r)+A\beta\widetilde{q_0})^2}{4(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)^2} + \frac{Tg^2(1-r)^2\sigma^2}{4(1+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)^2},$$

$$\Pi^*_{R2yn} = \frac{g^2(1-r)^2T(a-c(1-r)+A\beta\widetilde{q_0})^2}{4(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)^2} + \frac{Ts\sigma^2}{4(1+s)(2+s)} + \frac{Tg^2(1-r)^2\sigma^2}{4(1+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)^2},$$

$$\Pi^*_{Syn} = \frac{gT(a-c(1-r)+A\beta\widetilde{q_0})^2}{2g(2-r)(1-r)-2\beta^2\widetilde{q_0}^2} + \frac{gT\sigma^2}{2(1+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)}.$$

Appendix B

Proof of Corollary 1

(a) $w^*_{1yn} - w^*_{1nn} = w^*_{2yn} - w^*_{2nn} = \frac{g(2-r)Y_1}{2(1+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)}$,

$$\frac{\partial w^*_{1yn}-w^*_{1nn}}{\partial Y_1} = \frac{\partial w^*_{2yn}-w^*_{2nn}}{\partial Y_1} = \frac{g(2-r)}{2(1+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)} > 0.$$

(b) $p^*_{2yn} - p^*_{2nn} = \frac{(g(4-r-r^2+3s-2rs)+\beta^2\widetilde{q_0}^2)Y_1}{2(1+s)(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)} + (\frac{1}{4+2s} + \frac{1}{r-2(1+s)})Y_2$,

$$\frac{\partial p^*_{2yn}-p^*_{2nn}}{\partial Y_1} = \frac{(g(4-r-r^2+3s-2rs)+\beta^2\widetilde{q_0}^2)}{2(1+s)(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)} > 0,$$

$$\frac{\partial^2 p^*_{2yn}-p^*_{2nn}}{\partial Y_1\,\partial\lambda} = \frac{(-3+2r)T\beta^2\widetilde{q_0}^2}{2(1+s)((2-r)(1-r)\lambda-T\beta^2\widetilde{q_0}^2)^2} < 0, \frac{\partial p^*_{2yn}-p^*_{2nn}}{\partial Y_2} = \frac{2+r}{(4+2s)(r-2(1+s))} < 0.$$

$$p^*_{1yn} - p^*_{1nn} = \frac{g(3-2r)Y_1}{2(1+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)} - \frac{Y_1}{2-r+2s};$$

$$\frac{\partial p^*_{1yn}-p^*_{1nn}}{\partial Y_1} = \frac{g(-2+r+2(-1+(-1+r)r)s)-2(1+s)\beta^2\widetilde{q_0}^2}{2(1+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)(r-2(1+s))} > 0;$$

$$\frac{\partial^2 p^*_{1yn}-p^*_{1nn}}{\partial Y_1\,\partial\lambda} = \frac{(-3+2r)T\beta^2\widetilde{q_0}^2}{2(1+s)((2-r)(1-r)\lambda-T\beta^2\widetilde{q_0}^2)^2} < 0.$$

(c) $z^*_{yn} - z^*_{nn} = \frac{\beta\widetilde{q_0}Y_1}{(1+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)}$; $\frac{\partial z^*_{yn}-z^*_{nn}}{\partial Y_1} > 0$;

$\frac{\partial^2 z_{yn}^* - z_{nn}^*}{\partial Y_1\, \partial \lambda} = -\frac{(2-r)(1-r)T\beta\widetilde{q_0}}{(1+s)((2-r)(1-r)\lambda - T\beta^2\widetilde{q_0}^2)^2} < 0.$

(d) $D_{1yn}^* - D_{1nn}^* = \frac{1}{2}T(\frac{2}{r-2(1+s)} + \frac{g-gr}{(1+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)})Y_1$; if $\frac{T\beta^2\widetilde{q_0}^2}{2-3r+r^2} < \lambda \leq \frac{2(1+s)T\beta^2\widetilde{q_0}^2}{(1-r)(2-r+2(1-r)s)}$, $\frac{\partial D_{1yn}^* - D_{1nn}^*}{\partial Y_1} \geq 0$; else, $\frac{\partial D_{1yn}^* - D_{1nn}^*}{\partial Y_1} < 0$.

$D_{2yn}^* - D_{2nn}^* = \frac{T(g(1-r)(r+s)+\beta^2\widetilde{q_0}^2)Y_1}{2(1+s)(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)} + (\frac{1}{4+2s} + \frac{1}{r-2(1+s)})TY_2$,

$\frac{\partial D_{2yn}^* - D_{2nn}^*}{\partial Y_1} = \frac{T(g(1-r)(r+s)+\beta^2\widetilde{q_0}^2)}{2(1+s)(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)} > 0$, $\frac{\partial D_{2yn}^* - D_{2nn}^*}{\partial Y_2} = (\frac{1}{4+2s} + \frac{1}{r-2(1+s)})T < 0$.

Proof of Proposition 1

(a) When retailer 2 shares information, the supplier benefits from retailer 1's information sharing: $\Pi_{Syy}^* - \Pi_{Sny}^* = \frac{gsT\sigma^2}{2(1+s)(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)} > 0$; when retailer 2 does not share information, the supplier benefits from retailer 1's information sharing: $\Pi_{Syn}^* - \Pi_{Snn}^* = \frac{Tg\sigma^2}{2(1+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)} > 0$; when retailer 1 shares information, the supplier benefits from retailer 2's information sharing: $\Pi_{Syy}^* - \Pi_{Syn}^* = \frac{gsT\sigma^2}{2(1+s)(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)} > 0$; when retailer 1 does not share information, the supplier benefits from retailer 2's information sharing: $\Pi_{Sny}^* - \Pi_{Snn}^* = \frac{Tg\sigma^2}{2(1+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)} > 0$.

