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Decision and Coordination of Fresh Produce Three-Layer E-Commerce Supply Chain: A New Framework

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ABSTRACT This paper considers a fresh produce three-layer e-commerce supply chain consisting of a producer, a third-party logistics service provider, and a fresh produce e-commerce enterprise in a new framework. The market demand for the fresh produce is affected by the safety traceability system availability, the freshness level, the unit online selling price, and the random factor. We develop the game models under different supply chain decision scenarios. Two different types of contracts, namely, unilateral cost-sharing and revenue-sharing contract, and consolidated rebate and revenue-sharing contract are proposed to facilitate coordination of the supply chain. The impact of the changes of market preferences on the supply chain decisions, the supply chain profits, and the contract policies implementation is examined. The theoretical derivations and results are illustrated with numerical examples. While enriching the relevant literature, this paper also provides a practical guidance for the production, operation, and sales of the fresh produce e-commerce supply chain.

INDEX TERMS Fresh produce, fresh produce e-commerce enterprise, coordination contract, supply chain management, safety traceability system availability.

I. INTRODUCTION

With the development of the e-commerce, individuals in growing numbers gradually have the habit of online shopping, and the fresh agricultural products (FAPs) e-commerce has been developing rapidly. According to a recent report of the China Electronic Commerce Research Center, the total volume of the FAPs e-commerce in China is about CNY 140.28 billion in 2017, and it is expected to reach a higher level in 2018 [1]. But at present, the corresponding market penetration rate is still lower, not more than 5%. Behind it, there is a huge market with great potential for development.

In the rapidly evolving FAPs e-commerce environment, consumers have put forward higher requirements for the safety and quality of FAPs. Since the safety and quality of the FAPs has been highly concerned, the produce safety and quality is considered to be a direct factor influencing consumers' purchasing decisions [2]. The quality safety and quality of the FAPs are often affected by each link of the FAPs supply chain. Problems in any link of the supply chain may lead to problems in the safety and quality of the FAPs. In this case, it is extremely important to ensure that the safety of the FAPs can be traced back, and that the quality of the FAPs is fresh, in the FAPs e-commerce supply chain. Due to the special perishable characteristics of FAPs [3]–[6], it is also particularly necessary to control it properly during the supply chain process. Appropriate production and operation management in the whole FAPs e-commerce supply chain is of great significance not only to the development of supply chain enterprises, but also to people's safe consumption.

However, in actual supply chain production, the safety and quality problems are not optimistic. There are a series of consumption security incidents, such as the hand-dyed oranges, the poisonous strawberries, the vegetables with carcinogenic pesticides, which have greatly affected the consumers' consumption safety and confidence. More seriously, this may also affect the layout of the supply chain, the social harmony and stability in a region, and the international trade of the responsible countries. In recent years, fresh produce safety and quality problems have not been ease in a certain degree, but seem to be more serious. The past few years have witnessed several fresh produce safety events reports, such as microbiological hazards [7], pesticide residue [8] and heavy metals [9]. This also indicates from the side that in the source of current FAPs' supply chain, the concept of high quality and safety in production is insufficient. Besides, in actual supply chain operation, the lower preservation level is also detrimental to the quality of FAPs. The loss rate of perishable products is as high as 15/100 in the developed countries and as high as 30/100 in the developing countries, which have brought great losses to the supply chain, the society, and even the country [10]–[13]. All of these reflect the reality from the side that there are many problems in the production and operation of the real FAPs' supply chain.

Therefore, it requires the close collaboration of the supply chain members to increase FAPs safety and quality, and reduce FAPs loss. In FAPs' supply chain, the safety traceability system availability investment of the producer can help improve his safety traceability system availability, which not only makes it convenient and timely for consumers to understand the information of all stages of the agricultural products in the whole process of the supply chain, but also enables supply chain operators to quickly find relevant links in food safety incidents so as to reduce risks brought by the quality of the agricultural products, and improve FAPs' quality and safety [14]. Increasing investment in safety traceability systems can also provide companies with competitive advantages by improving the visibility of the processes performed and the corresponding control over product quality [15]. The safety traceability of FAPs from farm to din-table makes the consumers more reassured, especially in the e-commerce shopping environment. And the freshness-keeping effort of the third-party logistics service provider (TPLSP) in the process of logistics distribution can help keep FAPs' high freshness level. All these measures of the producer and the TPLSP can indirectly affect the market scale and benefits of the fresh produce e-commerce enterprise by affecting the experience and the second-time online shopping intention of the consumers. However, these will impose a considerable cost on the producer and the TPLSP respectively. Determining the best trade-off between the revenues and costs so as to maximize the total profit and provide higher quality and safer FAPs to the target market is therefore a key issue faced by the three supply chain members.

The purpose of this paper is to study the decision and coordination of the FAPs' three-layer e-commerce supply chain considering producer's safety traceability system availability investment and TPLSP's freshness-keeping in a new framework. We are going to address the following research issues:

- Should the three supply chain members, i.e., the producer, the TPLSP and the fresh produce e-commerce enterprise, independently make decisions on the safety traceability system availability investment, freshness-keeping effort, and unit online selling price, in the production, operation and sale process of the FAPs e-commerce supply chain?
- If no, are there different types of new contracts that can coordinate this supply chain?
- Can safety traceability system availability and freshness level of FAPs be improved?
- What is the impact of the market changes, such as the changes in consumers' preferences for the safety traceability system availability, the freshness, the online selling price, and marginal effort coefficient, on the supply chain decisions and profits?
- How do the changes of market preferences affect the implementation of the two new proposed contract policies? In which case, the supply chain is easy to coordinate, and in which case, the supply chain is not easy to coordinate?

In order to answer these questions, we will develop and establish the mathematical models for centralized, decentralized, and contractual FAPs' supply chains, respectively. We will explore and characterize the optimal decisions of the three supply chain parties in different FAPs' supply chain structures, and analyze the impact of consumers' sensitivities to the safety traceability system availability, the freshness level, the online selling price, and the marginal effort coefficient, on the supply chain decisions and profits. We will design and investigate different types of new contract mechanisms to coordinate this particular supply chain. And, we will explore the changes of market preferences on the implementation of the proposed new contracts. These will not only help improve the supply chain performance, but also help provide the safer and high-quality FAPs to target market under the e-commerce environment.

The remainder of the paper is organized as follows. Section II reviews the related literature. In Section III, the decision models under different scenarios are presented. In Section IV, we design two new and different types of contracts to coordinate this supply chain. The numerical analysis is conducted in Section V. The concluding remarks are given in Section VI, where the direction of future studies is provided. Appendix (A-N) presents the technical proofs of this study from start to finish.

II. LITERATURE REVIEW

Channel coordination is an important and leading issue in supply chain management [16], which is imperative for improving the supply chain performance [17]. How to make the individual goal and system goal of each node in the supply chain tend to be consistent is the problem to be solved in the channel coordination. There is one stream of the relevant studies that have been well reported in [19]–[26]. In these studies, the supply chain contracts such as wholesale contract [27], quantity discount contract [28], revenue sharing contract [29], buy back contract [30], sales rebate [31], quantity flexibility contract [32], and two-part pricing contract [33], option contract [34] are often taken as incentives by scholars to facilitate the coordination of supply chain. By eliminating certain channel conflicts, the corresponding supply chain performance has been better improved. However, these studies have only focused on the supply chain coordination of non-perishable products and haven't considered the unilateral cost-sharing and revenue-sharing contract, and the consolidated rebate and revenue-sharing contract in coordinating the FAPs' three-layer e-commerce supply chain.

With the development of the FAPs' supply chain and its increasingly important role in the lives of residents, some scholars have begun to pay attention to the coordination of the FAPs' supply chain. In recent years, a few relevant references have emerged, which provides some groundbreaking research for the coordination of FAPs supply chain. Cai*et al.*[10] considered a supply chain consisting of a producer and a distributor and found that the price-discount sharing and compensation schemes can achieve the optimization of the whole system. Xiao and Chen [4] presented a fixed inventory-plus factor strategy and demonstrated it is a Pareto improvement in a fresh products supply chain consisting of a producer and a distributor. Sun [35] developed a dynamic FAPs' supply chain model with supply disruptions and discovered that a lump-sum fee can motivate supplier and the retailer to accept two-part tariff contract. Wang and Chen [36] proposed the wholesale price and call option portfolio contracts to coordinate a one-supplier-one-retailer fresh produce supply chain, and showed that there was no correlation between the optimal option pricing policy of supplier and the demand risk and wholesale price. Zheng *et al.* [12] explored a two-layer FAPs' supply chain consisting of a supplier and a retailer, and designed a combination contract to achieve a win-win outcome. Yang *et al.* [37] focused on a two-layer FAP chain and proved the buy-back contract and the quantity discount contract are equivalent to the revenue sharing contract under certain conditions. However, the previous literature generally pays little attention to the coordination research of FAPs' e-commerce supply chain. Considering the rapid development of the FAPs e-commerce supply chain in recent years, we focus on the coordination of the FAPs e-commerce supply chain.

Besides the self-logistics mode, the third-party logistics mode adopted by the fresh produce e-commerce enterprise can have certain advantages in reducing fixed asset investment and providing flexible and diversified customer service. TPLSPs also have more professional facilities and facilities to provide FAPs protection. Since the decisions of TPLSP will have certain influence on the decisions of other channel members, it will be interesting to consider the participation of TPLSP in decision-making. At present, although some literature has considered the participation of TPLSP, these studies are mainly based on the principal-agent theory to study how to improve enterprise benefits or reduce enterprise cost [38], [39]. In addition, the literature does not take into account the supply chain of FAPs and lack of research on the contractual mechanism. Part of the literature has focused on the two-layer FAP supply chain, such as the research work of [40]. In our work, we consider the TPLSP in the first half of the logistics distribution of the FAPs' three-layer e-commerce supply chain.

When reviewing the literature on the coordination of multi-layer FAPs' e-commerce supply chain, we find that the research on coordination of the FAPs' supply chain among multiple channel members is relatively scarce, partly due to the difficulties related to the possible contracts. To the best of our knowledge, there are only a few scholars that have taken into consideration the coordination contracts with more than two FAPs' supply chain participants. For example, Cai *et al.* [41] presented a supply chain with multi-channel members and found that the wholesale-market clearance and wholesale-price-discount sharing contract can play down the risks involved in the process of the transportation and selling. Feng*et al.*[42] considered a three-layer supply chain and developed a supplier-led game model. Then a compound contract was designed to realize the coordination of the supply chain. The works of these scholars have inspired us very well. However, their works only considered one contract coordination mechanism and were without relying on e-commerce background. And they did not take into account the safety traceability system availability, freshness and online selling price sensitive random demand. Our model will study the effect of different types of contracts for coordinating the presented FAPs' e-commerce supply chain, under the safety traceability system availability, freshness and online selling price sensitive random demand.

In addition to being influenced by the retail price, the market demand for FAPs is also affected by other factors, such as the freshness [41], the price promotion [43], the sales effort [44], the safety traceability system availability, or other factors; however, fewer scholars have explored the impact of multiple factors on market demand. By combing the literature, we found that the literature on FAPs' supply chain coordination considering the producer's safety traceability system availability, the TPLSP' freshness-keeping, the fresh produce e-commerce enterprise's online selling price, and the random factor is also very sparse. And the existing literature has mainly studied the impact of the retail price and the freshness on the FAPs market demand. Wang and Dan [45] examined the coordination of FAPs' supply chain considering retailer's preservation, and demonstrated that preservation cost and revenue sharing contract can achieve supply chain coordination and enhance the overall utility of consumers. Wang and Dan [46] investigated an FAP supply chain coordination with supplier's preservation, and found that when the retailer was in a strong position, the purchase price based on product freshness contract could make the supply chain more profitable. These studies have very well portrayed the impact of less factors on supply chain demand. However, they only focused on the two-level supply chain composed of a supplier and a retailer, and didn't consider the producer's safety traceability system availability, the TPLSP's freshness-keeping, the fresh produce e-commerce enterprise's online selling price, and the random factor, simultaneously. How do these multiple factors affect the decisions and profits of the three channel members? How to design the new contract coordination mechanisms in this case? This is also one of the aspects that we are going to study.

Literature presented above has given us a certain degree of inspiration from different perspectives. From the above literature review, it can be found that coordination of FAPs' supply chain is a relative less studied area. No one has explored the coordination of the complex FAPs' three-layer e-commerce supply chain presented in this paper by taking into account all these scenarios simultaneously, such as the FAPs characteristics, the multi-layer supply chain, the endogenous prices, the TPLSP's participation, and the e-commerce environment, especially considering the market demand for FAPs is affected by the safety traceability system availability, the freshness, the unit online selling price, and the random factor, concurrently. In addition, although some scholars have used the contract as a tool to explore the FAPs supply chain coordination, as far as our understanding, the literature of concurrently examining different types of coordination contracts is still a few. To be precise, the existing literature has not yet simultaneously examined the unilateral cost-sharing and revenue-sharing contract (*CS&RS*) and consolidated rebate and revenue-sharing contract (*CR&RS*) in the study of the FAPs' three-layer e-commerce supply chain coordination issue. These, to a certain extent, motive our research in considering the coordination of such a FAPs' supply chain by new contracts.

In view of the realistic background and theoretical background, we carry out the research presented in this paper. We integrate all the above cases into a new supply chain framework and make the first attempt to study the channel coordination of the complex FAPs' three-layer e-commerce supply chain. That is, we will take into consideration that the demand for FAPs is affected by the safety traceability system availability, the freshness, the unit online selling price, and the random factor, simultaneously, for the first time. And we will take into account the TPLSP's participation in decisions and the fresh produce e-commerce enterprise's home delivery mode, and consider that all decision variables of the supply chain are endogenous, simultaneously. Then on the basis of these, we will describe and characterize the decisions under the different supply chain scenario, and develop the new and different types of channel coordination strategies (*CS&RS; CR&RS*) so as to improve the supply chain performance for the first such endeavor. Our study can help fill the research gap and complement the existing literature by coordinating such a supply chain. It will help provide a better understanding of the optimal decisions of such a particular FAPs' supply chain in different scenarios and the coordination effects of the different types of new proposed contract mechanisms in improving the supply chain performance. Therefore, this will be an interesting topic no matter in the realistic background or the theoretical background.

TABLE 1. Notations.

Parameter	Description
c_M	unit production cost of producer
c_T	unit logistics distribution cost of TPLSP
c_R	unit operating cost of fresh produce e-commerce enterprise
c_F	unit home delivery cost of fresh produce e-commerce enterprise
Q	online ordering quantity of consumers
θ_0	freshness level sensitivity coefficient
a	market potential
b	online selling price elasticity coefficient
ε	random variable affecting market demand
k	sensitivity coefficient affecting safety traceability system availability
λ	marginal effort coefficient
ξ	consumers' sensitivity to safety traceability system availability
δ	consumers' sensitivity to FAPs freshness
$g(e_M)$	safety traceability system availability function
$\theta(e_T)$	freshness function
$C(e_T)$	freshness-keeping cost function
$\prod^c$	total expected profit in centralized system
$\prod^{dc}$	total expected profit in decentralized system
$\prod_R^{dc}$	expected profit of fresh produce e-commerce enterprise in decentralized system
$\prod_T^{dc}$	expected profit of TPLSP in decentralized system
$\prod_M^{dc}$	expected profit of producer in decentralized system
Decision Variable	**Description**
P_M	unit wholesale price of producer
e_M	safety traceability system availability investment of producer
P_T	unit logistics distribution price of TPLSP
e_T	freshness-keeping effort of TPLSP
P_R	unit online selling price of fresh produce e-commerce enterprise

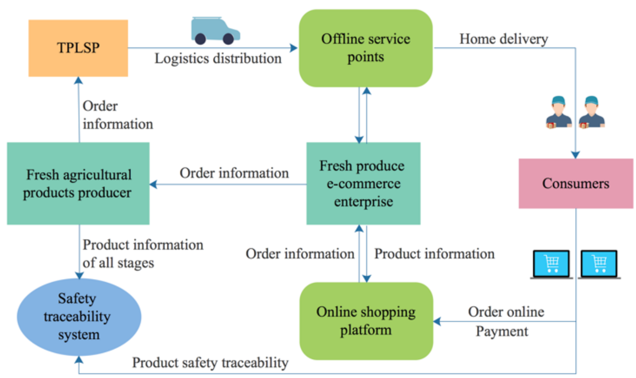

FIGURE 1. FAPs' supply chain under consideration.

