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Profit-Sharing Contracts for Fresh Agricultural Products Supply Chain Considering Spatio-Temporal Costs

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Abstract: This paper investigated the effects of the informational asymmetry phenomenon that occurs in the direct sale of fresh agricultural products (FAP) in an e-commerce environment. A three-level FAP supply chain was proposed, which was composed of a FAP supplier, a logistics service provider, and a large e-commerce platform. Considering the perishable nature of FAP, this paper analyzed the effects of logistics spatio-temporal costs and the freshness of FAP on the profit of each stakeholder in the supply chain. Three scenarios were considered: (1) complete information, (2) partial information, and (3) considering logistics spatio-temporal cost. Analytical models were developed based on the principal-agent theory and the supply chain coordination contract theory to depict the effects of a profit-sharing contract on the operations of the FAP supply chain. Modeling results indicated that under a complete information condition, an increase in the loss rate of FAP correlated to a decrease in the profit of the FAP supply chain. Under a partial information condition, considering the loss rate of FAP and the potential compensation costs to suppliers, when the loss rate of FAP was fixed, the profit of each stakeholder in the FAP supply chain displayed a decreasing trend in relation to compensation ratio. In comparison, when the compensation ratio was fixed, the total profit decreased as the freshness of the FAP degraded. To improve customer satisfaction, this paper recommends adding a front warehouse to improve the freshness of FAP. Although this option increases the logistics costs, it has the potential of increasing the overall profit of the FAP supply chain. Findings from this research have the potential to help the e-commerce platform with coordinating the various stakeholders on the supply chain to determine the optimal quality and quantity of FAPs, eventually improving the operational efficiency of the FAP direct sales supply chain by reducing the logistics costs of FAP.

Keywords: supply chain; fresh agricultural products; freshness-keeping effort; logistics spatio-temporal costs; profit-sharing contract

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1. Introduction

The production and consumption of fresh agricultural products (FAP) play a significant role in the development of agricultural economics [1–4]. With the improvement of agricultural production technologies, the production of FAP has been continuously increasing. According to the China National Bureau of Statistics, the gross production of FAP in China has reached 1036 million tons, which is 28.25 percent higher than the production in 2010 [5]. In recent years, taking advantage of the Internet of Things (IoT) and Information Technology (IT), and with the rapid development of e-commerce platforms, the emerging "direct sales" business mode, which allows consumers to directly place orders from suppliers through an e-commerce platform, has become increasingly popular throughout the world [6–10]. This is particularly significant after the outbreak of the COVID-19 pandemic [11–14]. The direct sales mode promotes a more efficient supply chain, as it eliminates or reduces the number of transits during the logistics operations, thereby reducing product circulation costs and eventually the sales prices of FAPs [15,16]. According to the 2021 China Fresh Food E-commerce Industry Research Report [17], the total annual transaction amount of fresh food e-commerce reached 8.868 billion China Yuan (CNY) in 2020 (approximately 1.4 billion U.S. Dollars, USD), which constitutes 14.6 percent of the fresh food market in 2020.

For the direct sales business mode, it is expected that an e-commerce platform serves as the intermediary agent between the FAP supplier and the logistics service provider. After receiving orders from consumers, the e-commerce platform coordinates between the logistics service provider and the supplier. It allows the logistics service provider to directly pick up the ordered FAP from the supplier, and then finalize the logistics circulation processes such as product allocation, packaging, and delivery. This kind of supply chain operational mode has the advantages of maximizing the freshness of the FAP and reducing the logistics costs, especially indirect costs charged by the sellers (such as supermarkets) [18–20]. This brings considerable economic benefits to both suppliers and consumers; as a result, there has been an increasing number of e-commerce platforms supporting the direct sales of FAP [21,22].

However, unlike industrial products, a FAP is usually available only during one or several designated seasons. Besides, as labor-intensive products, FAPs generally have a low gross unit profit, and their heavy shipping weights and the requirements for freshness-keeping effects call for higher logistics costs in comparison with other merchandises. Moreover, without interactive coordination between the supplier(s) and the physical seller(s), such as information related to consumer preferences and market demands of FAPs, an insufficient or an excessive supply of a particular FAP may occur. The former may result in a higher cost to consumers, while the latter tends to considerably lower the sales price of the FAP [23]. In other words, the information asymmetry phenomenon that occurs in the production-marketing circulation of FAP could mislead the operations of the supply chain. This may result in unexpected logistics costs, and, accordingly, profit losses to the supplier and increased costs for consumers [24–29]. Therefore, an effective and reliable FAP supply chain, which links rural agricultural suppliers and urban or suburban consumers, is crucial to both rural economics and people's basic living requirements in urban areas [30–32].

In this regard, to improve the operational efficiency of the FAP direct sales supply chain, there is an urgent need to investigate the impacts of information asymmetry problems on direct sales supply chain operations and the coordination between various stakeholders of the supply chain. Eventually, this may reduce the logistics spatio-temporal costs of FAP.

2. Literature Review

2.1. Fresh Agricultural Product Supply Chain Management

For the management of FAP supply chains, Grimsdell [33] has pointed out that coordinated planning or communication between the various stakeholders of the fresh vegetable supply chain is critical for the success of the supply chain. With a better understanding of each other's needs, stakeholders in the supply chain can make more effective investment decisions to reduce operational costs and increase profits. Widodo et al. [34] have indicated that due to the high loss rate of FAP, an effective supply chain management model is required. The research developed a mathematical model to deal with the periodical harvests in the flowering market, and an optimal harvesting pattern was derived to maximize the demand level satisfied. Azad et al. [35] analyzed the joint decision-making and decentralized decision-making of a two-stage supply chain with the participation of subcontractors in stocks, out-of-stock orders, and subcontracting strategies. Their research results show that the joint decision-making strategy provided a higher total profit than the decentralized decision-making strategy at each stage of the production and sales circle. Cai et al. [36] considered a three-tier fresh product supply chain with a supplier, a third-party logistics provider, and a distant market, assuming the market demand is random and sensitive to the sales price and the freshness of the product. An incentive scheme, which contains a wholesale-market clearance contract between the producer and the distributor and a wholesale-price-discount sharing contract between the producer and the logistics provider, was proposed to coordinate the supply chain.