(b) When retailer 2 shares information,

$\Pi_{R1yy}^* - \Pi_{R1ny}^* = -\frac{sT\sigma^2(g^2(3-r)(1-r)^3 - 2g(2-r)(1-r)\beta^2\widetilde{q_0}^2 + \beta^4\widetilde{q_0}^4)}{4(1+s)(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)^2}$,

if $\lambda \leq (>) \frac{T\beta^2\widetilde{q_0}^2}{(1-r)^2}$, $\Pi_{R1yy}^* \geq (<) \Pi_{R1ny}^*$.

$\Pi_{R2yy}^* - \Pi_{R2ny}^* = \frac{g^2(1-r)^2 sT\sigma^2}{4(1+s)(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)^2} > 0.$

(c) $\Pi_{R1yn}^* - \Pi_{R1nn}^* = T\sigma^2(\frac{F_1(g)(1-r)^2}{4(1+s)} - \frac{1+s}{(r-2(1+s))^2})$, $F_1(g) = \frac{g^2}{(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)^2}$, $\frac{\partial F_1(g)}{\partial g} = -\frac{2g\beta^2\widetilde{q_0}^2}{(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)^3} < 0$; if $g \leq (>) \frac{2(1+s)\beta^2\widetilde{q_0}^2}{(1-r)(2-r+2(1-r)s)}$, $\Pi_{R1yn}^* \geq (<) \Pi_{R1nn}^*$. $\Pi_{R2yn}^* - \Pi_{R2nn}^* = \frac{T\sigma^2 F_2(g)}{4(1+s)}$, $F_2(g) = \frac{s}{2+s} - \frac{4(1+s)^2}{(r-2(1+s))^2} + \frac{g^2(1-r)^2}{(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)^2}$, since $\frac{\partial F_2(g)}{\partial g} < 0$, we can get $\frac{\partial \Pi_{R2yn}^* - \Pi_{R2nn}^*}{\partial g} < 0$; thus, we can get if $\lambda < \lambda^*$, $\Pi_{R2yn}^* > \Pi_{R2nn}^*$, g^* satisfies $\Pi_{R2yn}^* = \Pi_{R2nn}^*$ and $g^* = \frac{\lambda^*}{T}$.

$$D_{2yn}^{*}-D_{2nn}^{*}=\frac{T(g(1-r)(r+s)+\beta^{2}\widetilde{q_0}^{2})Y_1}{2(1+s)(2+s)(g(2-r)(1-r)-\beta^{2}\widetilde{q_0}^{2})}+(\frac{1}{4+2s}+\frac{1}{r-2(1+s)})TY_2,$$

$$\frac{\partial D_{2yn}^{*}-D_{2nn}^{*}}{\partial Y_1}=\frac{T(g(1-r)(r+s)+\beta^{2}\widetilde{q_0}^{2})}{2(1+s)(2+s)(g(2-r)(1-r)-\beta^{2}\widetilde{q_0}^{2})}>0,$$

$$\frac{\partial D_{2yn}^{*}-D_{2nn}^{*}}{\partial Y_1\partial\lambda}=\frac{(2-r)(1-r)T^{2}(g(-1+r)(r+s)-\beta^{2}\widetilde{q_0}^{2})}{2(1+s)(2+s)((2-r)(1-r)\lambda-T\beta^{2}\widetilde{q_0}^{2})^{2}}<0,$$

$$\frac{\partial D_{2yn}^{*}-D_{2nn}^{*}}{\partial Y_2}=(\frac{1}{4+2s}+\frac{1}{r-2(1+s)})T<0;$$

$$m_{2yn}^{*}-m_{2nn}^{*}=\frac{(\beta^{2}\widetilde{q_0}^{2}+(1-r)(r+s)g)Y_1}{2(1+s)(2+s)\big(g(2-r)(1-r)-\beta^{2}\widetilde{q_0}^{2}\big)}+\frac{(2+r)Y_2}{(4+2s)(r-2(1+s))},$$

$$\frac{\partial m_{2yn}^{*}-m_{2nn}^{*}}{\partial Y_1}=\frac{(\beta^{2}\widetilde{q_0}^{2}+(1-r)(r+s)g)}{2(1+s)(2+s)\big(g(2-r)(1-r)-\beta^{2}\widetilde{q_0}^{2}\big)}>0,$$

$$\frac{\partial^{2} m_{2yn}^{*}-m_{2nn}^{*}}{\partial Y_1\partial\lambda}=\frac{-(1+r)\beta^{2}\widetilde{q_0}^{2}}{2T(1+s)(g(2-r)(1-r)-\beta^{2}\widetilde{q_0}^{2})^{2}}<0,\ \frac{\partial m_{2yn}^{*}-m_{2nn}^{*}}{\partial Y_2}=\frac{(2+r)}{(4+2s)(r-2(1+s))}<0.$$