III. DECISION MODELS

A. NOTATIONS AND ASSUMPTIONS

Table 1 shows the notations used to develop our models.

We consider a three-layer e-commerce FAPs' supply chain that consists of a producer, a TPLSP and a fresh produce e-commerce enterprise, which is described in Figure 1. The FAPs producer produces the FAPs at a certain cost, which provides a supply function to meet the needs of consumers. Through the e-commerce platform, the fresh produce e-commerce enterprise releases the FAPs information, displays the goods, and answer the questions for the consumers, which provides the consumers with personalized experience. As the end-users, the consumers choose and buy their favorite FAPs at any place, at any time, on the convenient network and the online platforms. When the orders need arise, the fresh produce e-commerce enterprise will feed back the orders information to the FAPs producer in a timely manner. Then, the producer deals with the orders, and distributes the orders to the offline service points of the fresh produce e-commerce enterprise through the professional TPLSP. Finally, the offline service points deliver the FAPs to the consumers' homes. Note that the consumers and supply chain operators can understand the information of the FAPs regularly and timely through the safety traceability system. We denote the unit wholesale price and the unit production cost of the FAPs producer as P_M and c_M, respectively. The variable e_M represents traceability system availability investment. We denote the unit logistics distribution price and unit logistics distribution cost of the TPLSP as P_T and c_T, respectively. The variable e_T represents the cold-chain logistics service level of the TPLSP, which is called the freshness-keeping effort [10]. P_R is the unit online selling price of the fresh produce e-commerce enterprise, c_R is the unit operating cost, and c_F is the unit home delivery cost of the FAPs.

Assume that the demand of the FAPs is online retail price, freshness, and safety traceability system availability sensitive, and subject to random factors. With reference to the additive type demand function, which is widely used in different studies [47]–[52], we assume that the market demand is $Q = a - bP_R + \xi g(e_M) + \delta\theta(e_T) + \varepsilon$. Where a is the market potential, b represents the online selling price elasticity, ξ measures the influence of the producer's safety traceability system availability on demand, and δ denotes the consumers' sensitivity to FAPs' freshness. Safety traceability system availability is affected by the safety traceability system availability investment. Considering that the safety traceability system availability investment has a nonlinear promotion effect on the safety traceability system availability, on the basis of [53], we assume that the function is $g(e_M) = k\sqrt{e_M}$, where k is the sensitivity coefficient affecting safety traceability system availability. Freshness-keeping effort has a certain effect on the freshness of FAPs. Referring to the contract theory, there is a linear relationship between the effort level and the dependent variable, and the multiplicative function form has been made in [10] and [45], so we assume it is of the form $\theta(e_T) = e_T\theta_0$, where θ_0 represents the sensitivity coefficient. ε is a random variable that reflects the fluctuations of the market demand, $\varepsilon \sim N(0, \sigma^2)$. The functional relationship between freshness-keeping cost and freshness-keeping effort is $C(e_T) = \lambda e_T^2/2$, where λ is the freshness-keeping cost coefficient (which is considered in some literature, e.g., [54]–[56]. It is mainly used to describe the nature of costs.

We assume the producer, the TPLSP and the fresh produce e-commerce enterprise are risk-neutral and rational. The three parties make decisions based on the principle of maximizing profits. In the process of games, the information is common knowledge. Taking into account the positive revenue, we assume that $P_R > c_R + c_F + P_M + P_T$. To ensure that the decision variables are all positive, the parameters meet the following conditions $a - b(c_M + c_T + c_R + c_F) > 0$.

B. CENTRALIZED DECISION

A centralized supply chain scenario is considered where the FAPs producer, the TPLSP and the fresh produce e-commerce enterprise are treated as an entity. A single decision maker makes the optimal decisions to maximize the total profit of the whole system. Centralized decision making does not take into account the transfer payments among the three supply chain members. The total expected profit of the FAPs' supply chain is

$$\prod^c = E[(P_R - c_M - c_T - c_R - c_F) \times \left(a - bP_R + \xi k\sqrt{e_M} + \delta e_T\theta_0 + \varepsilon\right)] - e_M - \frac{\lambda e_T^2}{2} \tag{1}$$

Theorem 1: For any given parameters, the optimal unit online selling price, safety traceability system availability investment, and freshness-keeping effort are

$$P_R^{c*} = \frac{2a\lambda + [2b\lambda - \left(\xi^2k^2\lambda + 2\delta^2\theta_0^2\right)](c_M + c_T + c_R + c_F)}{4b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)} \tag{2}$$

$$e_M^{c*} = \frac{\xi^2k^2\lambda^2[a - b(c_M + c_T + c_R + c_F)]^2}{[4b\lambda - \left(\xi^2k^2\lambda + 2\delta^2\theta_0^2\right)]^2} \tag{3}$$

$$e_T^{c*} = \frac{2\delta\theta_0[a - b(c_M + c_T + c_R + c_F)]}{4b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)} \tag{4}$$

Proof of Theorem 1 is provided in Appendix A. Theorem 1 means that in centralized FAPs' supply chain, there are unique optimal unit online selling price, optimal safety traceability system availability investment, and optimal freshness-keeping effort.

According to theorem 1, we substitute P_R^{c*}, e_M^{c*}, and e_T^{c*} $\mathrm{e}_\mathrm{T}^{\mathrm{c}*}$ into Q and Eq. (1), then the optimal online ordering quantity and total expected profit in the centralized system can be obtained as follows:

$$Q^{c*} = \frac{2b\lambda[a - b(c_M + c_T + c_R + c_F)]}{4b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)} \tag{5}$$

$$\prod^{c*} = \frac{[4b\lambda^2 - \left(\xi^2k^2\lambda^2 + 2\lambda\delta^2\theta_0^2\right)][a - b(c_M + c_T + c_R + c_F)]^2}{[4b\lambda - \left(\xi^2k^2\lambda + 2\delta^2\theta_0^2\right)]^2} \tag{6}$$

C. DECENTRALIZED DECISION

A decentralized supply chain is considered in which the FAPs producer, the TPLSP and the fresh produce e-commerce enterprise make their decisions independently and non-cooperatively based on their cost structures and profit forms to maximize their expected profits. The decisions of the three supply chain members are interrelated and mutually influential.

Game sequence: First of all, the FAPs producer makes the first move and determines the unit wholesale price P_M and the safety traceability system availability investment e_M using the response function of the fresh produce e-commerce enterprise. And the TPLSP determines the unit logistics distribution price P_T and the freshness-keeping effort e_T. Finally, the fresh produce e-commerce enterprise reacts to determine the unit online selling price P_R to maximize its own profit.

1) OPTIMAL DECISIONS OF THE FRESH PRODUCE E-COMMERCE ENTERPRISE

The expected profit function of fresh produce e-commerce enterprise is

$$\prod\nolimits_R^{dc} = E[(P_R - P_M - P_T - c_R - c_F) \times \left(a - bP_R + \xi k\sqrt{e}_M + \delta e_T\theta_0 + \varepsilon\right)] \tag{7}$$

Lemma 1: For any given parameters, the optimal unit online selling price is

$$P_R^{dc^*}(P_M, e_M, P_T, e_T) = \frac{a + \xi k\sqrt{e}_M + \delta e_T\theta_0 + b\,(P_M + P_T + c_R + c_F)}{2b} \tag{8}$$

Proof of Lemma 1 is provided in Appendix B. Lemma 1 describes the optimal online selling price decision for the fresh produce e-commerce enterprise, which can be employed to maximize its own profit in decentralized supply chain without a contract.

2) OPTIMAL DECISIONS OF THE TPLSP

The expected profit function of the TPLSP is

$$\prod\nolimits_T^{dc} = E[(P_T - c_T) \times \left(a - bP_R + \xi k\sqrt{e}_M + \delta e_T\theta_0 + \varepsilon\right)] - \frac{\lambda e_T^2}{2} \tag{9}$$

Substituting Eq. (8) into Eq. (9), we have

$$\prod\nolimits_T^{dc} = \frac{(P_T - c_T)\,[a + \xi k\sqrt{e}_M + \delta e_T\theta_0 - b\,(P_M + P_T + c_R + c_F)]}{2} - \frac{\lambda e_T^2}{2} \tag{10}$$

Lemma 2: The optimal unit logistics distribution price and optimal freshness-keeping effort are

$$P_T^{dc^*}(P_M, e_M, e_T) = \frac{a + \xi k\sqrt{e}_M + \delta e_T\theta_0 - b\,(P_M + c_R + c_F - c_T)}{2b} \tag{11}$$

$$e_T^{dc^*}(P_T) = \frac{(P_T - c_T)\,\delta\theta_0}{2\lambda} \tag{12}$$

Proof of Lemma 2 is provided in Appendix C. Lemma 2 portrays the optimal decisions of the TPLSP.

3) OPTIMAL DECISIONS OF THE PRODUCER

The expected profit function of the producer is

$$\prod\nolimits_M^{dc} = E[(P_M - c_M)\left(a - bP_R + \xi k\sqrt{e}_M + \delta e_T\theta_0 + \varepsilon\right)] - e_M \tag{13}$$

Substituting Eq. (8) into Eq. (13), we have

$$\prod\nolimits_M^{dc} = \frac{(P_M - c_M)\,[a + \xi k\sqrt{e}_M + \delta e_T\theta_0 - b\,(P_M + P_T + c_R + c_F)]}{2} - e_M \tag{14}$$

Lemma 3: The optimal unit wholesale price and optimal safety traceability system availability investment are

$$P_M^{dc^*}(P_T, e_T, e_M) = \frac{a + \xi k\sqrt{e}_M + \delta e_T\theta_0 - b\,(P_T + c_R + c_F - c_M)}{2b} \tag{15}$$

$$e_M^{dc^*}(P_M) = \frac{(P_M - c_M)^2\,\xi^2 k^2}{16} \tag{16}$$

Proof of Lemma 3 is provided in Appendix D. Lemma 3 presents the optimal decisions of the FAPs producer.

From Lemma 1, Lemma 2 and Lemma 3, we can find that the decisions of each decentralized supply chain member are directly or indirectly influenced by the decisions of other supply chain members. The optimal unit online selling price is positively influenced by the decisions of the TPLSP' unit logistics distribution price and freshness-keeping effort and the decisions of the producer' unit wholesale price and safety traceability system availability investment. TPLSP' unit logistics distribution price decision is not only positively influenced by its own freshness-keeping effort, but also positively influenced by the producer' safety traceability system availability investment decision and negatively influenced by the unit wholesale price decision. The freshness-keeping effort decision of the TPLSP is influenced by the unit logistics distribution price decision while the safety traceability system availability investment of the FAPs producer is influenced by the unit wholesale price. In addition to being positively influenced by its safety traceability system availability investment decision, unit wholesale price decision for the FAPs producer is also subject to the positive impact of the freshness-keeping effort and the negative impact of the unit logistics distribution price decision from TPLSP. Then what is the optimal equilibrium solution? By Lemma 1, Lemma 2 and Lemma 3, we have the following observations.

Theorem 2: The optimal equilibrium decisions in the decentralized FAPs' supply chain are

$$P_M^{dc^*} = \frac{4\lambda\,[a + b\,(2c_M - c_T - c_R - c_F)] - \left(\xi^2k^2\lambda + 2\delta^2\theta_0^2\right)c_M}{12\mathrm{b}\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)} \tag{17}$$

$$e_M^{dc^*} = \frac{\xi^2k^2\lambda^2\,[a - b\,(c_M + c_T + c_R + c_F)]^2}{\left[12\mathrm{b}\lambda - \left(\xi^2k^2\lambda + 2\delta^2\theta_0^2\right)\right]^2} \tag{18}$$

TABLE 2. Optimal decisions and profits.

	Centralized system	Decentralized system
P_M	/	$\frac{4\lambda[a+b(2c_M-c_T-c_R-c_F)]-(\xi^2k^2\lambda+2\delta^2\theta_0^2)c_M}{12b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)}$
e_M	$\frac{\xi^2k^2\lambda^2[a-b(c_M+c_T+c_R+c_F)]^2}{[4b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)]^2}$	$\frac{\xi^2k^2\lambda^2[a-b(c_M+c_T+c_R+c_F)]^2}{[12b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)]^2}$
P_T	/	$\frac{4\lambda[a+b(2c_T-c_M-c_R-c_F)]-(\xi^2k^2\lambda+2\delta^2\theta_0^2)c_T}{12b\lambda-(\xi^2\lambda+2\delta^2\theta_0^2)}$
e_T	$\frac{2\delta\theta_0[a-b(c_M+c_T+c_R+c_F)]}{4b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)}$	$\frac{2\delta\theta_0[a-b(c_M+c_T+c_R+c_F)]}{12b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)}$
P_R	$\frac{2a\lambda+[2b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)](c_M+c_T+c_R+c_F)}{4b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)}$	$\frac{10a\lambda+[2b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)](c_M+c_T+c_R+c_F)}{12b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)}$
Q	$\frac{2b\lambda[a-b(c_M+c_T+c_R+c_F)]}{4b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)}$	$\frac{2b\lambda[a-b(c_M+c_T+c_R+c_F)]}{12b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)}$
$\prod_M$	/	$\frac{(8b-\xi^2k^2)\lambda^2[a-b(c_M+c_T+c_R+c_F)]^2}{[12b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)]^2}$
$\prod_T$	/	$\frac{(8b\lambda^2-2\lambda\delta^2\theta_0^2)[a-b(c_M+c_T+c_R+c_F)]^2}{[12b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)]^2}$
$\prod_R$	/	$\frac{4b\lambda^2[a-b(c_M+c_T+c_R+c_F)]^2}{[12b\lambda-(\xi^2\lambda+2\delta^2\theta_0^2)]^2}$
$\prod$	$\frac{[4b\lambda^2-(\xi^2k^2\lambda^2+2\lambda\delta^2\theta_0^2)][a-b(c_M+c_T+c_R+c_F)]^2}{[4b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)]^2}$	$\frac{[20b\lambda^2-(\xi^2k^2\lambda^2+2\lambda\delta^2\theta_0^2)][a-b(c_M+c_T+c_R+c_F)]^2}{[12b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)]^2}$

$$P_T^{dc*} = \frac{4\lambda\left[a+b\left(2c_T-c_M-c_R-c_F\right)\right]-\left(\xi^2k^2\lambda+2\delta^2\theta_0^2\right)c_T}{12b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)} \tag{19}$$

$$e_T^{dc*} = \frac{2\delta\theta_0\left[a-b\left(c_M+c_T+c_R+c_F\right)\right]}{12b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)} \tag{20}$$

$$P_R^{dc*} = \frac{10a\lambda+[2b\lambda-\left(\xi^2k^2\lambda+2\delta^2\theta_0^2\right)]\left(c_M+c_T+c_R+c_F\right)}{12b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)} \tag{21}$$

Proof of Theorem 2 is provided in Appendix E. Theorem 2 shows the optimal equilibrium decisions in the decentralized FAPs' supply chain, which enable the three supply chain members to maximize their own profits.

According to the Theorem 2, we substitute Eq. (17)- (21) into Eq. (7), Eq. (9) and Eq. (13), the optimal expected profits of the fresh produce e-commerce enterprise, the TPLSP and the FAPs producer in the decentralized system are obtained:

$$\prod\nolimits_M^{dc*} = \frac{(8b-\xi^2k^2)\lambda^2\left[a-b\left(c_M+c_T+c_R+c_F\right)\right]^2}{\left[12b\lambda-\left(\xi^2k^2\lambda+2\delta^2\theta_0^2\right)\right]^2} \tag{22}$$

$$\prod\nolimits_T^{dc*} = \frac{(8b\lambda^2-2\lambda\delta^2\theta_0^2)\left[a-b\left(c_M+c_T+c_R+c_F\right)\right]^2}{\left[12b\lambda-\left(\xi^2k^2\lambda+2\delta^2\theta_0^2\right)\right]^2} \tag{23}$$

$$\prod\nolimits_R^{dc*} = \frac{4b\lambda^2\left[a-b\left(c_M+c_T+c_R+c_F\right)\right]^2}{\left[12b\lambda-\left(\xi^2k^2\lambda+2\delta^2\theta_0^2\right)\right]^2} \tag{24}$$

And, the optimal online ordering quantity and total expected profit in the decentralized system are derived:

$$Q^{dc*} = \frac{2b\lambda[a-b\left(c_M+c_T+c_R+c_F\right)]}{12b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)} \tag{25}$$

$$\prod\nolimits^{dc*} = \frac{[20b\lambda^2-\left(\xi^2k^2\lambda^2+2\lambda\delta^2\theta_0^2\right)][a-b(c_M+c_T+c_R+c_F)]^2}{[12b\lambda-\left(\xi^2k^2\lambda+2\delta^2\theta_0^2\right)]^2} \tag{26}$$

4) COMPARISON OF CENTRALIZED AND DECENTRALIZED DECISIONS

Table 2 shows the optimal decisions and profits of the centralized and decentralized FAPs' supply chain systems.