Recently, Dellino et al. [37] have proposed a decision support system for the supply chain of packaged fresh and highly perishable products. The system enables sales forecasting according to the outdating, shortage, and freshness of products, as well as residual stock, eventually providing order plans with associated satisfactory performances. Ghazanfari et al. [38] studied the impact of government incentives on a fresh-product supply chain with stochastic demands. Both traditional selling cycles in the open market (without government incentives) and modern selling cycles in an organized market (with government incentives) were considered. Based on a real-world case study, it was found that government incentives increased the profit of all the stakeholders in the fresh-product supply chain. Zheng et al. [39] explored the optimal channel selection strategy for a fresh produce supply chain that consists of both online direct sales and physical store retailers. It was found that retailers' profits increased with the increasing freshness sensitivity in the dual-channel model. Yu and Xiao [40] developed game-theoretic models for a FAP supply chain that consists of a supplier, a retailer, and a third-party logistics provider. Two service outsourcing modes were compared: supplier-outsourcing, and retailer outsourcing. It was found that under a traditional quantity discount scheme, retailer-outsourcing is preferred under a low market size condition. Otherwise, supplier-outsourcing is better if service cost is low and the market size is high. Fasihi et al. [41] developed a mathematical model based on the epsilon-constraint method and Lp-metric to maximize responsiveness to customer demand and minimize the cost of the fish closed-loop supply chain. Chen et al. [42] investigated the effects of supply chain finance on agricultural product supply chain operations through a case study. Results show that supply chain finance has a considerable impact on supply chain management, which solves the capital constraint problems in the agricultural development process as well as promoting the implementation of integration strategies and innovation in the agricultural industry.

2.2. Profit-Sharing Contract

In terms of the design and implementation of profit-sharing contracts, Gan et al. [43] have defined a coordinated contract with a Pareto-optimal solution that is acceptable to each agent in supply chains involving risk-averse agents. Three cases were analyzed, and modeling results showed that each case can have a set of Pareto-optimal solutions, and that a corresponding contract could be designed to achieve the Pareto-optimal solutions. Leng and Parlar [44] employed the game-theory model to study the delivery cycle in the two-level supply chain involving a manufacturer and a retailer. The three parts of a delivery cycle include preparation, production, and shipment time. A profit-sharing contract was designed to achieve supply chain coordination. Results show that the manufacturer should be responsible for the preparation time and production time at their normal durations, and the profit-sharing contract could maximize the system-wide profit. Sheu [45] explored the equilibrium relationship of a supplier-retailer distribution channel with and without revenue-sharing contracts. Based on analytical modeling, it was concluded that both the supplier and retailer can get more profits through revenue-sharing contracts with appropriate promotional pricing strategies.

Yang and Tang [46] developed a supplier-retailer fresh product supply chain under three sales modes (retail mode, dual-channel mode, and Online-to-Offline mode) to identify the optimal pricing and freshness-keeping efforts. It was found that in a decentralized system, the dual-channel mode could outperform the Online-to-Offline mode for the supplier, while when the system was coordinated, the Online-to-Offline mode brings the highest supply chain profit. Song and He [47] developed a three-layer fresh agricultural product supply chain that consists of an e-commerce enterprise, a third-party logistics service provider, and a community convenience store. Different contract coordination mechanisms were designed to improve the supply chain performance. Results show that a decentralized supply chain can be coordinated by a freshness-keeping cost-sharing and revenue-sharing contract to maximize the total profit and also satisfy consumer requirements. Moon et al. [48] investigated investment decisions in a fresh agricultural products supply chain. Three different scenarios are considered: decentralized scenario, revenue sharing coupled with investment cost-sharing, and incremental quantity discount contracts. The research revealed that an incremental quantity discount contract has the potential to encourage the manufacturer to charge a wholesale price greater than the marginal cost, which could maximize the utility of the supply chain. Jabarzare and Rasti-Barzoki [49] analyzed the impacts of profit-sharing contracts on optimal pricing and quality decisions, as well as the profit of a dual-channel supply chain that consists of a manufacturer and a packaging company. It was concluded that the competitive game played between the manufacturer and the packaging company is beneficial for price-seeking customers, and when the customers' demand is highly sensitive to the quality of the products, the cooperation of the manufacturer and the packaging company under a profit-sharing contract is preferable. Ghosh et al. [50] investigated the coordination among the two stakeholders in a two-echelon supply chain in terms of pricing strategies. Modeling results show that decentralized decisions increase the selling price of the product and decrease the total profit of the supply chain. In comparison, the joint decision taken by the manufacturer and the retailer resulted in maximum profit for the supply chain. Sarkar and Bhala [51] showed that a constant wholesale price contract can coordinate a decentralized channel in a manufacturer-led closed-loop supply chain. The research recommended that when supply chain coordination is achieved by a constant wholesale price contract, it would be more efficient to have the manufacturer collecting the end-of-use products, particularly when the cost of increasing the collection rate is high.

2.3. Summary

Through the review of the state-of-the-practice in FAP supply chain management, it was found that, although sufficient literature exists on supply chain management practices of various agricultural products, the majority of these studies focused on the traditional two-level supply chain that contains a supplier and a retailer. Not much work has been conducted on investigating FAP supply chain operations under the emerging direct sales mode. Besides, most of the works in question attempted to solve problems encountered by individual stakeholders of the supply chain. Despite a few studies that have been conducted on the coordination of the various stakeholders, there is a lack of systemic comparisons of supply chain management under various information asymmetry scenarios. Thus, this study contributes towards a better understanding of the effects of information asymmetry on FAP supply chain operations under a direct sales mode, and how profit-sharing contracts between the various stakeholders will benefit the FAP supply chain management.