Proof of Proposition 2

(a) For retailer 2, given that retailer 1 shares information, retailer 2 shares information if $\Pi_{R2yy}^{*}>\Pi_{R2yn}^{*}$, otherwise non-sharing; given that retailer 1 conceals information, retailer 2 shares information if $\Pi_{R2ny}^{*}>\Pi_{R2nn}^{*}$, otherwise non-sharing. For retailer 1, given that retailer 2 shares information, retailer 1 shares information, if $\Pi_{R1yy}^{*}>\Pi_{R1ny}^{*}$, otherwise non-sharing; given that retailer 2 conceals information, retailer 1 shares information, if $\Pi_{R1yn}^{*}>\Pi_{R1nn}^{*}$, otherwise non-sharing. By equating Π_{R2yy}^{*} and Π_{R2yn}^{*}, we get that the threshold quality disclosure cost coefficient satisfies $\lambda_1=\frac{T\beta^{2}\widetilde{q_0}^{2}}{(1-r)^{2}}$, if $\lambda<(\geq)\lambda_1$, $\Pi_{R2yy}^{*}>(\leq)\Pi_{R2yn}^{*}$; by equating Π_{R2ny}^{*} and Π_{R2nn}^{*}, we get $\lambda_2=\frac{2T(1+s)\beta^{2}\widetilde{q_0}^{2}}{(1-r)(2-r+2(1-r)s)}$, if $\lambda\leq(>)\lambda_2$, $\Pi_{R2ny}^{*}\geq(<)\Pi_{R2nn}^{*}$; by equating Π_{R1yy}^{*} and Π_{R1ny}^{*}, we get $\lambda_1=\frac{T\beta^{2}\widetilde{q_0}^{2}}{(1-r)^{2}}$; if $\lambda<(\geq)\lambda_1$, $\Pi_{R1yy}^{*}>(\leq)\Pi_{R1ny}^{*}$; by equating Π_{R1yn}^{*} and Π_{R1nn}^{*}, we get $\lambda_2=\frac{2T(1+s)\beta^{2}\widetilde{q_0}^{2}}{(1-r)(2-r+2(1-r)s)}$; if $\lambda\leq(>)\lambda_2$, $\Pi_{R1yn}^{*}\geq(<)\Pi_{R1nn}^{*}$. $\lambda_1-\lambda_2=\frac{rT\beta^{2}\widetilde{q_0}^{2}}{(1-r)^{2}(2-r+2(1-r)s)}>0$. Thus, we get if $\lambda\leq\lambda_2=\frac{2T(1+s)\beta^{2}\widetilde{q_0}^{2}}{(1-r)(2-r+2(1-r)s)}$, two retailers will achieve (*y*, *y*) equilibrium, and information sharing is retailer 2's dominant strategy; if $\lambda_2<\lambda<\lambda_1$, two retailers will achieve (*y, y*) equilibrium or (*n, n*) equilibrium, and two retailers neither have a dominant strategy; if $\lambda\geq\lambda_1$, two retailers will achieve (*n, n*) equilibrium, and non-information sharing is retailer 2's dominant strategy.

(b) $\Pi_{Riyy}^{*}-\Pi_{Rinn}^{*}=\frac{Tg^{2}(1-r)^{2}\sigma^{2}}{2(2+s)(g(2-r)(1-r)-\beta^{2}\widetilde{q_0}^{2})^{2}}-\frac{T(1+s)\sigma^{2}}{(r-2(1+s))^{2}}$, we let $\lambda_0=$

$\frac{T\beta^2\widetilde{q_0}^2}{(2-r)(1-r)-\frac{(2(1+s)-r)(1-r)}{\sqrt{2(2+s)(1+s)}}}$, if $\lambda \leq \lambda_0$, $\Pi^*_{Riyy} - \Pi^*_{Rinn} \geq 0$, two retailers will share information; otherwise, not share. $\frac{\partial \Pi^*_{Syy} - \Pi^*_{Snn}}{\partial r} = \frac{g^2 T\sigma^2(3-2r)}{(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)^2} > 0$. $\lambda_0 = \frac{T\beta^2\widetilde{q_0}^2}{(1-r)F_3(r,s)}$, we let $F_3(r,s) = 2 - r - \frac{(2(1+s)-r)}{\sqrt{2(2+s)(1+s)}}$, $\frac{\partial F_3(r,s)}{\partial r} = -1 + \frac{1}{\sqrt{2(1+s)(2+s)}} < 0$, $F_3(r=0,s) = 2 - \frac{\sqrt{2}(1+s)}{\sqrt{(1+s)(2+s)}} > 0$, $F_3(r=1,s) = 1 - \frac{1+2s}{\sqrt{2(1+s)(2+s)}} < 0$, $F_3(r = \frac{6+2s(5+2s-\sqrt{2(1+s)(2+s)})}{3+2s(3+s)}, s) = 0$, if $r < (\geq) \frac{6+2s(5+2s-\sqrt{2(1+s)(2+s)})}{3+2s(3+s)}$, $F_3(r,s) > (\leq) 0$.