A few observations with respect to the above results are in order.

Proposition 1: e_M^i, e_T^i, P_R^i, Q^i and $\prod^i$ are increasing functions of ξ and δ, but decreasing functions of b and λ. Where $i = c, dc$.

Proof of Proposition 1 is provided in Appendix F.

Proposition 1 reveals that when there is a higher consumers' sensitivity to safety traceability system availability and FAPs' freshness, the safety traceability system availability investment and the freshness-keeping effort will be promoted. At this point, because consumers have a lower preference for prices, then the fresh produce e-commerce enterprise will properly raise the online selling price. As the online selling price is not as far-reaching as the impact of the safety traceability system availability investment and the freshness-keeping effort on the order volume, then ultimately led to an increase in the overall supply chain profits. When the market is more sensitive to the online selling price, the channels will lower the online selling price to increase online ordering quantities. At the moment, because the market sensitivity to the safety traceability system availability and the FAPs freshness does not change, the system will further increase profits by reducing the safety traceability system availability investment and the freshness-keeping effort. However, as the reduction of the safety traceability system availability investment and the freshness-keeping effort has reduced the market demand, the final system profits have been relatively reduced. When freshness-keeping costs are more sensitive to the freshness-keeping effort, both the centralized and decentralized channels will reduce the freshness-keeping effort due to the increased cost. Meanwhile, the channels will decrease the safety traceability system availability investment and reduce the online selling price so as to enhance the corresponding profit. However, the lower freshness-keeping effort will lead to a lower product freshness and further lead to a decrease in the FAPs' market demand. And the decrease of profits caused by the decline of freshness-keeping effort and the decrease of the safety traceability system availability investment is much larger than the increase of the profits caused by the increase of the online selling price. Then there will be a corresponding decline in total supply chain expected profits.

Proposition 2:

(1) $e_M^{dc^*} < e_M^{c*}$; $e_T^{dc^*} < e_T^{c*}$.

(2) When $\xi^2k^2\lambda + 2\delta^2\theta_0^2 < 2b\lambda$, $P_R^{dc^*} > P_R^{c*}$; When $2b\lambda < \xi^2k^2\lambda + 2\delta^2\theta_0^2 < 4b\lambda$, $P_R^{dc^*} < P_R^{c*}$.

(3) $Q^{dc*} < Q^{c^*}$; $\prod^{dc*} < \prod^{c*}$.

Proof of Proposition 2 is provided in Appendix G.

Proposition 2 further validates the double marginalization caused by decentralized decision-making mode. However, there's a novel finding: When $\xi^2k^2\lambda+2\delta^2\theta_0^2 < 2b\lambda$, the optimal unit online selling price in the decentralized system is higher than that in the centralized system. When $2b\lambda < \xi^2k^2\lambda+2\delta^2\theta_0^2 < 4b\lambda$, the optimal unit online selling price in the decentralized system is less than that in the centralized system. This shows that under the different constraints of the supply chain parameters, the optimal pricing decisions of fresh produce e-commerce enterprise in the decentralized supply chain are different. Under certain condition, it is higher than the centralized situation; whereas under another condition, it may be lower than the centralized situation. This is different from the pricing of the decentralized decision deduced in most literature, which is generally higher than that of the centralized decision. Therefore, the fresh produce e-commerce enterprise should make the optimal price decision higher or lower than the centralized situation according to different market parameters. However, centralized supply chains seem to be more profitable, regardless of how the three supply chain members make decisions.

Therefore, it is necessary to design the corresponding contracts to coordinate the decentralized FAPs' supply chain to improve its performance and efficiency. In the next section, we will investigate several new and different types of contract policies in the coordination of the decentralized FAPs supply chain.

IV. COORDINATION MODELS

According to the above propositions, when the supply chain channel increases the safety traceability system availability investment and promotes the freshness-keeping effort, the profit of the supply chain members will be damaged because of the rising cost. In addition, given that revenue sharing contract plays an important role in supply chain incentives [25], we consider to design the revenue sharing contract for the incentive compensation, and consider to share the safety traceability system availability investment and the freshness-keeping cost to stimulate the motivation of the supply chain channel members. When the members of the supply chain strictly abide by the decentralized quoted price, the rebate contract can optimize the profit of the two-layer supply chain to a certain extent [17]. With this in mind, we first try to realize the coordination of the fresh produce three-layer e-commerce supply chain channel by combining the rebate contract with the revenue sharing.

In this section, two new and different types of contracts namely unilateral cost-sharing and revenue-sharing contract (*CS&RS*); consolidated rebate and revenue-sharing contract (*CR&RS*) are developed for the FAPs' supply chain coordination. Accordingly, we develop two contract coordination models. Firstly, the *CS&RS* contract is designed when the producer and the TPLSP may not have enough motivation to increase safety traceability system availability investment and improve freshness-keeping effort, respectively. Secondly, the*CR&RS* contract is developed under the scenario that the producer, the TPLSP and the fresh produce e-commerce enterprise strictly keep their quoted prices in line with the prices of the decentralized system. In the last sub-section of this section, the implementation of the contracts is further discussed.

A. UNILATERAL COST-SHARING AND REVENUE-SHARING CONTRACT STRATEGY

Idea of this proposed contract: The producer and the TPLSP provide the higher safety traceability system availability investment and freshness-keeping effort can increase the FAPs market demand and further increase the profit of the fresh produce e-commerce enterprise. However, this will reduce the profits of the producer and the TPLSP relatively. If the fresh produce e-commerce enterprise is willing to compensate their loss by providing a fraction of its own revenues and sharing a certain proportion of their costs and enable them to obtain more profits, then it will encourage them to do that. On the other hand, if the produce e-commerce enterprise provides the optimal unit online selling price of the centralized, its own profits will be relatively reduced. If the producer and the TPLSP is willing to reduce their unit wholesale price and unit logistics distribution price as compensation for the produce e-commerce enterprise, then it will motivate the fresh produce e-commerce enterprise to do that.

Game sequence: First, the producer, the TPLSP and the fresh produce e-commerce enterprise jointly determine the *CS&RS* contract. The producer and TPLSP quote the unit wholesale price P_M and unit logistics distribution price P_T. The fresh produce e-commerce enterprise determines the investment costs and freshness-keeping costs share coefficients η_1, η_2, and the revenue share contract coefficients ω_1, ω_2. Then the producer determines the safety traceability system availability investment e_M, and the TPLSP determines the freshness-keeping effort e_T. Finally, on the basis of the safety traceability system availability investment e_M and the freshness-keeping effort e_T, the fresh produce e-commerce enterprise determines the unit online selling price P_R.

From what we have described above, it can be obtained the expected profit functions of the three supply chain members as follows:

$$\prod_M^{cs} = E[(P_M - c_M)\left(a - bP_R + \xi k\sqrt{e_M} + \delta e_T\theta_0 + \varepsilon\right)] - \eta_1 e_M + \omega_1 E[P_R \times \left(a - bP_R + \xi k\sqrt{e_M} + \delta e_T\theta_0 + \varepsilon\right)] \tag{27}$$

$$\prod_T^{cs} = E[(P_T - c_T)\left(a - bP_R + \xi k\sqrt{e_M} + \delta e_T\theta_0 + \varepsilon\right)] - \frac{\eta_2\lambda e_T^2}{2} + \omega_2 E[P_R \times \left(a - bP_R + \xi k\sqrt{e_M} + \delta e_T\theta_0 + \varepsilon\right)] \tag{28}$$

$$\prod_R^{cs} = E\left[(1-\omega_1-\omega_2)P_R - P_M - P_T - c_R - c_F\right] \times \left(a - bP_R + \xi k\sqrt{e_M} + \delta e_T\theta_0 + \varepsilon\right) - (1-\eta_1)e_M - \frac{(1-\eta_2)\lambda e_T^2}{2} \tag{29}$$

Theorem 3: Under the CS&RS contract, for any given the unit wholesale price P_M, the safety traceability system availability investment e_M, the unit logistics distribution price P_T, the freshness-keeping effort e_T, the unilateral cost share ratios η_1, η_2 and revenue share coefficients ω_1, ω_2, the optimal unit online selling price is

$$P_R^{cs^*} = \frac{(1-\omega_1-\omega_2)[a+\xi k\sqrt{e_M}+\delta e_T\theta_0]+b\,(P_M+P_T+c_R+c_F)}{2b\,(1-\omega_1-\omega_2)} \tag{30}$$

Proof of Theorem 3 is provided in Appendix H. Theorem 3 describes the optimal online selling price decision of the fresh produce e-commerce enterprise under the proposed contract. According to the Theorem 3, we derive the following Theorems.

Theorem 4:The optimal freshness-keeping effort is

$$e_T^{cs^*} = \frac{(P_T - c_T)\,b\delta\theta_0 + \omega_2\delta\theta_0(a + \xi k\sqrt{e_M})}{2b\eta_2\lambda - \omega_2\delta^2\theta_0^2} \tag{31}$$

Proof of Theorem 4 is provided in Appendix I.

Theorem 5: The optimal safety traceability system availability investment is

$$e_M^{cs^*} = \frac{(P_M - c_M)\,b\xi k + \omega_1\xi k(a + \delta e_T\theta_0)}{4b\eta_1 - \omega_1\xi^2k^2} \tag{32}$$

Proof of Theorem 5 is provided in Appendix J.

Theorems 4 and 5 respectively present the optimal safety traceability system availability investment and freshness-keeping effort for the producer and the TPLSP to maximize their own profits under this proposed contract. Iterative solving the Eq. (31) and Eq. (32), we derive the specific expressions of $e_M^{cs^*}$ and $e_T^{cs^*}$ as (33) and (34), shown at the bottom of this page.

On the basis of the Theorem 1, Theorem 3-5 and the above expression, the following Propositions can be derived.

Proposition 3: If the contract parameters are satisfied by $(1-\omega_1-\omega_2)(c_M+c_T+c_R+c_F) = P_M + P_T + c_R + c_F$, $\eta_1 = \omega_1$, $\eta_2 = \omega_2$, $\eta_1\eta_2 = 1/2b$, $(P_T - c_T)(4b\eta_1 - \omega_1\xi^2k^2) + \omega_2\xi^2k^2(P_M - c_M) = -2(c_M + c_T + c_R + c_F)$, and $(P_M - c_M)\left(2b\eta_2\lambda - \omega_2\delta^2\theta_0^2\right) + \omega_1\delta^2\theta_0^2(P_T - c_T) = -\lambda(c_M + c_T + c_R + c_F)$, then $\prod_M^{cs*} + \prod_T^{cs*} + \prod_R^{cs*} = \prod^{c*}$ can be achieved.

Proof of Proposition 3 is provided in Appendix K.

Proposition 3 indicates that the decentralized supply chain can achieve the profit level of the centralized supply chain when the contract coefficients satisfy these contract conditions. In this case, the overall performance of the FAPs' supply chain system is improved.

Proposition 4. *If the contract parameters are satisfied by proposition 3, (P1), and (P2) where*

$$\omega_1 \geq \frac{(8b - \xi^2k^2)[4b\lambda - \left(\xi^2k^2\lambda + 2\delta^2\theta_0^2\right)]^2}{(4b - \xi^2k^2)[12b\lambda - \left(\xi^2k^2\lambda + 2\delta^2\theta_0^2\right)]^2}, \tag{P1}$$

$$\omega_2 \geq \frac{(8b\lambda - 2\delta^2\theta_0^2)[4b\lambda - \left(\xi^2k^2\lambda + 2\delta^2\theta_0^2\right)]^2}{(4b\lambda - 2\delta^2\theta_0^2)[12b\lambda - \left(\xi^2k^2\lambda + 2\delta^2\theta_0^2\right)]^2}, \tag{P2}$$

and (P3) as shown at the top of the next page, the decentralized FAPs' supply chain can be coordinated and Pareto improvement can be achieved.

Proof of Proposition 4 is provided in Appendix L.

Proposition 4 indicates that the *CR&RS* contract can perfectly coordinate this FAPs' supply chain and achieve the Pareto improvement of the three supply chain members. This means that the profits of each supply chain member are improved compared with the decentralized FAPs' supply chain without a contract. A win-win situation emerged for all supply chain members. In addition, from Proposition 3 and Proposition 4, one can see that $-c_R - c_F \leq P_M + P_T \leq$

$$e_T^{cs^*} = \frac{[b\,(P_T - c_T) + \omega_2 a]\,\delta\theta_0\left(4b\eta_1 - \omega_1\xi^2k^2\right) + \omega_2\delta\theta_0\xi^2k^2[b\,(P_M - c_M) + \omega_1 a]}{8b^2\eta_1\eta_2 - 2b\eta_2\omega_1\xi^2k^2\lambda - 4b\eta_1\omega_2\delta^2\theta_0^2} \tag{33}$$

$$e_M^{cs^*} = \left\{\frac{[b\,(P_M - c_M) + \omega_1 a]\,\xi k\left(2b\eta_2\lambda - \omega_2\delta^2\theta_0^2\right) + \omega_1\xi k\delta^2\theta_0^2\,[b\,(P_T - c_T) + \omega_2 a]}{8b^2\eta_1\eta_2 - 2b\eta_2\omega_1\xi^2k^2\lambda - 4b\eta_1\omega_2\delta^2\theta_0^2}\right\}^2 \tag{34}$$

$$\left(4b\lambda-\xi^2k^2\lambda\right)\omega_1+\left(4b\lambda-2\delta^2\theta_0^2\right)\omega_2 \le \frac{\left(4b\lambda-2\delta^2\theta_0^2-\xi^2k^2\lambda\right)\left[12b\lambda-\left(\xi^2k^2\lambda+2\delta^2\theta_0^2\right)\right]^2-4b\lambda[4b\lambda-\left(\xi^2k^2\lambda+2\delta^2\theta_0^2\right)]^2}{[12b\lambda-\left(\xi^2k^2\lambda+2\delta^2\theta_0^2\right)]^2}, \tag{P3}$$

$c_M + c_T$, due to $0 \le (1-\omega_1-\omega_2) \le 1$. This means the *CR&RS* contract can not only motivate the producer and TPLSP to increase safety traceability system availability investment and improve the freshness-keeping effort, but also motivate them to reduce their quotations. From this contract, we can also find that $\eta_1 = \omega_1$, $\eta_2 = \omega_2$, and $\eta_1\eta_2 = 1/2b$. That means that, under this proposed contract, the contribution rates of both the producer and the TPLSP to the safety traceability system availability investment and the freshness-keeping effort are always equal to the rates of return. In the process of unilaterally motivating the producer and the TPLSP, to who incentivizes more, the fresh produce e-commerce enterprise needs to combine specific case to undertake specific analysis. If the producer and the TPLSP can get extra profits, they will be willing to accept the proposed contract. This is enough to see the important incentive role of the proposed contract.

B. CONSOLIDATED REBATE AND REVENUE-SHARING CONTRACT STRATEGY

Idea of this proposed contract: The producer offers the rebate $\emptyset_1$ and the safety traceability system availability investment e_M, and the TPLSP offers the rebate $\emptyset_2$ and the freshness-keeping effort e_T. This will bring more FAPs online ordering quantities and make the fresh produce e-commerce enterprise more profitable but reduce the profits of the producer and the TPLSP. If the fresh produce e-commerce enterprise provides extra compensation for them by sharing a portion of his revenues and entices them to obtain extra profits than before, then it will be acceptable for the producer and the TPLSP.