3. Methodology

3.1. Model Specification

This paper assumes an e-commerce platform-based direct sales mode. A three-level FAP supply chain is proposed, which is composed of a FAP supplier, a logistics service provider, and a large e-commerce platform. FAP suppliers refer to farmers, agricultural enterprises, or agricultural cooperatives. Logistics service providers are responsible for the circulation of FAP such as direct procurement from the farm, product allocation, sorting, and packaging, etc. E-commerce platforms serve as the sellers of FAP.

It is expected that to maximize the sales volume, the e-commerce platform keeps analyzing the effects of FAP suppliers' efforts on the quality of FAP, and the combined impacts of the quality of FAP and logistics spatio-temporal costs on order quantity [6,8,9,15,21]. The operational feature of the supply chain is specified as follows. First, after negotiating the terms related to the production and sales of FAP, the e-commerce platform signs a profit-sharing contract with each of the FAP suppliers. Then, to execute the profit-sharing contract, FAP suppliers make decisions on the amount of agricultural capital inputs, types of agricultural products to be planted, the scope of the plantation, etc. based on the consumers' demands provided by the e-commerce platform. Finally, when the agricultural products are ready for entering the market, the e-commerce platform decides the sales price, and the logistics service provider directly picks up the agricultural products from the suppliers and delivers them to consumers. Graphical illustrations of the FAP supply chain for the traditional retail mode and the proposed three-level direct sales mode are presented in Figure 1.

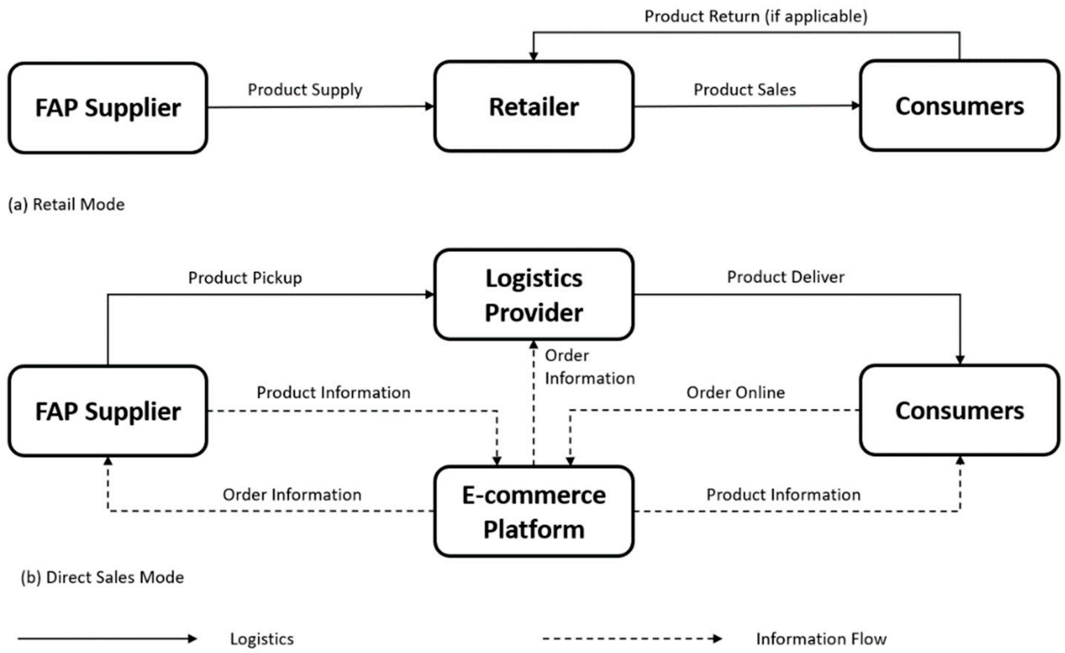

Figure 1. FAP supply chain: (**a**) Retail mode, (**b**) Direct sales mode.

In this entire production and sales process, the information among e-commerce platforms, fresh produce suppliers, and logistics service providers is asymmetrical. FAP suppliers and logistics service providers do not have access to the big data related to consumer preferences and market demands. Moreover, FAP suppliers are not able to identify whether the increases in profit-sharing are caused by the supplier's efforts (e) or by exogenous factors (x) such as disasters, unexpected events, and government subsidy policies. When designing a profit-sharing contract, the e-commerce platform needs to take into account the corresponding constraints on profit sharing between FAP suppliers and logistics service providers. In this case, the optimal solution achieved is defined as the second-best solution; this second-best solution principle also works for analyzing each of the confounding factors in the FAP profit-sharing contract [52,53]. These factors mainly include but are not limited to the following: the degree of effort made by the fresh agriculture products supplier, spatio-temporal costs of the logistics service provider, percentage of sales profit made to each of the stakeholders in the supply chain, operational costs of the e-commerce platform, the degree of effort made by e-commerce platforms to stimulate market sales, and the freshness of FAP [9,29,30,32,38,44,48,54].

The profit-sharing contract discussed in this paper aims at encouraging the e-commerce platform to increase direct sales volume; besides this, it also stimulates the FAP suppliers and logistics service providers to actively participate in the improvement of product and service qualities. Eventually, it maximizes the expected utility of the FAP supply chain. According to the principal-agent theory and the supply chain coordination contract theory, to maximize the expected utility, the e-commerce platform should satisfy a series of constraints.