(c) $\lambda_2 - \lambda_0 = \frac{T\beta^2\widetilde{q_0}^2}{(1-r)} F_4(r,s)$, $F_4(r,s) = \frac{2(r-2(1+s))(\sqrt{2}+\sqrt{2}s-\sqrt{(1+s)(2+s)})}{\sqrt{(1+s)(2+s)}(2-r+2s-2rs)(4-2r+\frac{\sqrt{2}(r-2(1+s))}{\sqrt{(1+s)(2+s)}})}$,

if $r > (\leq) \frac{6+2s(5+2s-\sqrt{2(1+s)(2+s)})}{3+2s(3+s)}$, we can get $\lambda_2 > (\leq) \lambda_0$;$\lambda_1 - \lambda_0 = \frac{T\beta^2\widetilde{q_0}^2}{(1-r)} F_5(r,s)$, $F_5(r,s) = \frac{1}{(1-r)} - \frac{1}{(2-r)-\frac{(2(1+s)-r)}{\sqrt{2(2+s)(1+s)}}}$,
$\frac{\partial F_5(r,s)}{\partial s} = -\frac{\sqrt{2}(2+3r+2(1+r)s)}{\sqrt{(1+s)(2+s)}(\sqrt{2}(2-r)+2\sqrt{2}s-4\sqrt{(1+s)(2+s)}+2r\sqrt{(1+s)(2+s)})^2} < 0$, $F_5(r, s=0) = \frac{r}{2-3r+r^2} > 0$, if $s < (\geq) \frac{1}{2}(2r - 1 + \sqrt{1+2r(2+r)})$, namely, if $r > (\leq) 2 + 2s - \sqrt{2(1+s)(2+s)}$, we can get $F_5(r,s) > (\leq) 0$, $\lambda_1 > (\leq) \lambda_0$. If $s > \frac{1}{2}(1+\sqrt{7})$, we can get $2 + 2s - \sqrt{2(1+s)(2+s)} > 1$, and $\frac{6+2s(5+2s-\sqrt{2(1+s)(2+s)})}{3+2s(3+s)} < 1$, then, we further get that $\lambda_2 < \lambda_1 \leq \lambda_0$. If $s \leq \frac{1}{2}(1+\sqrt{7})$, we can get $2 + 2s - \sqrt{2(1+s)(2+s)} \leq 1$, and $\frac{6+2s(5+2s-\sqrt{2(1+s)(2+s)})}{3+2s(3+s)} \geq 1$, then, we further get that $\lambda_2 \leq \lambda_0 < \lambda_1$ if $r > 2 + 2s - \sqrt{2(1+s)(2+s)}$; and $\lambda_2 \leq \lambda_1 \leq \lambda_0$ if $r \leq 2 + 2s - \sqrt{2(1+s)(2+s)}$.

(d) If $s \leq \frac{1}{2}(1+\sqrt{7})$, $\frac{\partial \lambda_0}{\partial r} = -\frac{4\left(-3+2r+\frac{1-r}{\sqrt{2(1+s)(2+s)}}+\frac{2-r+2s}{\sqrt{2(1+s)(2+s)}}\right)T\widetilde{q_0}^2\beta^2}{(1-r)^2\left(4-2r+\frac{\sqrt{2}(r-2(1+s))}{\sqrt{(1+s)(2+s)}}\right)^2} > 0$,

$\frac{\partial \lambda_0}{\partial \beta} = \frac{4T\widetilde{q_0}^2\beta}{(1-r)(4-2r+\frac{\sqrt{2}(r-2(1+s))}{\sqrt{(1+s)(2+s)}})} > 0$; $\frac{\partial \lambda_1}{\partial r} = \frac{2T\widetilde{q_0}^2\beta^2}{(1-r)^3} > 0$, $\frac{\partial \lambda_1}{\partial \beta} = \frac{2T\widetilde{q_0}^2\beta}{(1-r)^2} > 0$.

Proof of Corollary 2

$\Delta = \Pi^*_{R1yy} - \Pi^*_{R1yn} = \Pi^*_{R2yy} - \Pi^*_{R2ny} = \frac{s}{4(2+3s+s^2)} \frac{Tg^2(1-r)^2\sigma^2}{(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)^2}$, $\frac{\partial \Delta}{\partial s} = \frac{2-s^2}{4(2+3s+s^2)^2} \frac{Tg^2(1-r)^2\sigma^2}{(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)^2}$, $\frac{\partial \Delta}{\partial s} > 0$ if $s < \sqrt{2}$, else, $\frac{\partial \Delta}{\partial s} < 0$; $\frac{\partial \Delta}{\partial r} =$

$\frac{s}{4(2+3s+s^2)}\frac{2g^2(1-r)T\sigma^2(g(1-r)^2+\beta^2\widetilde{q_0}^2)}{(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)^3} > 0$; $\frac{\partial\Delta}{\partial\widetilde{q_0}} = \frac{g^2(1-r)^2 sT\beta^2\sigma^2\widetilde{q_0}}{(1+s)(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)^3} > 0$.