Game sequence: First, the producer announces the unit wholesale price P_M and the safety traceability system availability investment e_M, and the TPLSP announces the unit logistics distribution price P_T and the freshness-keeping effort e_T. Then, based on the unit wholesale price P_M, the safety traceability system availability investment e_M, the unit logistics distribution price P_T and the freshness-keeping effort e_T, the fresh produce e-commerce enterprise announces the unit online selling price P_R. Third, the three supply chain members jointly determine the *CR&RS* contract. The producer determines the rebate $\emptyset_1$ and the safety traceability system availability investment e_M, and the TPLSP determines the rebate $\emptyset_2$ and the freshness-keeping effort e_T. On the basis of the rebate $\emptyset_1$, the safety traceability system availability investment e_M, the rebate $\emptyset_2$ and the freshness-keeping effort e_T, the fresh produce e-commerce enterprise determines the revenue share coefficients ω_1, ω_2.

According to the above description, we get the expected profit functions of the producer, the TPLSP and the fresh produce e-commerce enterprise as follows:

$$\begin{aligned}\prod\nolimits_M^{rc} &= E\left(P_M-c_M-\emptyset_1\right)\left[a-b(P_R-\emptyset_1-\emptyset_2)\right.\\&\quad\left.+\xi k\sqrt{e_M}+\delta e_T\theta_0+\varepsilon\right]\}-e_M\\&\quad+\omega_1E\{P_R[a-b(P_R-\emptyset_1-\emptyset_2)\\&\quad+\xi k\sqrt{e_M}+\delta e_T\theta_0+\varepsilon]\}\end{aligned} \tag{35}$$

$$\begin{aligned}\prod\nolimits_T^{rc} &= E\{(P_T-c_T-\emptyset_1)[a-b(P_R-\emptyset_1-\emptyset_2)\\&\quad+\xi k\sqrt{e_M}+\delta e_T\theta_0+\varepsilon]\}-\frac{\lambda e_T^2}{2}\\&\quad+\omega_2E\{[(1-\omega_1-\omega_2)P_R-P_M-P_T-c_R-c_F]\\&\quad\times[a-b(P_R-\emptyset_1-\emptyset_2)+\xi k\sqrt{e_M}+\delta e_T\theta_0+\varepsilon]\}\end{aligned} \tag{36}$$

$$\begin{aligned}\prod\nolimits_R^{rc} &= E\left[(1-\omega_1-\omega_2)P_R-P_M-P_T-c_R-c_F\right]\\&\quad\times\left[a-b(P_R-\emptyset_1-\emptyset_2)\right.\\&\quad\left.+\xi k\sqrt{e_M}+\delta e_T\theta_0+\varepsilon\right]\}\end{aligned} \tag{37}$$

Based on the above, we can derive the following Proposition.

Proposition 5: The FAPs' supply chain can be coordinated and Pareto improvement of profits of the three channel members can be achieved with the contract parameters satisfying (P4)–(P7), as shown at the top of the next page. Among them, $\tau = \left(\xi^2k^2\lambda+2\delta^2\theta_0^2\right)$ *and* $\upsilon = c_M+c_T+c_R+c_F$.

Proof of Proposition 5 is provided in Appendix M.

Proposition 5 implies that the *CR&RS* contract can coordinate the supply chain and make the supply chain channel members get more profits than that without the *CR&RS* contract. Under this contract, the producer and the TPLSP undertake the safety traceability system availability investment and freshness-keeping effort, and provide the consolidated rebate, which improve the supply chain performance and bring more profits to the fresh produce e-commerce enterprise. But who should carry out more rebate, which requires the producer to negotiate well with the TPLSP. It can be found that, for the producer and the TPLSP, when either side of them implements more rebate, the minimum income compensation rate from the fresh produce e-commerce enterprise will be increased accordingly. Then, by sharing the revenues with them, the fresh produce e-commerce enterprise makes the three supply chain parties profit together. Therefore, the three supply chain members will have enough motivation to accept this contract.

$$\emptyset_1 + \emptyset_2 = \frac{16ab\lambda^2 - 8b\lambda(2b\lambda-\tau)\upsilon - 8a\lambda\tau}{(12b\lambda-\tau)(4b\lambda-\tau)}, \tag{P4}$$

$$\omega_1 \geq \frac{12b\lambda-\tau}{10a\lambda+(2b\lambda-\tau)\upsilon}\left\{\frac{[-64b^2\lambda^2-\xi^2k^2\lambda^2(2b\lambda-\tau)](a-b\upsilon)}{2b(12b\lambda-\tau)^2}+\frac{\xi^2k^2\lambda^2(a-b\upsilon)}{2b(4b\lambda-\tau)}+\emptyset_1\right\}, \tag{P5}$$

$$\omega_2 \geq \frac{12b\lambda-\tau}{10a\lambda+[2b\lambda-\tau]\upsilon}\left\{\frac{[-64b^2\lambda^2-2\delta^2\theta_0^2(4b\lambda-\tau)](a-b\upsilon)}{2b(12b\lambda-\tau)^2}+\frac{2\delta^2\theta_0^2(a-b\upsilon)}{b(4b\lambda-\tau)}+\emptyset_2\right\}, \tag{P6}$$

$$\omega_1+\omega_2 \leq 1-\left\{\frac{2\lambda(a-b\upsilon)(4b\lambda-\tau)}{(12b\lambda-\tau)\,[10a\lambda+(2b\lambda-\tau)\upsilon]}+\frac{8a\lambda+(4b\lambda-\tau)\upsilon}{10a\lambda+(2b\lambda-\tau)\upsilon}\right\} \tag{P7}$$

C. FURTHER DISCUSSION OF THE COORDINATION CONTRACTS

In this sub-section, we further discuss the implementation of the contracts. Note that the difference between the profit after the coordination of the supply chain and the profit before the coordination of the supply chain is $\frac{64b^2\lambda^3[a-b(c_M+c_T+c_R+c_F)]^2}{[4b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)][12b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)]^2}$. Its value increases with the increase of ξ, and δ, respectively, and decreases with the increase of b (The Proofs are provided in Appendix N). This means that when consumers in the e-commerce market are more sensitive to the FAPs freshness and the safety traceability system availability, the profit difference between after and before the coordination will become greater. Then, the supply chain members are relatively easier to accept the contracts, and supply chain is relatively easier to coordinate. Whereas when the consumers in the e-commerce market are more sensitive to the online selling price of FAPs, the profit difference between after and before the coordination will become smaller. At this point, the supply chain members are relatively less liable to accept the contracts, and the supply chain is relatively difficult to coordinate. Therefore, when the channel members are planning to carry out a negotiation contract, a comprehensive survey should be made on the e-commerce market environment of the FAPs to clarify the main driving factors of the consumers market so as to facilitate the better implementation of the contracts. Besides, in the above, we give the scope of implementation of the contract parameters. As for the specific parameter values, it depends on the negotiation ability of the supply chain members. In the real supply chain, those who are in the dominant position and have stronger bargaining power are often more likely to get more incremental profits. However, in order to promote the long-term cooperation and cooperative development of the party with the weaker negotiating ability, the party in a strong position should make the concession appropriately. Within the scope of maintaining Pareto's improved contractual parameters, the supply chain members with stronger negotiating power should give the relatively weak supply chain members more profit sharing. Only in this way can other supply chain members be more motivated to integrate closely with it, cooperate sincerely and develop in the long run. And only in this way can the implementation of the contracts has a more far-reaching impact.

In addition, from the above derived formulas, one can find that the profit margin that can be optimized is an increasing function of market potential (It is easy to observe from the formulas derived above, so the proof is omitted). This indicates that while achieving the efficiency and performance of the centralized FAPs supply chain system through the contract coordination policies, it is also necessary for the decentralized supply chain members to work more closely together to explore the market potential imperceptibly. The means, such as WeChat, mobile APP, news media, Internet micro-blogs, FAPs e-commerce platform, can be used as information tools to develop the potential market, cultivate the market.

Overall, the development of the society and the change of consumers' consumption concept have led to more and more individualized demand for higher freshness and safety of FAPs, especially under the FAPs e-commerce environment. As aforementioned proposition, this is beneficial to the FAPs' supply chain, because it can promote the profits of the supply chain. Whereas the double marginalization effect often makes decentralized supply chain lose many benefits. It seems very necessary to optimize the decentralized supply chain decisions and profits. As the effective means of supply chain coordination, the contract mechanisms are very meaningful. Through the implementation of the new proposed contracts, the supply chain profits can be improved significantly, the supply chain integration can be further promoted [57], and the supply chain members will be brought together to move forward in closer collaboration. It is important to note, however, that the ease with which supply chain is coordinated, and the ease with which contract is enforced, are closely related to market preferences. When implementing the proposed contracts, the supply chain members should adjust measures to local conditions.

V. NUMERICAL EXAMPLES

In the above sections, we theoretically reason and compare the differences of the FAPs' supply chains under different scenarios, demonstrate the impact of the correlation coefficients on the decisions and supply chain profits, and develop two new contract strategies (the *CS&RS* contract and the *CR&RS* contract) to coordinate this decentralized FAPs' supply chain. In order to further clearly show its internal principles and examine the effect of various relevant factors on the production and operations decisions and the profits of the three

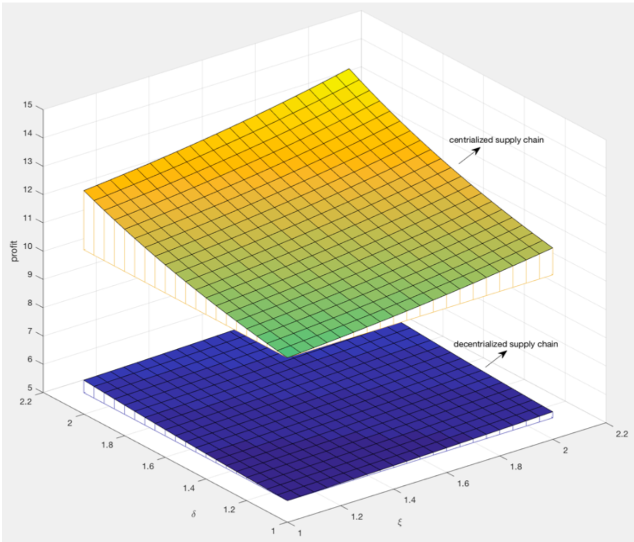

FIGURE 2. The effect of ξ and δ on FAPs' supply chain profit.

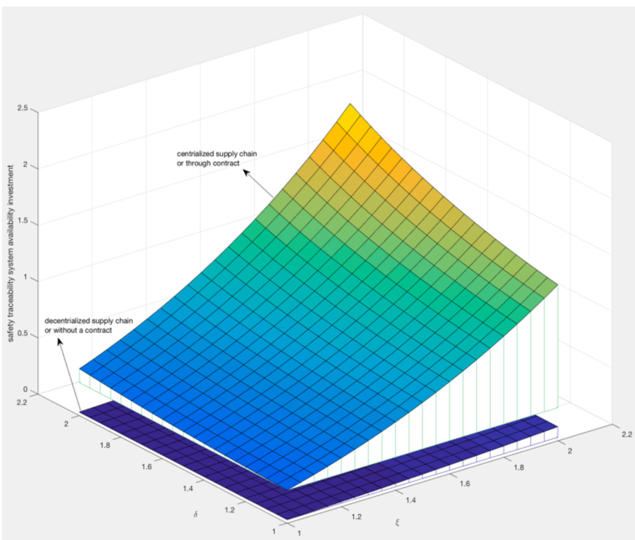

FIGURE 3. The effect of ξ and δ on safety traceability system availability investment.

supply chain members in the real world, the numerical examples are provided in this section.

From the above, it can be seen that $a - b(c_M + c_T + c_R + c_F) > 0$, $\xi^2 k^2 < 4b$ and $2(\delta^2\theta_0^2 - 2b\lambda) + \xi^2 k^2 \lambda < 0$. In order to ensure that our research is within the feasible region, we specify that the market potential a as 100, the price-elasticity of the market demand b as 10, the sensitivity coefficient affecting safety traceability system availability k as 1, the producer's unit production cost c_M as 3, the sensitivity coefficient affecting the freshness level θ_0 as 1, the TPLSP's unit logistics distribution cost c_T as 2, the fresh produce e-commerce enterprise's unit operating cost c_R as 1.5, the unit FAPs home delivery cost c_F as 1.5, the freshness-keeping cost coefficient λ as 1, and the random variable $\varepsilon \sim N(0, 10^2)$. And the corresponding results are shown in Fig. 2-9.

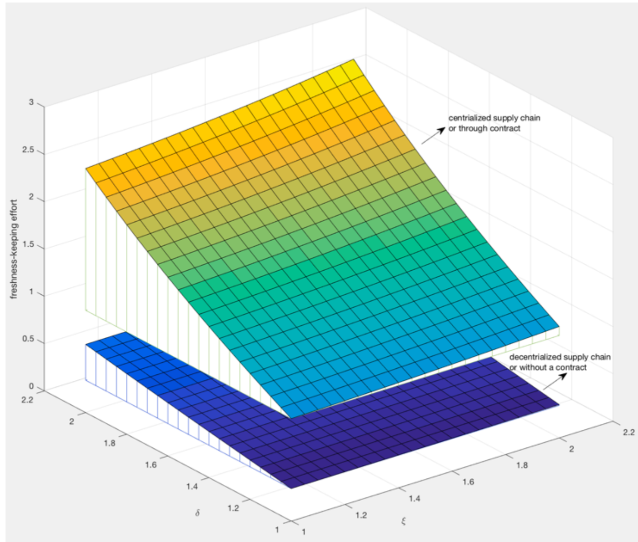

FIGURE 4. The effect of ξ and δ on freshness-keeping effort.

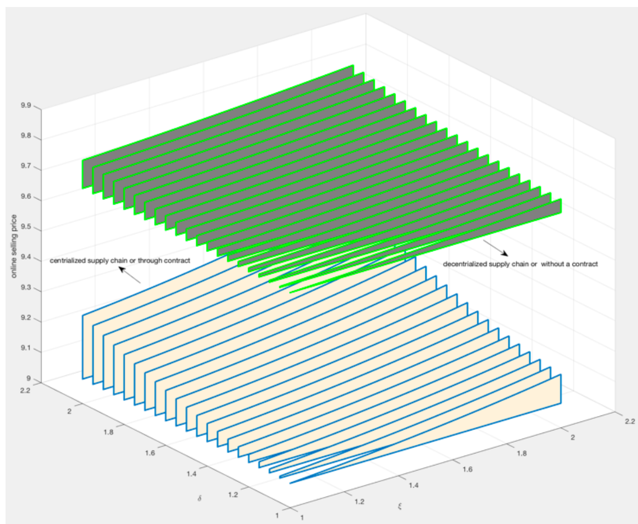

FIGURE 5. The effect of ξ and δ on online selling price.

From Fig. 2, it can be seen that the profits of the centralized and decentralized FAPs' supply chain are proportional to the consumers' sensitivity to safety traceability system availability and freshness level. It means that if consumers are more sensitive to safety traceability system availability and freshness level, the profits of the FAPs' supply chain will increase by improving the safety traceability system availability investment and freshness-keeping effort. However, the safety traceability system availability investment and the freshness-keeping effort in the decentralized FAPs' supply chain is less than that in the centralized FAPs' supply chain because of the decentralized decisions and channel conflict (Fig. 3 and Fig. 4). And the online selling price in the decentralized system is larger than that in the centralized system (Fig. 5). The lower safety traceability system availability investment and lower freshness-keeping effort reduce the FAPs' safety traceability and freshness level, the higher

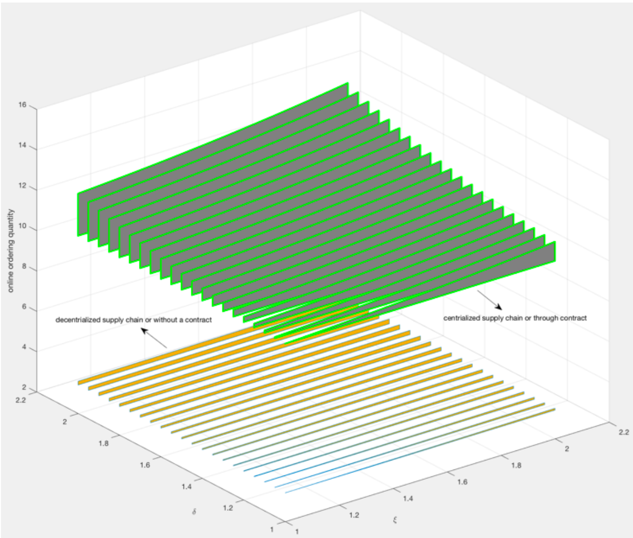

FIGURE 6. The effect of ξ and δ on online ordering quantity.