The following parameters are used in this paper:

- e: the degree of effort made by the fresh agriculture products supplier to reduce product costs,
- y: utility function of the fresh agriculture products supplier,
- g: spatio-temporal costs of the logistics service provider,
- θ: the freshness of the fresh agriculture products,
- k: sales profit (in percentage) made to FAP supplier,
- m: sales profit (in percentage) made to the logistics service provider,
- $1 - k - m$: sales profit (in percentage) made to the e-commerce platform,
- u_0: the minimum profit to FAP suppliers and logistics service providers to cover their production costs,
- β: cost coefficient,
- $\pi(y)$: profit-sharing contract signed by the FAP supplier, the logistics service provider, and the e-commerce platform,
- $c(e)$: operational costs of the e-commerce platform,
- $u(.)$: expected utility function of the e-commerce platform.

Based on the actual conditions of the FAP supply chains in China, the following reasonable assumptions are made to facilitate the modeling process:

Hypothesis 1. *The FAP supply chain is composed of a FAP supplier, a logistics service provider, and a large e-commerce platform. Each of the three stakeholders is an independent unit that has fully rational analytical capabilities and pursues its maximum profits.*

Hypothesis 2. *The sales of FAP are affected by a series of exogenous factors such as natural disasters, unexpected events, and government subsidy policies. These factors tend to be stochastic and uncertain in terms of duration and magnitude. The effects of these factors could either be positive or negative, which follows a normal distribution with a mean effect of zero and a variance of* σ^2.

Hypothesis 3. *E-commerce platforms have access to "big data" resources, which contain both macroscopic level demand and supply distributions and microscopic level market pricing information. While fresh agriculture produce suppliers and logistics service providers do not have the authorization to directly access such data resources, this indicates that there are information asymmetries between the three stakeholders.*

Hypothesis 4. *Due to the perishability of FAP, and considering the fact that consumers usually have strict requirements regarding the freshness of FAP, this research assumes that if there are any quality problems with the FAP that have been sold, the seller will make a full refund to the consumers without having consumers return the product (to avoid incurring additional transporting costs). This indicates that the residual value will be zero.*

Hypothesis 5. *In case a signatory FAP supplier cannot provide the designated quantity of products, the supplier needs to pay a contracted compensation to the e-commerce platform.*

3.2. Profit-Sharing Contract under Complete Information

This paper defines the utility function of the FAP supplier as $y = e + x$, where x represents the exogenous uncertain factors such as natural disasters, emergencies, government subsidy policies, etc., and $x \sim N(0, \sigma^2)$. This could also be described as: $Ey = E(e + x) = e$, $var(y) = \sigma^2$. The profit-sharing contract designed by the e-commerce platform is defined as: $\pi(y) = s + ky + my$, where s is the fixed income agreed by the partners of the FAP supply chain, k is the sales profit made by the FAP supplier, m is the sales profit made by the logistics service provider, and $1 - k - m$ is the sales profit made by the e-commerce platform. Apparently, when the utility function of the FAP supplier, y, increases by one unit, the profit to the e-commerce platform increases by $1 - k - m$ units, where $0 \leq k \leq 0.8$, m is a fixed value and $0.2 \leq m < 1$.

Theorem 1. *For a three-level fresh agricultural product supply chain, the profit-sharing contract mechanism could promote the use of complete information. It also helps determine the optimal amount of supplies that the fresh agricultural product suppliers may produce and may determine the optimal profit shares that can maximize the revenue of each partner in the fresh agricultural product supply chain.*

Proof of Theorem 1. Under a designated profit-sharing contract $\pi(y) = s + ky + my$, the utility of the FAP supplier is $\pi(y)$ [55]. Under the complete information condition, the expected revenue of the e-commerce platform equals the expected utility, so, we have: $E(u(y - \pi(y))) = E(y - s - ky - my) = -s + (1 - k - m)e$. □

The e-commerce platform tends to stimulate FAP suppliers' degree of effort through the profit-sharing contract mechanism. According to the findings from a previous study [43], the degree of effort could be quantified as $c(e) = \frac{1}{2}\beta e^2$, where β is the cost coefficient, $\beta > 0$. Apparently, a larger β indicates a higher cost to achieve the desired degree of effort.

Previous research revealed that the loss rate of FAP increases with time [56], where the loss rate function could be described as: $h(\theta(t)) = -\theta t ln\theta \; 0 < \theta < 1,\; h(\theta(t)) < 0$.

The spatio-temporary cost, (g), is the expenses that the e-commerce platform has to pay to the logistics service provider for picking up the FAP from the supplier and delivering it to the consumer.

The actual profit of the FAP supplier and logistics service provider is: $u = \pi(y) - c(e) = s + k(e + x) + m(e + x) - \frac{1}{2}\beta e^2$.

Since all parties in the supply chain have access to the complete information, the profit is the actual revenue minus the supply chain operational costs and product wastage losses during the product circulation process. Therefore, the certainty equivalent revenue of the FAP suppliers and logistics service providers is: $(1 - h(\theta(t)))\left[s + k(e + x) + m(e + x) - \frac{1}{2}\beta e^2\right]$.

Under the constraints of the profit-sharing contract, u_0 is defined as the minimum profit to the fresh agricultural suppliers and the logistics service providers to cover their operational costs. Therefore, the profit function should be greater than u_0.

$$(1 - h(\theta(t)))\left[s + k(e + x) + m(e + x) - \frac{1}{2}\beta e^2\right] \geq u_0 \tag{1}$$

Additionally, under the designated profit-sharing contract, each stakeholder in the FAP supply chain seeks to maximize its profits, and the profit-sharing contract can be optimized by the effort of the fresh-agricultural product supplier. The profit-sharing contract could be depicted using the following mathematical model:

$$\max_{s,k,m,e} Eu = -s + (1 - k - m)e - g$$

$$s.t\left\{(1 - h(\theta(t)))\left[s + k(e + x) + m(e + x) - \frac{1}{2}\beta e^2\right] \geq u_0\right. \tag{2}$$

Nevertheless, it is necessary to point out that in reality, an e-commerce platform usually serves as a market intermediary that usually seeks to maximize its profit instead of sharing profits with all stakeholders in the supply chain. With this consideration in mind, the above profit-sharing contract model can be revised as:

$$\max_{s,k,e,m}\left(e - \frac{u_0}{1 + \theta^t \ln\theta} + kx + mx - \frac{1}{2}\beta e^2 - g\right) \tag{3}$$

According to the implicit function derivation rule, derivations were made to parameters k and e, respectively, as a result of which we have:

$$k^* = 0,\; e^* = \frac{1}{\beta} \tag{4}$$

Combining Equation (4) into Equation (1), we have

$$s^* = \frac{1}{2\beta} + \frac{u_0}{1 + \theta^t \ln \theta} \tag{5}$$

Equation (5) is the Pareto optimal profit-sharing contract. Under a complete information condition, the fixed revenue agreed by the partners of the FAP supply chain equals the sum of the minimum retained revenue and the operational costs.