Proof of Proposition 3

When two retailers reach *(y, y)* equilibrium, if the supplier discloses product information, the supplier's profit can be denoted by : $\Pi_{Syy}^{D*} = \frac{gT(a-c(1-r)+A\beta q_0)^2}{2g(2-r)(1-r)-2\beta^2 q_0^2} + \frac{gT\sigma^2}{(2+s)(g(2-r)(1-r)-\beta^2 q_0^2)} - F$; if the supplier does not disclose product information, the supplier's profit can be denoted by :$\Pi_{Syy}^{ND*} = \frac{gT(a-c(1-r)+A\beta\overline{q_o})^2}{2g(2-r)(1-r)-2(\overline{q_o}\beta)^2} + \frac{gT\sigma^2}{(2+s)(g(2-r)(1-r)-(\overline{q_0}\beta)^2)}$. The supplier will disclose information if $\Pi_{Syy}^{D*} \geq \Pi_{Syy}^{ND*}$; otherwise, the supplier will not disclose information. The quality would be revealed if and only if $q_0 \geq \widehat{q_{0yy}}$, where $\widehat{q_{0yy}}$ represents the disclosure threshold and satisfies $\Pi_{Syy}^{D*}(q_0 = \widehat{q_0}) = \Pi_{Syy}^{ND*}$. The consumers' conditional expectation $\overline{q_0}$ can be derived by $\overline{q_0} = E(q_0|q_0 \leq \widehat{q_0}) = \frac{\widehat{q_0}}{2}$, thus, the equilibrium quality disclosure threshold satisfies $\frac{gT(a-c(1-r)+A\beta\widehat{q_{0yy}})^2}{2g(2-r)(1-r)-2\beta^2\widehat{q_{0yy}}^2} + \frac{gT\sigma^2}{(2+s)(g(2-r)(1-r)-\beta^2\widehat{q_{0yy}}^2)} - F = \frac{gT(a-c(1-r)+A\beta\frac{\widehat{q_{0yy}}}{2})^2}{2g(2-r)(1-r)-2\left(\frac{\widehat{q_{0yy}}}{2}\beta\right)^2} + \frac{gT\sigma^2}{(2+s)(g(2-r)(1-r)-\left(\frac{\widehat{q_{0yy}}}{2}\beta\right)^2)}$ when two retailers reach (*y, y*) equilibrium. Similarly, when two retailers reach (*n, n*) equilibrium, we can get the equilibrium quality disclosure threshold satisfies $\frac{gT(a-c(1-r)+A\beta\widehat{q_{0nn}})^2}{2g(2-r)(1-r)-2\beta^2\widehat{q_{0nn}}^2} - F = \frac{gT(a-c(1-r)+A\beta\frac{\widehat{q_{0nn}}}{2})^2}{2g(2-r)(1-r)-2\left(\frac{\widehat{q_{0nn}}}{2}\beta\right)^2}$.

Proof of Proposition 5

(a) $w_{iyy}^* - w_{inn}^* = \frac{g(2-r)(Y_1+Y_2)}{2(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)}$; $z_{yy}^* - z_{nn}^* = \frac{\widetilde{q_0}\beta(Y_1+Y_2)}{(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)}$; $\frac{\partial z_{yy}^*-z_{nn}^*}{\partial Y_i} > 0$, $\frac{\partial z_{yy}^*-z_{nn}^*}{\partial Y_{3-i}} > 0$.

(b) $p_{iyy}^* - p_{inn}^* = \frac{Y_i}{r-2(1+s)} + \frac{g(3-2r)(Y_i+Y_{3-i})}{2(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)}$; $\frac{\partial p_{iyy}^*-p_{inn}^*}{\partial Y_i} = \frac{1}{r-2(1+s)} + \frac{g(3-2r)+2k(k(-1+r)+\widetilde{q_0}\beta)}{2(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)}$, $\frac{\partial p_{iyy}^*-p_{inn}^*}{\partial Y_i\,\partial g} = \frac{\widetilde{q_0}\beta(k(-1+r)+q_0\beta(-3+2r))}{2(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)^2} < 0$, if $\lambda < (\geq)\frac{2T\beta^2\widetilde{q_0}^2(2+s)}{2-2s+r(-5-2s+2r(1+s))}$, $\frac{\partial p_{iyy}^*-p_{inn}^*}{\partial Y_i} > (\leq)0$. $\frac{\partial p_{iyy}^*-p_{inn}^*}{\partial Y_{3-i}} = \frac{g(3-2r)}{2(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)} > 0$.

(c) $D_{iyy}^* - D_{inn}^* = \frac{1}{2}T((\frac{2}{r-2(1+s)} + \frac{g-gr}{(2+s)\left(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2\right)})Y_i + \frac{g(1-r)Y_{3-i}}{(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)})$, $\frac{\partial D_{iyy}^*-D_{inn}^*}{\partial Y_i} = \frac{T}{r-2(1+s)} + \frac{g(1-r)T}{2(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)}$,

$$\frac{\partial^2 D_{iyy}^*-D_{inn}^*}{\partial Y_i\,\partial g}=\frac{-(1-r)T\beta^2\widetilde{q_0}^2}{2(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)^2}<0\quad,\quad \text{if}\quad \lambda\geq(<)\frac{2T(2+s)\beta^2\widetilde{q_0}^2}{(1-r)(2(3+s)-r(3+2s))}\quad,$$

$$\frac{\partial D_{iyy}^*-D_{inn}^*}{\partial Y_i}\leq(>)0;\ \frac{\partial D_{iyy}^*-D_{inn}^*}{\partial Y_{3-i}}=\frac{g(1-r)T}{2(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)}>0.$$

(d) $\Pi_{Syy}^*-\Pi_{Snn}^*=\frac{Tg\sigma^2}{(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)}>0.$