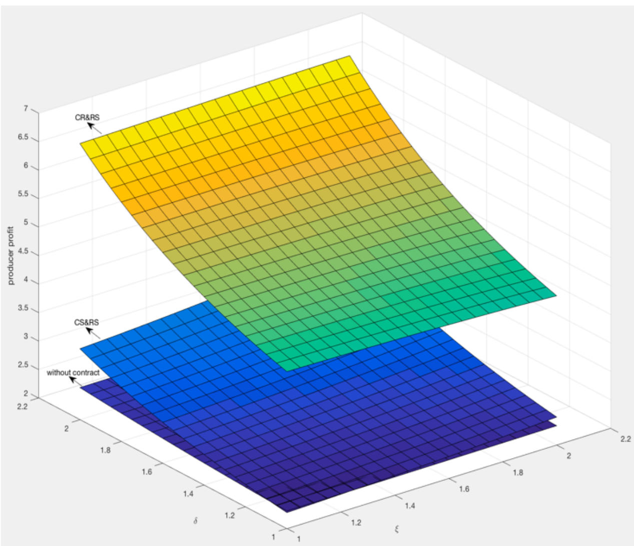

FIGURE 7. The effect of ξ and δ on producer's profit.

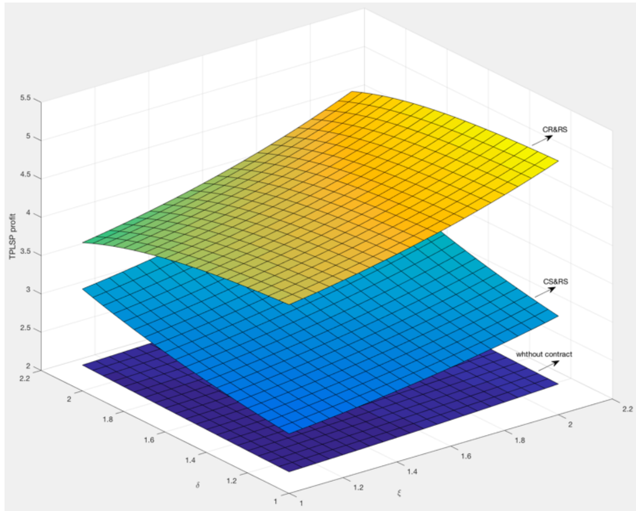

FIGURE 8. The effect of ξ and δ on TPLSP's profit.

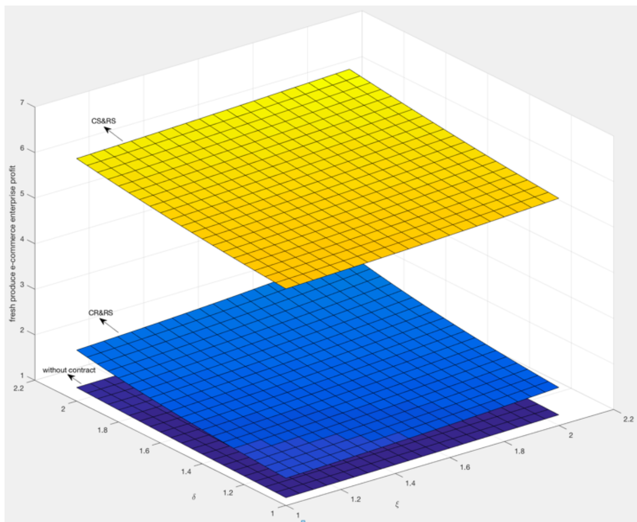

FIGURE 9. The effect of ξ and δ on fresh produce e-commerce enterprise's profit.

online selling price reduces the consumers' consumption enthusiasm, and then further affect the market demand of FAPs (Fig. 6), clearly resulting in the profit in the decentralized FAPs' supply chain is less than that in the centralized FAPs' supply chain (Fig. 2). Through the *CS&RS* contract and the *CR&RS* contract among the three FAPs' supply chain members, the safety traceability system availability investment and the freshness-keeping effort are enhanced (Fig. 3 and Fig. 4), the online selling price is cut down (Fig. 5), the online ordering quantity is increased (Fig. 6), the performance of the supply chain is improved (Fig. 2), and the profits of producer, TPLSP and fresh produce e-commerce enterprise are raised respectively (Fig. 7, Fig. 8 and Fig. 9). It's interesting to find that the two new proposed coordination contracts play an important role in improving the safety degree and freshness level of FAPs, eliminating the channel conflict, increasing the overall profit of the FAPs' supply chain, and enhancing the profits of the three supply chain members.

When comparing the results in the Fig. 3 and Fig. 4, we also find that although consumers' sensitivity to safety traceability system availability and freshness have positive effects on safety traceability system availability investment and freshness-keeping effort respectively, the consumers' sensitivity to safety traceability system availability has a greater positive effect on safety traceability system availability investment but less positive effect on freshness-keeping effort. Similarly, the consumers' sensitivity to freshness has a greater positive effect on freshness-keeping effort but less positive effect on safety traceability system availability investment. It illustrates that the more sensitive the consumer is to safety traceability system availability, the more it can motivate the FAPs' supply chain members to increase safety traceability system availability investment, and the more sensitive the consumer is to the freshness, the more it can motivate the FAPs' supply chain members to improve freshness-keeping effort.

Fig. 7, Fig. 8 and Fig. 9 reveal that compared with the decentralized scenario without a contract, the two different types of new contracts bring more profit to the supply chain participants. Under the two contracts, the profit of each channel member in the decentralized channel is no less than that in the decentralized channel without the contracts. Pareto improvement is achieved. Meanwhile, as can be seen from Fig. 7-9, under the *CS&RS* contract, the profit of each supply chain member increases with the increase of ξ and δ. However, under the *CR&RS* contract, the profit of the producer increases as δ increases and decreases as ξ increases; the profit of the TPLSP decreases as δ increases and increases as ξ increases; whereas the profit of the fresh produce e-commerce enterprise has an increasing trend with the increase of ξ and δ. It indicates that under the *CS&RS* contract, when consumers are more sensitive to safety traceability system availability and freshness, *CS&RS* contract can make the three supply chain members obtain more additional profits. Therefore, when drawing up *CS&RS* contracts, the three channel members should expand the influence of the freshness and the safety traceability system availability, which can not only help improve the overall performance of the supply chain, but also make them benefit separately. Under the *CR&RS* contract, when consumers are more sensitive to the freshness, the producer can obtain more additional profit increments, but when consumers are more sensitive to safety traceability system availability, the profit increments of producer will be reduced. This is because the increased consumers' sensitivity to safety traceability system availability has stimulated the producer to invest more in safety traceability system availability, resulting in a relative increase in its own cost. Then the additional incremental profits generated by the producer are relatively reduced. For the TPLSP, it can gain more additional profit growth when consumers are more sensitive to safety traceability system availability, but less profit growth when consumers are more sensitive to freshness. This is because that the increased freshness sensitivity has stimulated the TPLSP's efforts for keeping the FAPs freshness. As a result, the freshness-keeping cost is relatively increased, thus the extra incremental profit gained by producers is relatively reduced. Therefore, for both the producer and the logistics provider, while improving their own investment structure or fresh-keeping efficiency, they should cultivate customer loyalty from the perspective of market impact of each other, which can directly or indirectly increase their own profits. For the fresh produce e-commerce enterprise, the effect of *CR&RS* contract and *CS&RS* contract is similar. When consumers are more sensitive to freshness and safety traceability system availability, the fresh produce e-commerce enterprise can obtain relatively more additional profits. This also indicates that the fresh produce e-commerce enterprise should improve the FAPs' safety traceability and freshness awareness, so as to make it more profitable. Note that the optimal profit difference between the centralized supply chain and the decentralized supply chain increases gradually with the two coefficients. Therefore, when the two coefficients are larger, the members of the supply chain will have the possibility to obtain more incremental profits through contract coordination. At this point, the two proposed contracts will be more easily implemented and the supply chain will be more easily coordinated. But in any case, under the two contracts, the profits of each member of the three supply chains achieve Pareto improvement. The results also explain the reason why the producer, TPLSP and fresh produce e-commerce enterprise would cooperate with each other so as to benefit more from the two new contract mechanisms.

In summary, although the decentralized decision leads to lower product safety traceability system availability and freshness level, and lower supply chain profits, the decentralized supply chain can be coordinated by the *CR&RS* contract and the *CS&RS* contracts. When FAPs safety traceability and quality are more valued, the fresh produce e-commerce supply chain members should invest more capital in these aspects on the original basis, which is beneficial to them, not only for the short term economic performance, but also for the long term economic performance. Through the reasonable implementation of these proposed new contracts, the total profit of the supply chain can be promoted, the Pareto improvement of the channel members can be realized, and the FAPs safety traceability and quality are also better guaranteed. Therefore, the two new coordination contracts are of great significance for improving the production and operation performance of FAPs' e-commerce supply chains.

VI. CONCLUDING REMARKES

In addition to the online selling price, whether the safety of fresh produce can be traced and whether the fresh produce is fresh are increasingly valued by people, especially in the e-commerce environment. In FAPs' e-commerce supply chain production and operation, should supply chain members invest more money to establish quality traceability system and put more efforts into good fresh preservation? What are the optimal decisions of the channel members in this case? How to design reasonable incentive mechanisms to coordinate the supply chain so as to maximize channel profits? All these are not only related to the consumers' consumption safety, but also related to the interests of the channel members, and the long-term development of the whole supply chain.

In this paper, we have explored the decision and coordination of the FAPs' three-layer e-commerce supply chain in a new framework. The main contributions of this paper are summarized as follows:

1) Due to the lack of literature on the decision and coordination of this FAPs' e-commerce supply chain presented in this paper, in order to fill the research gap, we make the first attempt to consider a new and innovative FAPs supply chain framework. On the basis of the new FAPs e-commerce supply chain framework, the new models are developed. One highlight of the models is taking the safety traceability system availability investment as a new decision variable, especially

characterizing the impact of multiple factors on the product demand. Another highlight of this research is proposing two new contract mechanisms, i.e., the unilateral cost-sharing and revenue-sharing contract, and the consolidated rebate and revenue-sharing contract, for the FAPs' supply chain coordination. In addition, the five decision variables, i.e., the unit wholesale price, the safety traceability system availability investment, the unit logistics distribution price, the freshness-keeping effort and the unit online selling price in this research are all endogenous variables, which also makes the decision and coordination situation more complicated. All of these are significantly different from the previous studies.

2) The optimal decisions of the three supply chain members and the optimal profits of the supply chain system have been portrayed. In particular, we analyze the impact of consumers' sensitivities to the safety traceability system availability, the freshness, the online selling price, and the marginal effort coefficient on the supply chain decisions and profits.

3) Two new contracts (*CS&RS* contract and *CR&RS* contract) are designed to coordinate the decentralized FAPs' three-layer e-commerce supply chain. And we also have made a further discussion about the impact of the market preferences on the implementation of the proposed contracts. As one of the highlights of our research, it also helps to further promote the development of the contract theory in the application of the FAPs' e-commerce supply chain management.

4) Numerical experiments are carried out to help further better understand the theoretical results and show the application of our research in the real FAPs' supply chain world.

We find that as compared with the centralized system, the optimal safety traceability system availability investment, freshness-keeping effort, online ordering quantity and total expected profit in the decentralized system are lower; whereas the optimal unit online selling price depends on the corresponding parameter conditions. Thus, we draw a conclusion that the centralized decision scenario is always optimal. In addition, we find that the two new contract mechanisms (*CS&RS* contract and *CR&RS*contract) can improve the safety traceability system availability investment and freshness-keeping effort, maximize the profit of the decentralized FAPs' supply chain, and enable the three channel participants to make additional profits in comparison to decentralized FAPs' supply chain without the two contract mechanisms. Thus, another conclusion can be drawn that the two new contracts proposed can perfectly coordinate this supply chain. Besides, we find that the profits of the FAPs' supply chain are positively correlated with the safety traceability system availability coefficient and the freshness level coefficient, but negatively correlated with the online selling price coefficient and the marginal effort coefficient. Finally, we find that when consumers are more sensitive to the safety traceability system availability and the freshness, the two proposed contract policies are easier to implement and the supply chain is easier to coordinate; however, when consumers are more sensitive to the online selling price, the two proposed contract policies are relatively difficult to implement and the supply chain is not easy to coordinate.

Our findings convey many interesting managerial implications. Effective FAPs' e-commerce supply chain management is not only crucial to the development of the enterprise at the micro level, but also to the development of the supply chain at the middle level, as well as to the development of the social safe consumption at the macro level. From the perspective of the enterprises, profits are what members of the supply chain have been pursuing. Naturally, how to balance cost and self-profit to make the optimal decision has always been what they need to think about repeatedly. Our results can provide a reference for enterprises in safety traceability system investment, freshness-keeping effort and various pricing decisions, in order to better balance the costs and the profits. From the perspective of the overall FAPs' supply chain, we have proposed two different types of new contracts and study the impact of the market preferences on the implementation of the proposed contracts. Under different circumstances, the supply chain node enterprises can coordinate their interests by adjusting the contract parameters appropriately. The deep-seated reason behind many factors of supply chain imbalance is that each member enterprise in the supply chain is independent and lacks cooperation. Through reasonable implementation of these contracts, the supply chain node enterprises will cooperate more closely. It also helps to promote long-term maintenance of supply chain partnership, which will make the supply chain more competitive, cooperative and strategic. From the perspective of the society and consumers, through close cooperation, these three channel members can jointly make active efforts to improve the safety of the FAPs. It is of great significance to the development of product safety traceability. This will not only provide necessary support for the harmonious development of the society, but also make consumers more comfortable with the consumption of FAPs. When the utility of society and consumers is well reflected, it will, in turn, promote the development of the three supply chain enterprises and the development of the whole supply chain. At that time, supply chain performance will continue to move forward through the interplay of the internal elements.

Although this paper provides some insightful results and managerial implications, still it has some limits and there are several interesting yet challenging topics worthy of further study. In this paper, we only study the FAPs' supply chain coordination under the additive non-linear demand function, and do not discuss other demand functions, such as the multiplicative demand function [41], and the iso-elastic demand function [17], which makes the adaptability of the models have some limitations. In the further work, we will explore other types of demand functions and examine the suitable contract coordination mechanisms. In addition, this paper merely explores the case of complete information, so there is an interesting topic that is to consider the incomplete information dynamic game, so there is an interesting topic that is to consider the complete information static game, incomplete information static game, and incomplete information dynamic game scenarios [58]. Besides, in our models, we only consider one supply chain structure. However, in the real FAPs supply chain, there are more complex supply chain structures, such as considering the consumer decision-making and the homogeneous supply chain members competition. Then, another interesting topic is to study the coordination issues under the different FAPs' supply chain structures [9], [59].

APPENDIX A

Proof of Theorem 1. We differentiate $\prod^c$ with respect to P_R, e_M and e_T. $\frac{\partial \prod^c}{\partial P_R} = -2bP_R + a + \xi k\sqrt{e_M} + \delta e_T\theta_0 + b(c_M + c_T + c_R + c_F)]$, $\frac{\partial^2 \prod^c}{\partial P_R^2} = -2b < 0$. $\frac{\partial \prod^c}{\partial e_M} = \frac{(P_R-c_M-c_T-c_R-c_F)\xi k}{2\sqrt{e_M}} - 1$, $\frac{\partial^2 \prod^c}{\partial e_M^2} = -\frac{(P_R-c_M-c_T-c_R-c_F)\xi k}{4\sqrt{e_M^3}} < 0$, $\frac{\partial \prod^c}{\partial e_T} = (P_R - c_M - c_T - c_R - c_F)\,\delta\theta_0 - \lambda e$, $\frac{\partial^2 \prod^c}{\partial e_T^2} = -\lambda < 0$. The Hessian matrix of $\prod^c$ is

$$H\left(\prod^c\right) = \begin{bmatrix} -2b & \frac{\xi k}{2\sqrt{e_M}} & \delta\theta_0 \\ \frac{\xi k}{2\sqrt{e_M}} & -\frac{(P_R-c_M-c_T-c_R-c_F)\xi k}{4\sqrt{e_M^3}} & 0 \\ \delta\theta_0 & 0 & -\lambda \end{bmatrix}$$

The K-order principal minor∗(-1) ^k > 0 when $\xi^2k^2 < 4b$, $2(\delta^2\theta_0^2 - 2b\lambda)+\xi^2k^2\lambda < 0$. Then $\prod^c$ is the concave function of P_R, e_M and e_T. In this case we obtain the unique optimal values of P_R, e_M and e_T: $P_R^*(e_M, e_T) = \frac{a+\xi k\sqrt{e_M}+\delta e_T\theta_0+b(c_M+c_T+c_R+c_F)}{2b}$, $e_M^*(P_R) = \frac{\xi^2k^2(P_R-c_M-c_T-c_R-c_F)^2}{4}$, $e_T^*(P_R) = \frac{\delta\theta_0(P_R-c_M-c_T-c_R-c_F)}{\lambda}$. Solving the Equations, we derive Equations (2), (3) and (4).