Under the complete information condition, the e-commerce platform can monitor the degree of effort, e, made by the fresh agriculture products supplier. When $e < \frac{1}{\beta}$, the FAP supplier's incentive contract is determined as $\underline{s} < u_0 < s^*$, and the Pareto optimum will be reached when $e < \frac{1}{\beta}$.

3.3. Profit-Sharing Contract under Partial Information

Under a partial information condition, due to the information asymmetries in the quantity and quality of the FAP supplied by the suppliers, and the sorting, packaging, transporting, and distributing capabilities of the logistics service providers, neither the e-commerce platform nor the logistics service providers can accurately estimate the demands and supplies of the FAP. This indicates that the Pareto optimal cannot be achieved under complete information, since external factors will have a considerable impact on FAP. For example, if a FAP supplier accidentally purchased fake or inferior seeds, consequently, the supplier may not be able to provide agricultural products to the e-commerce platform in a timely manner. This will result in losses to the e-commerce platform, and, based on the signed contract, the e-commerce platform may request compensation from the supplier. Assume the supplier pays compensation to the e-commerce platform and the compensation ratio is Φ, where $0 \leq \Phi \leq 1$, and the amount of monetary losses of the supplier is: $\frac{1}{2}\Phi k^2 \sigma^2$.

Theorem 2. *For a supply chain with a partial information operational condition, when the total profit of the fresh agricultural product supplier and the logistics service provider is greater than zero, the fresh agricultural product supplier will incur a certain cost due to the insufficient quantity of FAP. Although the e-commerce platform cannot fully track the degree of effort of the fresh agricultural product supplier, it can still maximize the profit of the e-commerce platform through the profit-sharing contract mechanism.*

Proof of Theorem 2. When $k = 0$, the FAP supplier determines a degree of effort that can maximize its profit, and determines the maximum profit through the corresponding certainty equivalent revenue, and determines the desired degree of effect that can maximize its certainty equivalent revenue. The derivation of certainty equivalent revenue, which is the constraint of the FAP supply chain profit-sharing contract, is $e = \frac{k+m}{\beta}$. Accordingly, the optimal profit of the e-commerce platform could be depicted as follows:

$$\max_{s,k,m,e} Eu = -s + (1 - k - m)e - g$$

$$s.t \begin{cases} (1 - h(\theta(t)))\left[s + ke + me - \frac{1}{2}\beta e^2 - \frac{1}{2}\Phi k^2 \sigma^2\right] \geq u_0 \\ e = \frac{k+m}{\beta} \end{cases} \tag{6}$$

According to the above formula, we can get:

$$\max_{k} = \frac{k+m}{\beta} - \frac{(k+m)^2}{2\beta} - \frac{1}{2}\Phi k^2 \sigma^2 - g - \frac{u_0}{1 + \theta^t \ln \theta} \tag{7}$$

According to the implicit function derivation rule, we have:

$$k = \frac{1-m}{1+\Phi\beta\sigma^2} \quad (8)$$

□

Equation (7) indicates that under the condition of partial information, the profits of all parties can be maximized through the restriction of the profit-sharing contract mechanism on each party in the FAP supply chain. From Equation (8), it can be seen that $k > 0$, which means that when the FAP supplies are insufficient, the FAP supplier will need to pay a designated compensation cost.

When the stakeholders in the fresh produce supply chain can only partially share the information, the Pareto optimal profit-sharing mechanism cannot be achieved, which will negatively affect the degree of effort of FAP suppliers. These potential compensation costs and the reduced degree of effect will result in a loss in FAP production. The difference between this loss and the savings from the reduced degree of effect is defined as the incentive cost of the profit-sharing contract mechanism.

Under such a condition, the compensation cost is:

$$C_{r1} = \frac{1}{2}\Phi k^2\sigma^2 = \frac{\Phi\sigma^2(1-m)^2}{2(1+\Phi\beta\sigma^2)^2} \quad (9)$$

Under a complete information condition, when the fresh produce supplier's degree of effort reaches $e^* = \frac{1}{\beta}$, the Pareto optimal profit-sharing contract mechanism can be achieved. While under a partial information condition, the fresh produce supplier's degree of effort will be reduced. Therefore, the optimal degree of effort is: $e = \frac{k+m}{\beta} = \frac{1+m\Phi\beta\sigma^2}{1+\Phi\beta\sigma^2} < e^*$.