Proof of Proposition 6

(a) $A=\frac{1-e^{-\theta T}}{\theta T},\ \frac{\partial A}{\partial\theta}=\frac{T\theta e^{-\theta T}-(1-e^{-\theta T})}{T\theta^2}<0,$

$$\frac{\partial z_{yy}^*}{\partial\theta}=\frac{g(2-r)(1-r)}{g(2-r)(1-r)-\beta^2\widetilde{q_0}^2}\frac{\partial A}{\partial\theta}<0,\ \frac{\partial z_{nn}^*}{\partial\theta}=\frac{g(2-r)(1-r)}{g(2-r)(1-r)-\widetilde{q_0}^2\beta^2}\frac{\partial A}{\partial\theta}<0,$$

$$\frac{\partial z_{yy}^*}{\partial\beta}=\frac{\widetilde{q_0}(2Ag(2-r)(1-r)(2+s)\beta\widetilde{q_0}+(g(2-r)(1-r)+\beta^2\widetilde{q_0}^2)((a-c(1-r))(2+s)+Y_1+Y_2))}{(2+s)(g(2-r)(1-r)-(k(-1+r)+B\beta)^2)^2}>0,$$

$$\frac{\partial z_{nn}^*}{\partial\beta}=\frac{T\widetilde{q_0}((a-c(1-r))T\widetilde{q_0}^2\beta^2+(2-r)(1-r)(a-c(1-r)+2A\widetilde{q_0}\beta)\lambda)}{(T\widetilde{q_0}^2\beta^2-(2-r)(1-r)\lambda)^2}>0,$$

$$\frac{\partial z_{yy}^*}{\partial s}=-\frac{\beta\widetilde{q_0}(Y_1+Y_2)}{(2+s)^2(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)},\ \text{if}\ Y_1+Y_2>(\leq)0,\ \frac{\partial z_{yy}^*}{\partial s}<(\geq)0,$$

$$\frac{\partial z_{yy}^*}{\partial\lambda}=-\frac{(2-r)(1-r)T\beta\widetilde{q_0}((a-c(1-r))(2+s)+A(2+s)\beta\widetilde{q_0}+Y_1+Y_2)}{(2+s)((2-r)(1-r)\lambda-T\beta^2\widetilde{q_0}^2)^2}<0,$$

$$\frac{\partial z_{nn}^*}{\partial\lambda}=-\frac{(2-r)(1-r)T\widetilde{q_0}\beta(a-c(1-r)+A\widetilde{q_0}\beta)}{\left(T\widetilde{q_0}^2\beta^2-(2-r)(1-r)\lambda\right)^2}<0.$$

(b) $\frac{\partial p_{iyy}^*}{\partial\theta}=\frac{\partial p_{inn}^*}{\partial\theta}=\frac{g(3-2r)\beta\widetilde{q_0}}{2g(2-r)(1-r)-2\beta^2\widetilde{q_0}^2}\frac{\partial A}{\partial\theta}<0,$

$$\frac{\partial p_{iyy}^*}{\partial\lambda}=\frac{\partial p_{inn}^*}{\partial\lambda}=\frac{(-3+2r)T\widetilde{q_0}\beta(Ag(2-r)(1-r)+(a-c(1-r))\widetilde{q_0}\beta)}{2(T\widetilde{q_0}^2\beta^2-(2-r)(1-r)\lambda)^2}<0.$$

(c) $\frac{\partial w_{iyy}^*}{\partial\theta}=\frac{\partial w_{inn}^*}{\partial\theta}=\frac{g(2-r)\beta\widetilde{q_0}}{2g(2-r)(1-r)-2\beta^2\widetilde{q_0}^2}\frac{\partial A}{\partial\theta}<0,$

$$\frac{\partial w_{iyy}^*}{\partial\lambda}=\frac{\partial w_{inn}^*}{\partial\lambda}=\frac{(-2+r)T\widetilde{q_0}^2\beta^2(a-c(1-r)+A\widetilde{q_0}\beta)}{2(T\widetilde{q_0}^2\beta^2-(2-r)(1-r)\lambda)^2}<0,$$

$$m_{iyy}^*=\frac{g(1-r)((a-c(1-r))(2+s)+A(2+s)\beta\widetilde{q_0}+Y_1+Y_2)}{2(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)},$$

$$m_{inn}^*=-\frac{g(-1+r)(a-c(1-r)+A\widetilde{q_0}\beta)}{2g(2-r)(1-r)-2\widetilde{q_0}^2\beta^2}+\frac{Y_i}{2-r+2s},$$

$$\frac{\partial m_{iyy}^*}{\partial\theta}=\frac{\partial m_{inn}^*}{\partial\theta}=\frac{g(1-r)\beta\widetilde{q_0}}{2g(2-r)(1-r)-2\beta^2\widetilde{q_0}^2}\frac{\partial A}{\partial\theta}<0,\ \frac{\partial D_{iyy}^*}{\partial\theta}=\frac{\partial D_{inn}^*}{\partial\theta}=\frac{g(1-r)T\beta\widetilde{q_0}}{2g(2-r)(1-r)-2\beta^2\widetilde{q_0}^2}\frac{\partial A}{\partial\theta}<0,$$

$$\frac{\partial m_{iyy}^*}{\partial\lambda}=\frac{(-1+r)T\widetilde{q_0}^2\beta^2((2+s)(a-c(1-r)+A\widetilde{q_0}\beta)+Y_1+Y_2)}{2(2+s)(T\widetilde{q_0}^2\beta^2-(2-r)(1-r)\lambda)^2}<0,$$

$$\frac{\partial m_{inn}^*}{\partial\lambda}=\frac{(-1+r)T\widetilde{q_0}^2\beta^2(a-c(1-r)+A\widetilde{q_0}\beta)}{2(T\widetilde{q_0}^2\beta^2-(2-r)(1-r)\lambda)^2}<0,$$

$$\frac{\partial D_{iyy}^*}{\partial\lambda}=\frac{(-1+r)T^2\beta^2\widetilde{q_0}^2((a-c(1-r))(2+s)+A(2+s)\beta\widetilde{q_0}+Y_1+Y_2)}{2(2+s)((2-r)(1-r)\lambda-T\beta^2\widetilde{q_0}^2)^2}<0,$$

$$\frac{\partial D_{inn}^*}{\partial\lambda}=\frac{(-1+r)T^2\beta^2\widetilde{q_0}^2(a-c(1-r)+A\beta\widetilde{q_0})}{2((2-r)(1-r)\lambda-T\beta^2\widetilde{q_0}^2)^2}<0.$$