APPENDIX B

Proof of Lemma 1. Taking the first derivative and second derivative of Eq. (7) with respect to P_R, we get $\frac{\partial \prod_R^{dc}}{\partial P_R} = -2bP_R + a + \xi k\sqrt{e_M} + \delta e_T\theta_0 + b(P_M + P_T + c_R + c_F)$, $\frac{\partial^2 \prod_R^{dc}}{\partial P_R^2} < 0$, which is concave to P_R. Solving $\frac{\partial \prod_R^{dc}}{\partial P_R} = 0$, we derive Eq. (8).

APPENDIX C

Proof of Lemma 2. In order to get the optimal unit logistics distribution price and freshness-keeping effort, we differentiate $\prod_T^{dc}$ with respect to P_T and e_T. $\frac{\partial \prod_T^{dc}}{\partial P_T} = \frac{1}{2}[a + \xi k\sqrt{e_M} + \delta e_T\theta_0 - b(P_M + c_R + c_F - c_T) - 2bP_T]$, $\frac{\partial^2 \prod_T^{dc}}{\partial p_T^2} = -b < 0$. $\frac{\partial \prod_T^{dc}}{e_T} = \frac{1}{2}\delta\theta_0(P_T - c_T) - 2\lambda e$, $\frac{\partial^2 \prod_T^{dc}}{\partial e_T^2} = -2\lambda < 0$. The Hessian matrix of $\prod_T^{dc}$ is

$$H\left(\prod_T^{dc}\right) = \begin{bmatrix} -b & \frac{\delta\theta_0}{2} \\ \frac{\delta\theta_0}{2} & -\lambda \end{bmatrix}$$

The K-order principal minor∗(-1) ^k >0 when $\delta^2\theta_0^2 < 4b\lambda$. In like manner, we derive Eq. (11) and Eq. (12).

APPENDIX D

Proof of Lemma 3. In order to obtain the optimal unit wholesale price and safety traceability system availability investment, we differentiate $\prod_M^{dc}$ with respect to P_M and e_M. $\frac{\partial \prod_M^{dc}}{\partial P_M} = \frac{1}{2}[a + \xi k\sqrt{e_M} + \delta e_T\theta_0 - b(P_T + c_R + c_F - c_M) - 2bP_M]$, $\frac{\partial^2 \prod_M^{dc}}{\partial p_M^2} = -b < 0$. $\frac{\partial \prod_M^{dc}}{e_M} = \frac{\xi k(P_M-c_M)}{4\sqrt{e_M}} - 1$, $\frac{\partial^2 \prod_M^{dc}}{\partial e_M^2} = -\frac{\xi k(P_M-c_M)}{8\sqrt{e_M^3}} < 0$. The Hessian matrix of $\prod_M^{dc}$ is

$$H\left(\prod_M^{dc}\right) = \begin{bmatrix} -b & \frac{\xi k}{4\sqrt{e_M}} \\ \frac{\xi k}{4\sqrt{e_M}} & -\frac{\xi k\,(P_M - c_M)}{8\sqrt{e_M^3}} \end{bmatrix}$$

The K-order principal minor∗(-1) ^k >0 when $\xi^2k^2 < 8b$. Then Eq. (15) and Eq. (16) can be obtained.

APPENDIX E

Proof of Theorem 2. Solving the equations consisting of Eq. (11), Eq. (12), Eq. (15) and Eq. (16), we can derive the equations

$$P_M^{dc*} = \frac{4\lambda\,[a+b\,(2c_M-c_T-c_R-c_F)] - \left(\xi^2k^2\lambda+2\delta^2\theta_0^2\right)c_M}{12b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)},$$

$$e_M^{dc*} = \frac{\xi^2k^2\lambda^2\,[a - b\upsilon]^2}{\left[12b\lambda - \left(\xi^2k^2\lambda + 2\delta^2\theta_0^2\right)\right]^2},$$

$$P_T^{dc*} = \frac{4\lambda\,[a+b\,(2c_T-c_M-c_R-c_F)] - \left(\xi^2k^2\lambda+2\delta^2\theta_0^2\right)c_T}{12b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)}$$

and

$$e_T^{dc*} = \frac{2\delta\theta_0\,[a - b\upsilon]}{12b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)}.$$

Substituting them into Eq. (8), and then we obtain $P_R^{dc*} = \frac{10a\lambda+[2b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)]\upsilon}{12b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)}$.

APPENDIX F

Proof of Proposition 1. Differentiating $e_M^{c*}, e_T^{c*}, P_R^{c*}, Q^{c*}, \prod^{c*}$, $e_M^{dc*}, e_T^{dc*}, P_R^{dc*}, Q^{dc*}$ and $\prod^{dc*}$ with respect to the ξ, δ, b and λ, we obtain the following formulas, i.e., (F1)-(F19) as shown at the top of the next page and (F20), as shown at the top of page 18, that is, they are the increasing function with respect to ξ and δ. (F21)–(F23) as shown at the top of page 18. As $\xi^2k^2\lambda + 2\delta^2\theta_0^2 < 4b\lambda$, we obtain $2\lambda(\xi^2k^2\lambda + 2\delta^2\theta_0^2)\,(c_M + c_T + c_R + c_F) < 4b\lambda(c_M + c_T + c_R + c_F)$. Meanwhile, because $a - b(c_M + c_T + c_R + c_F)$, we derive the numerator is less than 0, thus $\frac{\partial P_R^{c*}}{\partial b} < 0$.

$$\frac{\partial Q^{c*}}{\partial b} = \frac{-8b^2\lambda^2\upsilon + 2\lambda(\xi^2k^2\lambda + 2\delta^2\theta_0^2)[2b\upsilon - a]}{\left[4b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)\right]^2}. \quad \text{(F24)}$$

Since $2\lambda(\xi^2k^2\lambda + 2\delta^2\theta_0^2) < 8b\lambda^2$, we have $2\lambda(\xi^2k^2\lambda + 2\delta^2\theta_0^2)[2b(c_M + c_T + c_R + c_F) - a] < 8b\lambda^2[2b(c_M + c_T + c_R + c_F) - a]$, then the numerator is less

$$\frac{\partial e_M^{c*}}{\partial \xi} = \frac{[a-b\upsilon]^2\{2\xi^3k^3\lambda^3 + 2\xi k\lambda^2[4b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]\}}{[4b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^3} > 0, \tag{F1}$$

$$\frac{\partial e_T^{c*}}{\partial \xi} = \frac{4\xi k\lambda\delta\theta_0[a-b\upsilon]}{[4b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^2} > 0, \tag{F2}$$

$$\frac{\partial P_R^{c*}}{\partial \xi} = \frac{4[a-b\upsilon]\xi k^2\lambda^2}{[4b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^2} > 0, \tag{F3}$$

$$\frac{\partial Q^{c*}}{\partial \xi} = \frac{4b\xi k\lambda^2[a-b\upsilon]}{[4b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^2} > 0, \tag{F4}$$

$$\frac{\partial \prod^{c*}}{\partial \xi} = \frac{2\lambda^2\xi k\,[a-b\upsilon]^2}{[4b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^2} > 0, \tag{F5}$$

$$\frac{\partial e_M^{c*}}{\partial \delta} = \frac{4\delta\theta_0^2\xi^2k^2\lambda^2[a-b\upsilon]^2}{[4b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^3} > 0, \tag{F6}$$

$$\frac{\partial e_T^{c*}}{\partial \delta} = \frac{2\theta_0[a-b\upsilon](4b\lambda - \xi^2k^2\lambda + 2\delta^2\theta_0^2)}{[4b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^2} > 0, \tag{F7}$$

$$\frac{\partial P_R^{c*}}{\partial \delta} = \frac{8[a-b\upsilon]\lambda\delta^2\theta_0^2}{[4b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^2} > 0, \tag{F8}$$

$$\frac{\partial Q^{c*}}{\partial \delta} = \frac{8b\lambda\delta\theta_0^2[a-b\upsilon]}{[4b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^2} > 0, \tag{F9}$$

$$\frac{\partial \prod^{c*}}{\partial \delta} = \frac{2\lambda\delta\theta_0^2\,[a-b\upsilon]^2}{[4b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^2} > 0, \tag{F10}$$

$$\frac{\partial e_M^{dc*}}{\partial \xi} = \frac{[a-b\upsilon]^2\{2\xi^3k^3\lambda^3 + 2\xi k\lambda^2[4b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]\}}{[12b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^3} > 0, \tag{F11}$$

$$\frac{\partial e_T^{dc*}}{\partial \xi} = \frac{4\xi k\lambda\delta\theta_0[a-b\upsilon]}{[12b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^2} > 0, \tag{F12}$$

$$\frac{\partial P_R^{dc*}}{\partial \xi} = \frac{20[a-b\upsilon]\xi k^2\lambda^2}{[12b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^2} > 0, \tag{F13}$$

$$\frac{\partial Q^{dc*}}{\partial \xi} = \frac{4b\xi k\lambda^2[a-b\upsilon]}{[12b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^2} > 0, \tag{F14}$$

$$\frac{\partial \prod^{dc*}}{\partial \xi} = \frac{\{2\xi k\lambda^2[12b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)] + 4\xi k\lambda^2[20b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]\}\,[a-b\upsilon]^2}{[12b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^3} > 0, \tag{F15}$$

$$\frac{\partial e_M^{dc*}}{\partial \delta} = \frac{4\delta\theta_0^2\xi^2k^2\lambda^2[a-b\upsilon]^2}{[12b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^3} > 0, \tag{F16}$$

$$\frac{\partial e_T^{dc*}}{\partial \delta} = \frac{2\theta_0[a-b\upsilon](4b\lambda - \xi^2k^2\lambda + 2\delta^2\theta_0^2)}{[12b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^2} > 0, \tag{F17}$$

$$\frac{\partial P_R^{dc*}}{\partial \delta} = \frac{40[a-b\upsilon]\lambda\delta^2\theta_0^2}{[12b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^2} > 0, \tag{F18}$$

$$\frac{\partial Q^{dc*}}{\partial \delta} = \frac{8b\lambda\delta\theta_0^2[a-b\upsilon]}{[12b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^2} > 0 \tag{F19}$$

$$\frac{\partial \prod^{dc*}}{\partial \delta} = \frac{\{4\lambda\delta\theta_0^2[12b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)] + 4\lambda\delta\theta_0^2[20b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]\}\,[a - b\upsilon]^2}{[12b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^3} > 0, \tag{F20}$$

$$\frac{\partial e_M^{c*}}{\partial b} = \frac{-2\xi^2k^2\lambda\upsilon\,[a - b\upsilon]\left[4b\lambda - \left(\xi^2k^2\lambda + 2\delta^2\theta_0^2\right)\right] - 8\xi^2k^2\lambda^2[a - b\upsilon]^2}{[4b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^3} < 0, \tag{F21}$$

$$\frac{\partial e_T^{c*}}{\partial b} = \frac{-2\delta\theta_0\upsilon\left[4b\lambda - \left(\xi^2k^2\lambda + 2\delta^2\theta_0^2\right)\right] - 8\delta\theta_0\lambda(4b - \xi^2k^2)[a - b\upsilon]}{[4b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^2} < 0, \tag{F22}$$

$$\frac{\partial P_R^{c*}}{\partial b} = \frac{2\lambda\left(\xi^2k^2\lambda + 2\delta^2\theta_0^2\right)\upsilon - 8a\lambda^2}{[4b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^2}. \tag{F23}$$

$$\frac{\partial \prod^{c*}}{\partial b} = \frac{-2\lambda\,[a - b\upsilon]\,\{\upsilon + 2\lambda\,[a - b\upsilon]\}}{[4b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^3} < 0, \tag{F25}$$

$$\frac{\partial e_M^{dc*}}{\partial b} = \frac{-2\xi^2k^2\lambda\upsilon\,[a - b\upsilon]\left[12b\lambda - \left(\xi^2k^2\lambda + 2\delta^2\theta_0^2\right)\right] - 24\xi^2k^2\lambda^2[a - b\upsilon]^2}{[12b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^3} < 0, \tag{F26}$$

$$\frac{\partial e_T^{dc*}}{\partial b} = \frac{-2\delta\theta_0\upsilon\left[12b\lambda - \left(\xi^2k^2\lambda + 2\delta^2\theta_0^2\right)\right] - 24\delta\theta_0\lambda(4b - \xi^2k^2)[a - b\upsilon]}{[12b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^2} < 0, \tag{F27}$$

$$\frac{\partial P_R^{dc*}}{\partial b} = \frac{10\lambda\left(\xi^2k^2\lambda + 2\delta^2\theta_0^2\right)\upsilon - 10a\lambda^2}{[12b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^2} < 0. \tag{F28}$$

$$\frac{\partial Q^{dc*}}{\partial b} = \frac{-24b^2\lambda^2\upsilon + 2\lambda(\xi^2k^2\lambda + 2\delta^2\theta_0^2)[2b\upsilon - a]}{[12b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^2} < 0. \tag{F29}$$

$$\begin{aligned}\frac{\partial \prod^{dc*}}{\partial b} = &-\frac{\lambda^2[240b\lambda - \left(\xi^2k^2\lambda + 2\delta^2\theta_0^2\right)]\,[a - b\upsilon]^2}{[12b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^3} \\ &-\frac{2\upsilon\,[a - b\upsilon]\left[20b\lambda^2 - \left(\xi^2k^2\lambda^2 + 2\lambda\delta^2\theta_0^2\right)\right][12b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]}{[12b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^3}.\end{aligned} \tag{F30}$$

$$\frac{\partial e_M^{c*}}{\partial \lambda} = \frac{-4\xi^2k^2\lambda\,[a - b\upsilon]^2\,\delta^2\theta_0^2}{[4b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^3} < 0, \tag{F31}$$

$$\frac{\partial e_T^{c*}}{\partial \lambda} = \frac{-\delta\theta_0[a - b\upsilon](4b - \xi^2k^2)}{[4b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^2} < 0, \tag{F32}$$

$$\frac{\partial P_R^{c*}}{\partial \lambda} = \frac{-4\delta^2\theta_0^2[a - b\upsilon]}{[4b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^2} < 0, \tag{F33}$$

$$\frac{\partial Q^{c*}}{\partial \lambda} = \frac{-2b\delta^2\theta_0^2[a - b\upsilon]}{[4b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^2} < 0, \tag{F34}$$

$$\frac{\partial \prod^{c*}}{\partial \lambda} = \frac{-2\delta^2k^2\theta_0^2[a - b\upsilon]}{[12b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^2} < 0, \tag{F35}$$

$$\frac{\partial e_M^{dc*}}{\partial \lambda} = \frac{-4\xi^2k^2\lambda\,[a - b\upsilon]^2\,\delta^2\theta_0^2}{[12b\lambda - (\xi^2k^2\lambda + 2\delta^2\theta_0^2)]^3} < 0, \tag{F36}$$

$$\frac{\partial e_T^{dc*}}{\partial \lambda} = \frac{-\delta\theta_0[a-b\upsilon](12b-\xi^2k^2)}{[12b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)]^2} < 0, \tag{F37}$$

$$\frac{\partial P_R^{dc*}}{\partial \lambda} = \frac{-10\delta^2\theta_0^2[a-b\upsilon]}{[4b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)]^2} < 0, \tag{F38}$$

$$\frac{\partial Q^{dc*}}{\partial \lambda} = \frac{-2b\delta^2\theta_0^2[a-b\upsilon]}{[12b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)]^2} < 0, \tag{F39}$$

$$\frac{\partial \prod^{dc*}}{\partial \lambda} = \frac{\{\lambda(20b-\xi^2k^2)[12b\lambda-\tau]-\lambda(24b-2\xi^2k^2)[20b\lambda-\tau)]\}[a-b\upsilon]^2}{[12b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)]^3}. \tag{F40}$$

than $8b\lambda^2[b(c_M+c_T+c_R+c_F)-a]$. Therefore, $\frac{\partial Q^{c*}}{\partial b}<0$. (F25)–(F30) as shown at the top of the previous page. The first term is less than 0 and the second term is less than 0, thus we derive $\frac{\partial \prod^{dc*}}{\partial b}<0$. Similarly, (F31)–(F36) as shown at the bottom of the previous page and (F37)–(F40) as shown at the top of this page. Because $\xi^2k^2<4b$, so $\lambda\left(20b-\xi^2k^2\right)<\lambda(24b-2\xi^2k^2)$. Besides, because $12b\lambda-\left(\xi^2k^2\lambda+2\delta^2\theta_0^2\right)<20b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)$, therefore, $\frac{\partial \prod dc*}{\partial \lambda}<0$. That means they are the increasing function with respect to λ. Where $\tau=\left(\xi^2k^2\lambda+2\delta^2\theta_0^2\right)$ and $\upsilon=c_M+c_T+c_R+c_F$. Therefore, the Proposition 1 can be derived.