Since the expected production is: $Ey = e$, the net loss of expected production is:

$$\Delta Ey = \Delta e = e^* - e = \frac{1-k-m}{\beta} = \frac{\Phi\beta\sigma^2(1-m)}{\beta(1+\Phi\beta\sigma^2)} > 0 \quad (10)$$

The saving of effort cost is:

$$\Delta c = c(e^*) - c(e) = \frac{1-(k+m)^2}{2\beta} = \frac{2\Phi\beta\sigma^2(1-m) + \Phi^2\beta^2\sigma^4(1-m^2)}{2\beta(1+\Phi\beta\sigma^2)^2} > 0 \quad (11)$$

Then, the incentive cost is described as:

$$C_{i1} = \Delta Ey - \Delta c = \frac{\Phi\beta\sigma^2(1-m)}{\beta(1+\Phi\beta\sigma^2)} - \frac{2\Phi\beta\sigma^2(1-m) + \Phi^2\beta^2\sigma^4(1-m^2)}{2\beta(1+\Phi\beta\sigma^2)^2} = \frac{(1-m)^2\Phi^2\beta^2\sigma^4}{2\beta(1+\Phi\beta\sigma^2)^2} > 0 \quad (12)$$

$$C_{a1} = C_{r1} + C_{i1} = \frac{\Phi\sigma^2(1-m)^2}{2(1+\Phi\beta\sigma^2)^2} + \frac{(1-m)^2\Phi^2\beta^2\sigma^4}{2\beta(1+\Phi\beta\sigma^2)^2} = \frac{(1-m)^2\Phi\sigma^2(1-\Phi\beta^2\sigma^2)}{2\beta(1+\Phi\beta\sigma^2)^2} > 0 \quad (13)$$

Under a partial information condition, FAP suppliers need to consider the compensation costs they may have to pay if the supply is insufficient. Under this condition, the optimal effort level $e = \frac{1+m\Phi\beta\sigma^2}{1+\Phi\beta\sigma^2}$, and the cost of fresh produce suppliers during the operation of the supply chain is $\frac{(1-m)^2\Phi\sigma^2(1-\Phi\beta^2\sigma^2)}{2\beta(1+\Phi\beta\sigma^2)^2}$. Therefore, this paper employs a compensation ratio factor for designing the profit-sharing contract for the FAP supply chain.

3.4. Profit-Sharing Contract Considering Logistics Costs

When it is not feasible to accurately predict the demand-supply relationships, the supplier will either have the risk of losses due to the decay of the overstocked FAP or need to pay compensation due to insufficient product supplies. To eliminate this kind of dilemma, the design of the FAP supply chain profit-sharing contract should take into account the compensation costs, which is expected to stimulate the cooperation between the various partners in the agricultural product supply chain and thus improve the overall benefits. Moreover, with consumers' increased requirements on the quality of FAP and logistics services, e-commerce platforms have been requesting suppliers to set up an additional front warehouse to provide fast, timely, and accurate supporting services.

Theorem 3. *Under a partial information condition, to improve consumer satisfaction, e-commerce platforms require fresh agricultural product suppliers to erect an additional front warehouse. Therefore, an increased cost, b, is added to the fresh agricultural product suppliers, which can to some extent increase the e-commerce platform's profit shares, and also has the potential to reduce the incentive cost and total costs of the fresh agricultural product supply chain. Upon the establishment of the profit-sharing contract mechanism, the fresh agricultural product supplier can identify the optimal degree of effort, and each of the stakeholders in the supply chain can receive its optimal share so that the profits of each stakeholder can be maximized.*

Proof of Theorem 3. Under a partial information condition, assume b is the investment from the supplier to improve the operational condition of the supply chain, $b \sim N(0, \sigma^2)$. The amount of this investment is related to both external stochastic factors (such as government policies) and the e-commerce platform's utility function of purchasing agricultural products, y. To simplify the modeling, this paper assumes that b is not related to the supplier's degree of effort, e. □

To maximize profits, the e-commerce platform proposes an incentive contract: $\pi(y) = s + k(y + \gamma b) + m(y + \gamma b)$, where γ represents the correlation between the revenue of the e-commerce platform and b. If $\gamma = 0$, it means that the revenue of the e-commerce platform is not correlated to b. The principal consideration for fresh produce suppliers is to choose the optimal s, k and γ.

Given that the incentive contract is $\pi(y) = s + k(y + \gamma b) + m(y + \gamma b)$, the certainty equivalent revenue of FAP suppliers and logistics service providers is:

$$(1 - h(\theta(t)))\left[s + ke + me - \frac{1}{2}\beta e^2 - \frac{1}{2}\Phi k^2 var(y + \gamma b)\right] \quad (14)$$

After incorporating the corresponding relevance factor, we have:

$$(1 - h(\theta(t)))\left[s + ke + me - \frac{1}{2}\beta e^2 - \frac{1}{2}\Phi k^2\left(\sigma^2 + \sigma_b^2\gamma^2 + 2\gamma cov(y, b)\right)\right] \quad (15)$$

This formula describes the certainty equivalent revenue of fresh produce suppliers and logistics service providers, and it has a minimum guaranteed revenue u_0, so:

$$(1 - h(\theta(t)))\left[s + ke + me - \frac{1}{2}\beta e^2 - \frac{1}{2}\Phi k^2\left(\sigma^2 + \sigma_b^2\gamma^2 + 2\gamma cov(y, b)\right)\right] \geq u_0 \quad (16)$$

Based on the profit-sharing contract mechanism, the FAP suppliers are committed to optimizing their degree of effort to maximize the profits of the stakeholders in the entire FAP supply chain. The optimal degree of effort, e, is obtained by the derivation of Equation (9), where $e = \frac{k+m}{\beta}$.