(d) $\frac{\partial \Pi^*_{Syy}}{\partial \theta} = \frac{gT\beta^2\widetilde{q_0}((a-c(1-r))^2(2+s)+2\sigma^2)}{(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)^2}\frac{\partial A}{\partial \theta} < 0,$

$$\frac{\partial \Pi^*_{Syy}}{\partial \lambda} = \frac{T^2\beta^2\widetilde{q_0}^2(-(a-c(1-r))^2(2+s)-2\sigma^2-A(2+s)\beta\widetilde{q_0}(2(a-c(1-r))+A\beta\widetilde{q_0}))}{2(2+s)((2-r)(1-r)\lambda-T\beta^2\widetilde{q_0}^2)^2} < 0,$$

$$\frac{\partial \Pi^*_{Snn}}{\partial \theta} = \frac{gT\widetilde{q_0}\beta(a-c(1-r)+A\widetilde{q_0}\beta)}{g(2-r)(1-r)-\widetilde{q_0}^2\beta^2}\frac{\partial A}{\partial \theta} < 0,$$

$$\frac{\partial \Pi^*_{Snn}}{\partial \lambda} = -\frac{T^2\beta^2\widetilde{q_0}^2(a-c(1-r)+A\beta\widetilde{q_0})^2}{2((2-r)(1-r)\lambda-T\beta^2\widetilde{q_0}^2)^2} < 0,$$

$$\frac{\partial \Pi^*_{Riyy}}{\partial \theta} = \frac{g^2(1-r)^2T\beta^2\widetilde{q_0}((a-c(1-r))^2(2+s)+2\sigma^2)}{(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)^3}\frac{\partial A}{\partial \theta} < 0,$$

$$\frac{\partial \Pi^*_{Riyy}}{\partial \lambda} = -\frac{(1-r)^2T^2\beta^2\lambda\widetilde{q_0}^2((a-c(1-r))^2(2+s)+2\sigma^2+A(2+s)\beta\widetilde{q_0}(2(a-c(1-r))+A\beta\widetilde{q_0}))}{2(2+s)((2-r)(1-r)\lambda-T\beta^2\widetilde{q_0}^2)^3} < 0,$$

$$\frac{\partial \Pi^*_{Rinn}}{\partial \theta} = \frac{g^2(1-r)^2T\widetilde{q_0}\beta(a-c(1-r)+A\widetilde{q_0}\beta)}{2(g(2-r)(1-r)-\widetilde{q_0}^2\beta^2)^2}\frac{\partial A}{\partial \theta} < 0,$$

$$\frac{\partial \Pi^*_{Rinn}}{\partial \lambda} = -\frac{(1-r)^2T^2\beta^2\lambda\widetilde{q_0}^2(a+c(-1+r)+A\beta\widetilde{q_0})^2}{2((2-r)(1-r)\lambda-T\beta^2\widetilde{q_0}^2)^3} < 0.$$

Extension A

This section assumes that the retailer i's bargaining power over the supplier is α_i ($0 < \alpha_i < 1$ due to the supplier's dominant position). The issue of solving the optimal subsidy for the supplier can be represented as follows.

$$\max_G\left(\Pi^*_{Riyy} + G - \Pi^*_{Rinn}\right)^{\alpha_i}\left(\Pi^*_{Syy} - 2G - \Pi^*_{Snn}\right)^{1-\alpha_i}, s.t. \begin{cases} \Pi^*_{Riyy} + G - \Pi^*_{Rinn} \geq 0 \\ \Pi^*_{Syy} - 2G - \Pi^*_{Snn} \geq 0 \end{cases}$$

Taking the natural logarithm (ln) of both sides of the above equation and differentiating with respect to α_i, we can obtain the optimal subsidy is:

$$G = \frac{1}{2}T\sigma^2\left(\frac{2(1+s)(1-\alpha_i)}{(r-2(1+s))^2} - \frac{g^2(1-r)^2(1-\alpha_i)}{(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)^2} + \frac{g\alpha_i}{(2+s)(g(2-r)(1-r)-\beta^2\widetilde{q_0}^2)}\right).$$

Extension B

This section studies the situation when retailers disclose demand information first, then, the supplier discloses quality information. We first get the optimal quality disclosure threshold $\widehat{q_{0M}}$ under different information sharing arrangements. For example, in the scenario yn, $\widehat{q_{0yn}}$ can be obtained by $\frac{gT(a+c(-1+r)+A\beta\frac{\widehat{q_{0yn}}}{2})^2}{2(g(2-r)(1-r)-\beta^2\frac{\widehat{q_{0yn}}^2}{2})} +$

$$\frac{gT\sigma^2}{2(1+s)(g(2-r)(1-r)-\beta^2\frac{\widehat{q_{0yn}}^2}{2})} = \frac{gT(a+c(-1+r)+A\beta\widehat{q_{0yn}})^2}{2(g(2-r)(1-r)-\beta^2\widehat{q_{0yn}}^2)} + \frac{gT\sigma^2}{2(1+s)(g(2-r)(1-r)-\beta^2\widehat{q_{0yn}}^2)} - F.$$