APPENDIX G

Proof of Proposition 2. We derive that $\frac{e_M^{dc*}}{e_M^*}=\frac{[4b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)]^2}{[12b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)]^2}$. The numerator is smaller than the denominator, then it can be got $e_M^{dc*}<e_M^*$. By the same token, we get that $\frac{e_T^{dc*}}{e_T^*}=\frac{4b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)}{12b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)}<1$, $\frac{Q^{dc*}}{Q^*}=\frac{4b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)}{12b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)}<1$. Then we drive that $e_T^{dc*}<e_T^*$, $Q^{dc*}<Q^*$. We get equation (G1),

$$P_R^{dc*}-P_R^* = \frac{8\lambda[2b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)][a-b(c_M+c_T+c_R+c_F)]}{[12b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)][4b\lambda-(\xi^2k^2\lambda+2\delta^2\theta_0^2)]}, \tag{G1}$$

then, we obtain that when $\xi^2k^2\lambda+2\delta^2\theta_0^2<2b\lambda$, $P_R^{dc*}>P_R^{c*}$; When $2b\lambda<\xi^2k^2\lambda+2\delta^2\theta_0^2<4b\lambda$, $P_R^{dc*}<P_R^{c*}$. Similarly, it can be obtained (G2).

$$\frac{\prod^{dc*}}{\prod^{c*}} = \frac{80b^2\lambda^2+\left(\xi^2k^2\lambda+2\delta^2\theta_0^2\right)^2-24b\lambda\left(\xi^2k^2\lambda+2\delta^2\theta_0^2\right)}{144b^2\lambda^2+\left(\xi^2k^2\lambda+2\delta^2\theta_0^2\right)^2-24b\lambda\left(\xi^2k^2\lambda+2\delta^2\theta_0^2\right)} < 1 \tag{G2}$$

and then $\prod^{dc*}<\prod^{c*}$ can be reasoned out.

APPENDIX H

Proof of Theorem 3. According to dynamic game theory, the optimal unit online selling price can be gained by using backward induction. We differentiate $\prod_R^{cs}$ with respect to P_R. $\frac{\partial \prod_R^{cs}}{\partial P_R}=-2b\left(1-\omega_1-\omega_2\right)P_R+\left(1-\omega_1-\omega_2\right)(a+\xi k\sqrt{e}_M+\delta e_T\theta_0)+b\left(P_M+P_T+c_R+c_F\right)]$, $\frac{\partial^2 \prod_R^{cs}}{\partial P_R^2}=-2b\left(1-\omega_1-\omega_2\right)<0$. It can be found that $\prod_R^{cs}$ is a concave function of P_R. Then, we obtain Eq. (30).

APPENDIX I

Proof of Theorem 4. Substituting Eq. (30) into Eq. (28) and simplifying the equation, we obtain (I1), as shown at the top of the next page, where $\rho=P_M+P_T+c_R+c_F$. We differentiate $\prod_T^{cs}$ with respect to e_T. $\frac{\partial \prod_T^{cs}}{e_T}=\frac{1}{2}\delta\theta_0\left(P_T-c_T\right)-\eta_2\lambda e_T-\frac{\omega_2\delta\theta_0[a+\xi k\sqrt{e}_M+\delta e_T\theta_0]}{2b}$, $\frac{\partial^2 \prod_T^{cs}}{\partial e_T^2}=\frac{\omega_2\delta^2\theta_0^2}{2b}-\eta_2\lambda<0$. Solving $\frac{\partial \prod_T^{cs}}{e_T}=0$, we derive the Eq. (31).

APPENDIX J

Proof of Theorem 5. Substituting Eq. (30) into Eq. (27) and simplifying the equation, we get (J1), as shown at the top of the next page, where, $\rho=P_M+P_T+c_R+c_F$. We differentiate $\prod_M^{cs}$ with respect to e_M. $\frac{\partial \prod_M^{cs}}{e_M}=\frac{\xi k(P_M-c_M)}{4\sqrt{e}_M}-\eta_1-\frac{\omega_1\xi k[a+\xi k\sqrt{e}_M+\delta e_T\theta_0]}{8b\sqrt{e}_M}$, $\frac{\partial^2 \prod_M^{cs}}{\partial e_M^2}=-\frac{\xi k(P_M-c_M)}{8\sqrt{e}_M^3}-\frac{\omega_1\xi k[a+\xi k\sqrt{e}_M+\delta e_T\theta_0]}{8b\sqrt{e}_M^3}-\frac{\omega_1\xi k}{8b\sqrt{e}_M}<0$. Solving the equation $\frac{\partial \prod_M^{cs}}{e_M}=0$, we derive the Eq. (32).

APPENDIX K

Proof of Proposition 3. When coordinated, there is $P_R^{cs*}=P_R^{c*}$, i.e., $\left(1-\omega_1-\omega_2\right)[a+\xi k\sqrt{e}_M+\delta e_T\theta_0]+b(P_M+P_T+c_R+c_F)=\left(1-\omega_1-\omega_2\right)[a+\xi k\sqrt{e}_M+\delta e_T\theta_0+b(c_M+c_T+c_R+c_F)]$. Thus, we can obtain $\left(1-\omega_1-\omega_2\right)(c_M+c_T+c_R+c_F)=P_M+P_T+c_R+c_F$. Similarly, from $e_M^{cs*}=e_M^{c*}$, we get $\omega_1 a\xi k(2b\eta_2\lambda-\omega_2\delta^2\theta_0^2)+\omega_1\xi k\delta^2\theta_0^2\omega_2 a=\xi k\lambda a, b\left(P_M-c_M\right)\xi k\left(2b\eta_2\lambda-\omega_2\delta^2\theta_0^2\right)+\omega_1\xi k\delta^2\theta_0^2 b\left(P_T-c_T\right)=-\xi k\lambda b\left(c_M+c_T+c_R+c_F\right)$, $2b\eta_1\eta_2=1$, $2b\eta_2\omega_1=1$, $2b\eta_1\omega_2=1$. Therefore, we have $\left(P_M-c_M\right)\left(2b\eta_2\lambda-\omega_2\delta^2\theta_0^2\right)+\omega_1\delta^2\theta_0^2 b\left(P_T-c_T\right)=-\lambda\left(c_M+c_T+c_R+c_F\right)$, $\eta_1=\omega_1$, $\eta_2=\omega_2$ and $\eta_1\eta_2=\frac{1}{2b}$.

$$\prod_T^{cs} = \frac{(P_T - c_T)\left[(1-\omega_1-\omega_2)\left(a+\xi k\sqrt{e_M}+\delta e_T\theta_0\right)-b\rho\right]}{2\left(1-\omega_1-\omega_2\right)} - \frac{\eta_2\lambda e_T^2}{2} + \frac{\omega_2\{(1-\omega_1-\omega_2)\left[a+\xi k\sqrt{e_M}+\delta e_T\theta_0+b\rho\right]\}\left[a+\xi k\sqrt{e_M}+\delta e_T\theta_0-b\rho\right]}{4b\left(1-\omega_1-\omega_2\right)^2}, \tag{I1}$$

$$\prod_M^{cs} = \frac{(P_M - c_M)\left[(1-\omega_1-\omega_2)\left(a+\xi k\sqrt{e_M}+\delta e_T\theta_0\right)-b\rho\right]}{2\left(1-\omega_1-\omega_2\right)} - \eta_1 e_M \frac{\omega_1\{(1-\omega_1-\omega_2)\left[a+\xi k\sqrt{e_M}+\delta e_T\theta_0+b\rho\right]\}\left[a+\xi k\sqrt{e_M}+\delta e_T\theta_0-b\rho\right]}{4b\left(1-\omega_1-\omega_2\right)^2}, \tag{J1}$$

When $e_T^{cs^*} = e_T^{c^*}$, we obtain $\omega_2\delta^2\theta_0^2 a\left(4b\eta_1 - \omega_1\xi^2k^2\right) + \omega_2\delta\theta_0\xi^2k^2\omega_1 a = 2\delta\theta_0 a, b\left(P_T - c_T\right)\delta\theta_0(4b\eta_1 - \omega_1\xi^2k^2) + \omega_2\delta\theta_0\xi^2k^2 b\left(P_M - c_M\right) = -2\delta\theta_0(c_M + c_T + c_R + c_F)$, $2b\eta_1\eta_2 = 1$, $2b\eta_2\omega_1 = 1$, $2b\eta_1\omega_2 = 1$. Therefore, we obtain $(P_T - c_T)\left(4b\eta_1 - \omega_1\xi^2k^2\right) + \omega_2\xi^2k^2 (P_M - c_M) = -2\left(c_M + c_T + c_R + c_F\right)$, $\eta_1 = \omega_1$, $\eta_2 = \omega_2$ and $\eta_1\eta_2 = \frac{1}{2b}$. When $P_R^{cs^*} = P_R^*$, $e_M^{cs^*} = e_M^*$ and $e_T^{cs^*} = e_T^*$, there is $\prod_M^{cs^*} + \prod_T^{cs^*} + \prod_R^{cs^*} = \prod^{c^*}$.

APPENDIX L

Proof of Proposition 4. To make the supply chain members adopt the contract mode, the profits of any side need to be improved. According to Proposition 3, we simplify the Eq. (27), Eq. (28) and Eq. (29), we obtain (L1)-(L3) as shown at the bottom of this page. Simplifying the inequalities: $\prod_M^{cs^*} \geq \prod_M^{dc^*}$, $\prod_T^{cs^*} \geq \prod_T^{dc^*}$ and $\prod_R^{cs^*} \geq \prod_R^{dc^*}$, we derive Proposition 4.

APPENDIX M

Proof of Proposition 5. When the prices of the three channel members are kept in line with the prices of the decentralized system, if the producer and the TPLSP jointly carry out the rebate value $P_R^{dc^*} - P_R^{c^*}$, the optimal safety traceability system availability investment e_M^* and the optimal freshness-keeping effort e_T^* for the supply chain system, and the fresh produce e-commerce enterprise provides the revenue share coefficient ω_1 and ω_2 for the producer and the TPLSP, $\prod_M^{rc} + \prod_T^{rc} + \prod_R^{rc} = \prod^c$ is achieved. The smooth implementation of the CR&RS contract needs to meet the Pareto's improvement. Then $\emptyset_1 + \emptyset_2 = P_R^{dc^*} - P_R^{c^*}$, $\prod_M^{rc^*} \geq \prod_M^{dc^*}$, $\prod_T^{rc^*} \geq \prod_T^{dc^*}$ and $\prod_R^{rc^*} \geq \prod_R^{dc^*}$. That is (M1)–(M4) as shown at the bottom of this page. Among them, $\tau = \left(\xi^2k^2\lambda + 2\delta^2\theta_0^2\right)$ and $\upsilon = c_M + c_T + c_R + c_F$. Simplifying the equation and inequalities, we derive Proposition 5.

APPENDIX N

Proof. We define Δ as the profit difference between before and after the coordination. Then we obtain (N1)–(N3) as shown at the top of the next page, Where $\tau = \left(\xi^2k^2\lambda + 2\delta^2\theta_0^2\right)$ and $\upsilon = c_M + c_T + c_R + c_F$. Due to $\xi^2k^2\lambda + 2\delta^2\theta_0^2 < 4b\lambda$, then $3\left(\xi^2k^2\lambda + 2\delta^2\theta_0^2\right) < 20b\lambda$.

$$\prod_M^{cs^*} = \frac{\omega_1(4b\lambda^2 - \xi^2k^2\lambda)\left[a - b\left(c_M + c_T + c_R + c_F\right)\right]^2}{\left[4b\lambda - \left(\xi^2k^2\lambda + 2\delta^2\theta_0^2\right)\right]^2}, \tag{L1}$$

$$\prod_T^{cs^*} = \frac{\omega_2(4b\lambda^2 - 2\delta^2\theta_0^2\lambda)\left[a - b\left(c_M + c_T + c_R + c_F\right)\right]^2}{\left[4b\lambda - \left(\xi^2k^2\lambda + 2\delta^2\theta_0^2\right)\right]^2}, \tag{L2}$$

$$\prod_R^{cs^*} = \frac{\left[(1-\omega_1-\omega_2)\,4b\lambda^2 - (1-\omega_1)\,\xi^2k^2\lambda^2 - (1-\omega_2)2\delta^2\theta_0^2\lambda)\right]\left[a - b\left(c_M + c_T + c_R + c_F\right)\right]^2}{\left[4b\lambda - \left(\xi^2k^2\lambda + 2\delta^2\theta_0^2\right)\right]^2}. \tag{L3}$$

$$\emptyset_1 + \emptyset_2 = \frac{10a\lambda + (2b\lambda - \tau)\upsilon}{12b\lambda - \tau} - \frac{2a\lambda + (2b\lambda - \tau)\upsilon}{4b\lambda - \tau}, \tag{M1}$$

$$\left\{\frac{4\lambda(a - b\upsilon)}{12b\lambda - \tau} - \emptyset_1 + \frac{\omega_1[10a\lambda + (2b\lambda - \tau)\upsilon]}{12b\lambda - \tau}\right\}\frac{2b\lambda(a - b\upsilon)}{4b\lambda - \tau} \geq \frac{(8b - \xi^2k^2)\lambda^2(a - b\upsilon)^2}{(12b\lambda - \tau)^2} + \frac{\xi^2k^2\lambda^2(a - b\upsilon)^2}{(4b\lambda - \tau)^2}, \tag{M2}$$

$$\left\{\frac{4\lambda(a - b\upsilon)}{12b\lambda - \tau} - \emptyset_2 + \frac{\omega_2[10a\lambda + (2b\lambda - \tau)\,\upsilon]}{12b\lambda - \tau}\right\}\frac{2b\lambda(a - b\upsilon)}{4b\lambda - \tau} \geq \frac{(8b\lambda^2 - 2\lambda\delta^2\theta_0^2)(a - b\upsilon)^2}{(12b\lambda - \tau)^2} + \frac{2\delta^2\theta_0^2\lambda(a - b\upsilon)^2}{(4b\lambda - \tau)^2}, \tag{M3}$$

$$\frac{(1-\omega_1-\omega_2)\left[10a\lambda + (2b\lambda - \tau)\,\upsilon\right]}{12b\lambda - \tau} - \frac{8a\lambda + (4b\lambda - \tau)\upsilon}{12b\lambda - \tau} \geq \frac{4b\lambda^2(a - b\upsilon)^2}{(12b\lambda - \tau)^2}\,\frac{4b\lambda - \tau}{2b\lambda(a - b\upsilon)}. \tag{M4}$$

$$\Delta = \frac{[4b\lambda^2 - \tau\lambda][a-b\upsilon]^2}{[4b\lambda-\tau]^2} - \frac{\left[20b\lambda^2 - \tau\lambda\right][a-b\upsilon]^2}{[12b\lambda-\tau]^2} = \frac{\lambda\,[a-b\upsilon]^2\{[12b\lambda-\tau]^2 - [20b\lambda - tau][4b\lambda^2 - tau]\}}{[4b\lambda-\tau][12b\lambda-\tau]^2}$$
$$= \frac{64b^2\lambda^3[a-b\upsilon]^2}{[4b\lambda-\tau][12b\lambda-\tau]^2}, \tag{N1}$$
$$\frac{\partial\Delta}{\partial\xi} = \frac{64b^2\lambda^3\,[a-b\upsilon]^2\,(-1)\,\{-2\xi k^2\lambda\,[12b\lambda-\tau] - 4\xi k^2\lambda\,[4b\lambda-\tau]\}}{[4b\lambda-\tau]^2[12b\lambda-\tau]^3} = \frac{64b^2\lambda^3[a-b\upsilon]^2\{2\xi k^2\lambda\,[20b\lambda-3\tau]\}}{[4b\lambda-\tau]^2[12b\lambda-\tau]^3}, \tag{N2}$$
$$\frac{\partial\Delta}{\partial\delta} = \frac{64b^2\lambda^3\,[a-b\upsilon]^2\,(-1)\,\{-4\delta\theta_0^2\,[12b\lambda-\tau] - 8\xi k^2\lambda\,[4b\lambda-\tau]\}}{[4b\lambda-\tau]^2[12b\lambda-\tau]^3} = \frac{64b^2\lambda^3[a-b\upsilon]^2\{4\delta\theta_0^2\,[20b\lambda-3\tau]}{[4b\lambda-\tau]^2[12b\lambda-\tau]^3}. \tag{N3}$$

Then we get $\frac{\partial\Delta}{\partial\xi} > 0$, $\frac{\partial\Delta}{\partial\delta} > 0$. Similarly, we obtain (N4).

$$\frac{\partial\Delta}{\partial b} = \frac{-128b\lambda^3\,[a-b\upsilon]^2\,[24b^2\lambda^2 - (\tau)^2 + 2b\lambda\tau]}{[4b\lambda-\tau]^2[12b\lambda-\tau]^3}. \tag{N4}$$

Since $\left(\xi^2k^2\lambda + 2\delta^2\theta_0^2\right)^2 < 16b^2\lambda^2$, we derive $24b^2\lambda^2 - \left(\xi^2k^2\lambda + 2\delta^2\theta_0^2\right)^2 > 0$. Because the molecule is smaller than 0 and the denominator is greater than 0, then we obtain $\frac{\partial\Delta}{\partial b} < 0$.