Therefore, the expected revenue of the e-commerce platform is estimated as:

$$E(y - k(y + \gamma b) - m(y + \gamma b)) = -s + (1 - k - m)e \quad (17)$$

Accordingly, the optimal profit of the e-commence platform is depicted as follows:

$$\max_{s,k,m} = -s + (1-k-m)e - g \tag{18}$$

$$s.t\begin{cases} (1-h(\theta(t)))\left[s+ke+me-\frac{1}{2}\beta e^2-\frac{1}{2}\Phi k^2\left(\sigma^2+\sigma_b^2\gamma^2+2\gamma cov(y,b)\right)\right] \geq u_0 \\ e=\frac{k+m}{\beta} \end{cases} \tag{19}$$

Incorporating Equation (19) into Equation (18), we get:

$$\max_{s,k,m} = \frac{k+m}{\beta} - \frac{u_0}{1+\theta^t ln\theta} - \frac{(k+m)^2}{2\beta} - g - \frac{1}{2}\Phi k^2\left(\sigma^2+\sigma_b^2\gamma^2+2\gamma cov(y,b)\right) \tag{20}$$

By deriving k and γ in Equation (20), we have:

$$\frac{1}{\beta} - \frac{k+m}{\beta} - \Phi k\left(\sigma^2+\sigma_b^2\gamma^2+2\gamma cov(y,b)\right) = 0 \tag{21}$$

$$\gamma\sigma_b^2 + cov(y,b) = 0 \tag{22}$$

Based on Equation (21) and Equation (22), we have:

$$k = \frac{1-m}{1+\Phi\beta\left(\sigma^2 - \frac{cov^2(y,b)}{\sigma_b^2}\right)} \tag{23}$$

$$\gamma = -\frac{cov(y,b)}{\sigma_b^2} \tag{24}$$

Because $\sigma^2\sigma_b^2 \geq cov(y,b)$, so $0 < k < 1$.

Then, we added logistics spatio-temporal cost, b, to the FAP supply chain; the supply chain profit-sharing mechanism is designed to maximize the profits of all stakeholders in the supply chain. When γ is related to b, that is, $cov(y,b) \neq 0$, the share of the fresh produce supplier is $k = \frac{1-m}{1+\Phi\beta\left(\sigma^2-\frac{cov^2(y,b)}{\sigma_b^2}\right)} > \frac{1-m}{1+\Phi\beta\sigma^2}$; then, it can be found that after adding the logistics spatio-temporal cost b, the overall profit of the supply chain increases. This is due to the direct sales method, which reduces the logistics costs and loss costs that occur in the traditional indirect sales mode. This indicates that the direct sales mode could increase customer satisfaction, which leads to increased sales volume without reducing the original sales price and eventually increases the profit of the entire supply chain.

In addition, FAP suppliers may have to undertake a compensation cost caused by external factors; the compensation risk is estimated as:

$$var(\pi(y,b)) = \frac{(1-m)^2\left(\sigma^2 - \frac{cov^2(y,b)}{\sigma_b^2}\right)}{\left[1+\Phi\beta\left(\sigma^2 - \frac{cov^2(y,b)}{\sigma_b^2}\right)\right]^2}$$

Because $var(\pi(y)) = \frac{(1-m)^2\sigma^2}{(1+\Phi\beta\sigma^2)^2}$, $var(\pi(y,b)) < var(\pi(y))$.

As a result, the compensation cost is reduced accordingly, which further increases in the profits of the FAP supply chain.

For partial information conditions, it is necessary to take into account the changes in logistics spatio-temporal costs. In other words, adding a front warehouse to reduce the temporal cost of logistics and increase the profit sharing of the supply chain. Under this condition, the compensation cost is described as follows:

$$C_{r2} = \frac{1}{2}\Phi var(\pi(y,b)) = \frac{\Phi(1-m)^2\left(\sigma^2 - \frac{cov^2(y,b)}{\sigma_b^2}\right)}{2\left[1+\Phi\beta\left(\sigma^2 - \frac{cov^2(y,b)}{\sigma_b^2}\right)\right]^2}$$

The expected net loss of the fresh produce supplier is:

$$\Delta Ey = \Delta e = e^* - e = \frac{(1-m)\Phi\left(\sigma^2 - \frac{cov^2(y,b)}{\sigma_b^2}\right)}{1+\Phi\beta\left(\sigma^2 - \frac{cov^2(y,b)}{\sigma_b^2}\right)}$$

The saving of effort cost is:

$$\Delta C = C(e^*) - C(e) = (1-m)^2\frac{\Phi^2\beta(\sigma^2 - \frac{cov^2(y,b)}{\sigma_b^2})^2}{2\left[1+\Phi\beta\left(\sigma^2 - \frac{cov^2(y,b)}{\sigma_b^2}\right)\right]^2}$$

Incentive cost is:

$$C_{i2} = \Delta Ey - \Delta C = \frac{(1-m^2)\Phi^2\beta(\sigma^2 - \frac{cov^2(y,b)}{\sigma_b^2})^2}{2\left[1+\Phi\beta\left(\sigma^2 - \frac{cov^2(y,b)}{\sigma_b^2}\right)\right]^2}$$

Then, the costs incurred by the FAP supplier during the operation of the FAP supply chain are estimated as:

$$C_{a2} = C_{r2} + C_{i2} = \frac{\Phi(1-m)\left(\sigma^2 - \frac{cov^2(y,b)}{\sigma_b^2}\right)\left[1-m+(1+m)\Phi\beta\left(\sigma^2 - \frac{cov^2(y,b)}{\sigma_b^2}\right)\right]}{2\left[1+\Phi\beta\left(\sigma^2 - \frac{cov^2(y,b)}{\sigma_b^2}\right)\right]^2}$$

In summary, under a partial information condition, after increasing the investment of logistics cost, b, the share of each stakeholder in the FAP supply chain could be increased, and the corresponding incentives could also be increased accordingly. In the case of $cov(y,b) = 0$, the corresponding costs will not change; in the case of $cov(y,b) \neq 0$, the compensation cost and effort cost of FAP suppliers are reduced, thereby increasing the overall profits.