We assume $\sigma^2 = 1$, $a = 0.5$, $c = 0.2$, $T = 1$, $q_0 = 0.9$, $\theta = 0.1$, $\beta = 0.6$, $\lambda = 0.8$, $r = 0.42$, $F = 0.2$. Then, we can get the optimal quality disclosure thresholds satisfying $\widehat{q_{0yy}} = 0.61 + \frac{0.92\sqrt{29.3+9.769s}}{\sqrt{2+s}} + 0.5\sqrt{\frac{70.41+18.54s+4.5\sqrt{2+s}\sqrt{29.3+9.769s}}{2+s}}$,

$\widehat{q_{0yn}} = \widehat{q_{0ny}} = 0.61 + \frac{0.92\sqrt{14.65+9.767s}}{\sqrt{1+s}} - 0.5\sqrt{\frac{35.2+18.54s+4.5\sqrt{1+s}\sqrt{14.65+9.769s}}{1+s}}$, and $\widehat{q_{0nn}} = 0.641$. The retailers' ex-ante profits under different information sharing arrangements include two parts: If $q_0 \in [0, \widehat{q_{0M}}]$, the supplier will not disclose information, then, we get $\widetilde{q_0} = \frac{\widehat{q_{0M}}}{2}$; if $q_0 \in (\widehat{q_{0M}}, 1]$, the supplier will disclose information, and we can get $\widetilde{q_0} = q_0$. Then, the retailers' ex-ante profits under different information sharing arrangements are presented as follows. $\varPi_{R1yy}^{*} = \varPi_{R2yy}^{*} = \frac{\widehat{q_{0yy}}(0.0079+\frac{0.10765}{2+s}+(0.0118+0.00439\widehat{q_{0yy}})\widehat{q_{0yy}})}{(0.73312-0.09\widehat{q_{0yy}}^{2})^2} + \frac{0.3+0.069s}{2+s} + \frac{1}{(2+s)(-2.0364+\widehat{q_{0yy}}^{2})}\big(0.18 + 0.09s + 0.37\widehat{q_{0yy}} + 0.0828s\widehat{q_{0yy}} + \big(-0.07 + 0.035\widehat{q_{0yy}}^{2} + s(0.038 - 0.0185\widehat{q_{0yy}}^{2})\big) ln\big(1.427 - \widehat{q_{0yy}}\big) + \big(0.07 - 0.038s - 0.035\widehat{q_{0yy}}^{2} + 0.018s\widehat{q_{0yy}}^{2}\big) ln\big(1.427 + \widehat{q_{0yy}}\big)\big)$,

$\varPi_{R1yn}^{*} = \varPi_{R2ny}^{*} = \frac{1}{1+s}(0.151 + 0.069s + \frac{\widehat{q_{0yn}}(7.625+(1.4575+0.542\widehat{q_{0yn}})\widehat{q_{0yn}}+s(0.49+(0.729+0.271\widehat{q_{0yn}})\widehat{q_{0yn}}))}{(8.15-\widehat{q_{0yn}}^{2})^2} + \frac{1}{-2.036+\widehat{q_{0yn}}^{2}}(0.0911 + 0.091s + 0.185\widehat{q_{0yn}} + 0.083s\widehat{q_{0yn}} + (-0.035 + 0.017\widehat{q_{0yn}}^{2} + s(0.038 - 0.0185\widehat{q_{0yn}}^{2})) ln(1.427 - \widehat{q_{0yn}}) + (0.035 - 0.0376s - 0.0173\widehat{q_{0yn}}^{2} + 0.0185s\widehat{q_{0yn}}^{2}) ln(1.427 + \widehat{q_{0yn}})))$,

$\varPi_{R1nn}^{*} = \varPi_{R2nn}^{*} = 0.136 + \frac{0.54\widehat{q_{0nn}}(1.345+\widehat{q_{0nn}})^2}{(8.146-\widehat{q_{0nn}}^{2})^2} + \frac{0.0911+0.083\widehat{q_{0nn}}}{-2.04+\widehat{q_{0nn}}^{2}} - 0.0185\, ln(1.427 - \widehat{q_{0nn}}) + 0.0185\, ln(1.427 + \widehat{q_{0nn}}) + \frac{(1+s)}{(0.42-2(1+s))^2}$,

$\varPi_{R2yn}^{*} = \varPi_{R1ny}^{*} = \varPi_{R1yn}^{*} + \frac{s}{4(1+s)(2+s)}$.

The final information sharing strategies in equilibrium can be derived by comparing profits under different information arrangements. We find that the sequence of quality disclosure and demand sharing can affect the final information strategies combination. When two retailers first share demand information, it is difficult to determine whether the symmetrical retailer will adopt the same information strategy or not. If two retailers firstly share demand information, their information sharing strategies in equilibrium are derived by anticipating the supplier's quality disclosure. The quality disclosure threshold makes retailers' expected profit consist of two parts, which is unpredictable to achieve the symmetric information strategy. However, when the supplier first discloses quality information, once the supplier's quality disclosure strategy is fixed, the initial food perceived quality will also be determined, and the retailer will obtain the corresponding expected profit based on the relevant initial food perceived quality. Finally, two symmetric retailers will adopt the same information strategy.