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REFERENCES

[1] Anonymous. *The Scale of Fresh Produce E-Commerce of China in 2017 was CNY 140.28 Billion*. Accessed: Apr. 2018. [Online]. Available: http://www.100ec.cn/detail–6444769.html
[2] G. Liu, J. Zhang, and W. Tang, "Joint dynamic pricing and investment strategy for perishable foods with price-quality dependent demand," *Ann. Oper. Res.*, vol. 226, no. 1, pp. 397–416, Mar. 2015.
[3] Y. Qin, J. Wang, and C. Wei, "Joint pricing and inventory control for fresh produce and foods with quality and physical quantity deteriorating simultaneously," *Int. J. Prod. Econ.*, vol. 152, no. 2, pp. 42–48, Jun. 2014.
[4] Y. Xiao and J. Chen, "Supply chain management of fresh products with producer transportation," *Decis. Sci.*, vol. 43, no. 5, pp. 785–851, Oct. 2012.
[5] B. Yan, S. Shi, B. Ye, X. Zhou, and P. Shi, "Sustainable development of the fresh agricultural products supply chain through the application of RFID technology," *Inf. Technol. Manage.*, vol. 16, no. 1, pp. 67–78, Mar. 2015.
[6] H. Zhang, B. Qiu, and K. Zhang, "A new risk assessment model for agricultural products cold chain logistics," *Ind. Manage. Data Syst.*, vol. 117, no. 9, pp. 1800–1816, Oct. 2017.
[7] M. F. Lynch, R. V. Tauxe, and C. W. Hedberg, "The growing burden of foodborne outbreaks due to contaminated fresh produce: Risks and opportunities," *Epidemiol. Infection*, vol. 137, no. 3, pp. 307–315, Mar. 2009.
[8] C. K. Winter, "Pesticide residues in imported, organic, and 'suspect' fruits and vegetables," *J. Agricult. Food Chem.*, vol. 60, no. 18, pp. 4425–4429, Feb. 2012.
[9] K. Kirezieva, L. Jacxsens, M. A. J. S. van Boekel, and P. A. Luning, "Towards strategies to adapt to pressures on safety of fresh produce due to climate change," *Food Res. Int.*, vol. 68, no. 3, pp. 94–107, Feb. 2015.
[10] X. Cai, J. Chen, Y. Xiao, and X. Xu, "Optimization and coordination of fresh product supply chains with freshness-keeping effort," *Prod. Oper. Manage.*, vol. 19, no. 3, pp. 261–278, May/Jun. 2010.
[11] B. Yan, X.-H. Wu, B. Ye, and Y.-W. Zhang, "Three-level supply chain coordination of fresh agricultural products in the Internet of Things," *Ind. Manage. Data Syst.*, vol. 117, no. 9, pp. 1842–1865, Jun. 2017.
[12] Q. Zheng, P. Ieromonachou, T. Fan, and L. Zhou, "Supply chain contracting coordination for fresh products with fresh-keeping effort," *Ind. Manage. Data Syst.*, vol. 117, no. 3, pp. 538–559, Apr. 2017.
[13] J. Chen, M. Dong, and L. Xu, "A perishable product shipment consolidation model considering freshness-keeping effort," *Transp. Res. E, Logistics Transp. Rev.*, vol. 115, pp. 56–86, Jul. 2018.
[14] Y. Yun and W. Kun, "The key technology research of quality and safety traceability systems of agricultural products," in *Proc. IEEE Int. Conf. Intell. Transp., Big Data Smart City*, Dec. 2015, pp. 880–882.
[15] I. Expósito, J. A. Gay-Fernádez, and I. Cuiñas, "A complete traceability system for a wine supply chain using radio-frequency identification and wireless sensor networks [wireless corner]," *IEEE Antennas Propag. Mag.*, vol. 55, no. 2, pp. 255–267, Apr. 2013.
[16] X. Chen, X. Wang, and H. K. Chan, "Manufacturer and retailer coordination for environmental and economic competitiveness: A power perspective," *Transp. Res. E, Logistics Transp. Rev.*, vol. 97, pp. 268–281, Jan. 2017.
[17] S. Saha, "Supply chain coordination through rebate induced contracts," *Transp. Res. E, Logistics Transp. Rev.*, vol. 50, no. 1, pp. 120–137, Feb. 2013.
[18] X. Chen, X. Wang, and H. K. Chan, "Channel coordination through subsidy contract design in the mobile phone industry," *Int. J. Prod. Econ.*, vol. 171, pp. 97–104, Jan. 2013.
[19] M. Nouri, S.-M. Hosseini-Motlagh, M. Nematollahi, and R. Sarker, "Coordinating manufacturer's innovation and retailer's promotion and replenishment using a compensation-based wholesale price contract," *Int. J. Prod. Econ.*, vol. 198, pp. 11–24, Apr. 2018.
[20] T. Nie and S. Du, "Dual-fairness supply chain with quantity discount contracts," *Eur. J. Oper. Res.*, vol. 258, no. 2, pp. 491–500, Apr. 2017.
[21] B. Niu, L. Chen, X. Zhuo, and X. Yue, "Does buy-back induce more fashion sub-sourcing? Contract property and performance analysis," *Transp. Res. E, Logistics Transp. Rev.*, vol. 113, pp. 22–37, May 2018.
[22] M. Luo, G. Li, C. L. J. Wan, R. Qu, and P. Ji, "Supply chain coordination with dual procurement sources via real-option contract," *Comput. Ind. Eng.*, vol. 80, pp. 274–283, Feb. 2015.
[23] X. Chen, G. Hao, and L. Li, "Channel coordination with a loss-averse retailer and option contracts," *Int. J. Prod. Econ.*, vol. 150, pp. 52–57, Apr. 2014.
[24] L. Giannoccaro and P. Pontrandolfo, "Supply chain coordination by revenue sharing contracts," *Int. J. Prod. Econ.*, vol. 89, no. 2, pp. 131–139, May 2004.
[25] T. Xiao, D. Yang, and H. Shen, "Coordinating a supply chain with a quality assurance policy via a revenue-sharing contract," *Int. J. Prod. Res.*, vol. 49, no. 1, pp. 99–120, Jan. 2011.
[26] X. Chen, N. Wan, and X. Wang, "Flexibility and coordination in a supply chain with bidirectional option contracts and service requirement," *Int. J. Prod. Econ.*, vol. 193, pp. 183–192, Nov. 2017.
[27] R. Anupindi and Y. Bassok, "Centralization of stocks: Retailers vs. Manufacturer," *Manage. Sci.*, vol. 45, no. 2, pp. 91–178, Feb. 1999.
[28] X. Huang, S.-M. Choi, W.-K. Ching, T.-K. Siu, and M. Huang, "On supply chain coordination for false failure returns: A quantity discount contract approach," *Int. J. Prod. Econ.*, vol. 133, no. 2, pp. 634–644, Oct. 2011.
[29] O. D. Palsule-Desai, "Supply chain coordination using revenue-dependent revenue sharing contracts," *Omega*, vol. 41, no. 4, pp. 780–796, Aug. 2013.
[30] H. Xiong, B. Xiong, and J. Xie, "A composite contract based on buy back and quantity flexibility contracts," *Eur. J. Oper. Res.*, vol. 210, no. 3, pp. 559–567, May 2011.
[31] H. Krishan, R. Kapuscinski, and D. A. Butz, "Coordinating contracts for decentralized supply chains with retailer promotional effort," *Manage. Sci.*, vol. 50, no. 1, pp. 48–63, Jan. 2004.

[32] A. A. Tassy and W. S. Lovejoy, "Quantity flexibility contracts and supply chain performance," *Manage. Sci.*, vol. 45, no. 10, pp. 1339–1358, Apr. 1999.
[33] A. H. L. Lau, H.-S. Lau, and J.-C. Wang, "How a dominant retailer might design a purchase contract for a newsvendor-type product with price-sensitive demand," *Eur. J. Oper. Res.*, vol. 190, no. 2, pp. 443–458, Oct. 2008.
[34] P. H. Ritchken and C. S. Tapiero, "Contingent claims contracting for purchasing decisions in inventory management," *Oper. Res.*, vol. 34, no. 6, pp. 864–870, Dec. 1986.
[35] G. Sun, "Research on the fresh agricultural product supply chain coordination with supply disruptions," *Discrete Dyn. Nature Soc.*, vol. 2013, no. 5, Apr. 2013, Art. no. 416790.
[36] C. Wang and X. Chen, "Option pricing and coordination in the fresh produce supply chain with portfolio contracts," *Ann. Oper. Res.*, vol. 248, nos. 1–2, pp. 471–491, Jan. 2017.
[37] L. Yang, K. Chen, and G. Ma, "Optimal decisions and coordination mechanisms for a fresh agricultural product supply chain system," *Int. J. u-, e-Service, Sci. Technol.*, vol. 7, no. 5, pp. 63–78, Oct. 2014.
[38] W. S. Lim, "A lemons market? An incentive scheme to induce truth-telling in third party logistics providers," *Eur. J. Oper. Res.*, vol. 125, no. 3, pp. 519–525, Sep. 2000.
[39] O. Alp, N. K. Erkip, and R. Güllü, "Outsourcing logistics: Designing transportation contracts between a manufacturer and a transporter," *Transport Sci.*, vol. 37, no. 1, pp. 23–39, Feb. 2003.
[40] Q. Wu, Y. Mu, and Y. Feng, "Coordinating contracts for fresh product outsourcing logistics channels with power structures," *Int. J. Prod. Econ.*, vol. 160, pp. 94–105, Feb. 2015.
[41] X. Cai, J. Chen, Y. Xiao, X. Xu, and G. Yu, "Fresh-product supply chain management with logistics outsourcing," *Omega*, vol. 41, no. 4, pp. 752–765, Aug. 2013.
[42] Y. Feng, Y.-L. Yu, Y.-Z. Zhang, and Q. Wu, "Coordination in a three-echelon supply chain of fresh agri-products with TPLSP's participation in decision-making," *J. Ind. Eng. Eng. Manage.*, vol. 29, no. 4, pp. 213–221, Oct. 2015.
[43] J.-B. Sheu, "Marketing-driven channel coordination with revenue-sharing contracts under price promotion to end-customers," *Eur. J. Oper. Res.*, vol. 214, no. 2, pp. 246–255, Oct. 2011.
[44] Y. He, X. Zhao, L. Zhao, and J. He, "Coordinating a supply chain with effort and price dependent stochastic demand," *Appl. Math. Model.*, vol. 33, no. 6, pp. 2777–2790, Jun. 2009.
[45] L. Wang and B. Dan, "Coordination of fresh agricultural supply chain considering retailer's freshness-keeping and consumer Utility," *Oper. Res. Manage.*, vol. 24, no. 5, pp. 44–51, Oct. 2015.
[46] L. Wang and B. Dan, "The incentive mechanism for preservation in Fresh agricultural supply chain considering consumer utility," *J. Ind. Eng. Eng. Manage.*, vol. 29, no. 1, pp. 200–206, Jan. 2015.
[47] A. Hafezalkotob, "Competition, cooperation, and coopetition of green supply chains under regulations on energy saving levels," *Transp. Res. E, Logistics Transp. Rev.*, vol. 97, pp. 228–250, Jan. 2017.
[48] S. H. Yoo and T. Cheong, "Quality improvement incentive strategies in a supply chain," *Transp. Res. E, Logistics Transp. Rev.*, vol. 114, pp. 331–342, Jun. 2018.
[49] Y. Yu and T. Xiao, "Pricing and cold-chain service level decisions in a fresh agri-products supply chain with logistics outsourcing," *Comput. Ind. Eng.*, vol. 111, pp. 56–66, Sep. 2017.
[50] Q. Zhu, X. Li, and S. Zhao, "Cost-sharing models for green product production and marketing in a food supply chain," *Ind. Manage. Data Syst.*, vol. 118, no. 4, pp. 654–682, May2018.
[51] T. Xiao and T.-M. Choi, "Competitive capacity and price decisions for two build-to-order manufacturers facing time-dependent demands," *IEEE Trans. Syst., Man, Cybern. A, Syst. Humans*, vol. 40, no. 3, pp. 583–595, May 2010.
[52] T. Xiao, T.-M. Choi, and T. C. E. Cheng, "Pricing and benefit of decentralization for competing supply chains with fixed costs," *IEEE Trans. Eng. Manage.*, vol. 65, no. 1, pp. 99–112, Feb. 2018.
[53] J. Xie and J. C. Wei, "Coordinating advertising and pricing in a manufacturer–retailer channel," *Eur. J. Oper. Res.*, vol. 197, no. 2, pp. 785–791, Sep. 2009.
[54] T. A. Taylor, "Supply chain coordination under channel rebates with sales effort effects," *Manage. Sci.*, vol. 48, no. 8, pp. 992–1007, Aug. 2002.
[55] A. A. Taleizadeh, E. Sane-Zerang, and T. M. Choi, "The effect of marketing effort on dual-channel closed-loop supply chain systems," *IEEE Trans. Syst., Man, Cybern. Syst.*, vol. 48, no. 2, pp. 265–276, Feb. 2018.
[56] Q. Li, T. Xiao, and Y. Qiu, "Price and carbon emission reduction decisions and revenue-sharing contract considering fairness concerns," *J. Cleaner Prod.*, vol. 190, pp. 303–314, Jul. 2018.
[57] P.-K. Chang, F.-D. Chou, X. Dai, and Y. Ye, "Development of a supply chain integration process," *IEEE Access*, vol. 6, pp. 40226–40244, Aug. 2017.
[58] B. Zheng, C. Yang, J. Yang, and M. Zhang, "Pricing, collecting and contract design in a reverse supply chain with incomplete information," *Comput. Ind. Eng.*, vol. 111, pp. 109–122, Sep. 2017.
[59] X. Chen and Z.-J. Shen, "An analysis of a supply chain with options contracts and service requirements," *IIE Trans.*, vol. 44, no. 10, pp. 805–819, Oct. 2012.

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