Theorem 4. *In the case of a partial information condition, to improve customer satisfaction, adding an additional front warehouse will change the profits of various stakeholders in the fresh agricultural product supply chain. The profit-sharing of e-commerce platforms decreases with the increase of time. With the changes in logistics spatio-temporal costs, the corresponding compensation costs will be reduced, and the reduction in compensation cost is larger than the increase in logistics service cost. When y and b are correlated, the profits of various stakeholders in the fresh produce supply chain will increase to a certain extent.*

Proof of Theorem 4. Under a partial information condition, after increasing the investment in logistics spatio-temporal costs, the corresponding profit-sharing contract mechanism will change. The profit function of FAP suppliers and logistics service providers is:

$$\pi_s = (1-h(\theta(t)))\Big\{s+ke+me-\tfrac{1}{2}\beta e^2-\tfrac{1}{2}\Phi k^2\left(\sigma^2+\sigma_b^2\gamma^2+2\gamma cov(y,b)\right) - \frac{\Phi(1-m)\left(\sigma^2-\frac{cov^2(y,b)}{\sigma_b^2}\right)\left[1-m+(1+m)\Phi\beta\left(\sigma^2-\frac{cov^2(y,b)}{\sigma_b^2}\right)\right]}{2\left[1+\Phi\beta\left(\sigma^2-\frac{cov^2(y,b)}{\sigma_b^2}\right)\right]^2}\Big\}$$

□

The first-order and the second-order derivatives of fresh produce suppliers' profit function with respect to Φ are presented as follows:

$$\frac{d\pi_s}{d\Phi} = -\frac{1}{2}(1-h)k^2\left(\sigma^2+\sigma_b^2\gamma^2+2\gamma cov(y,b)\right) - \frac{(1-m^2)\beta^2\left(\sigma^2-\frac{cov^2(y,b)}{\sigma_b^2}\right)^2}{2\left[1+\beta\Phi\left(\sigma^2-\frac{cov^2(y,b)}{\sigma_b^2}\right)\right]^2} + \frac{(1-m)\beta^2\left[\Phi\beta\left(\sigma^2-\frac{cov^2(y,b)}{\sigma_b^2}\right)-m+1\right]}{\left[1+\beta\Phi\left(\sigma^2-\frac{cov^2(y,b)}{\sigma_b^2}\right)\right]^3}$$

$$\frac{d^2\pi_s}{d\Phi^2} = \frac{\beta^3\left(\sigma^2-\frac{cov^2(y,b)}{\sigma_b^2}\right)^3\left[5m-1+\beta\Phi\left(\sigma^2-\frac{cov^2(y,b)}{\sigma_b^2}\right)(1+m)\right]}{\left[1+\beta\Phi\left(\sigma^2-\frac{cov^2(y,b)}{\sigma_b^2}\right)\right]^4} > 0$$

Since $\frac{d^2\pi_s}{dg^2} > 0$, the profit of FAP first increases and then decreases. There is a maximum value, that is, the profit will first increase and then decrease with Φ. When the utility y and the increased logistics space-time cost b have a correlation, that is, $cov(y,b) \neq 0$, $\frac{\Phi(1-m)\left(\sigma^2-\frac{cov^2(y,b)}{\sigma_b^2}\right)\left[1-m+(1+m)\Phi\beta\left(\sigma^2-\frac{cov^2(y,b)}{\sigma_b^2}\right)\right]}{2\left[1+\Phi\beta\left(\sigma^2-\frac{cov^2(y,b)}{\sigma_b^2}\right)\right]^2}$ is lower than when b is not added. Therefore, increasing investment in logistics spatio-temporal cost could reduce the costs in the supply chain operation process and increase the profit of the FAP supply chain.

For FAP suppliers,

$$\frac{d\pi_s}{dh} = s+ke+me-\frac{1}{2}\beta e^2-g-\frac{1}{2}\Phi k^2\left(\sigma^2+\sigma_b^2\gamma^2+2\gamma cov(y,b)\right) < 0$$

$$\frac{d^2\pi_s}{dh^2} = 0$$

Additionally, $h(\theta(t)) = -\theta t ln\theta$, so the profit of FAP suppliers increases with the increase of the loss rate, and decreases with the increase of the freshness θ.

For logistics service providers, the profit function is:

$$\pi_l = (1-h(\theta))me$$
$$h(\theta(t)) = -\theta^t \ln\theta$$

Therefore, h increases with the increase of t, and increases with the decrease of the freshness θ. Derive π_l with respect to h, and the outcome is:

$$\frac{d\pi_l}{dh} - me < 0$$

π_l decreases monotonically with respect to h, so the profit of fresh produce suppliers decreases as time t increases and decreases as freshness θ decreases.

For fresh produce suppliers, the profit function is described as follows:

$$\pi_r = (1 - h(\theta))(s + ke) - \frac{\Phi(1-m)\left(\sigma^2 - \frac{cov^2(y,b)}{\sigma_b^2}\right)\left[1 - m + (1+m)\Phi\beta\left(\sigma^2 - \frac{cov^2(y,b)}{\sigma_b^2}\right)\right]}{2\left[1 + \Phi\beta\left(\sigma^2 - \frac{cov^2(y,b)}{\sigma_b^2}\right)\right]^2}$$

$$h(\theta(t)) = -\theta^t \ln\theta$$

Therefore, h increases with the increase of t, and increases with the decrease of the freshness θ. Derive π_r with respect to h, and the outcome is:

$$\frac{d\pi_r}{dh} - (s + ke)$$

Since $s + ke > 0$, $\frac{d\pi_r}{dh} < 0$, π_r is monotonically decreasing with h, so the profit of fresh produce suppliers decreases with the increase of time, t, and decreases with the decrease of freshness, θ. □

By introducing logistics service costs and increasing investments, the profit-sharing contract of the FAP supply chain could be optimized, which on the one hand reduces the related compensation costs and on the other hand improves the degree of effort of the FAP suppliers. Besides this, it has the potential to optimize the supply chain of FAP and accordingly increase the profits for all stakeholders in the supply chain.

4. Numerical Example

In this section, a specific numerical example is employed to verify the proposed profit-sharing contract model for the FAP supply chain. The following parameter values are assumed: the cost coefficient of FAP $\beta = 0.8$; the minimum income of FAP $u_0 = 0.2$; the fixed revenue of all stakeholders in the FAP supply chain $s = 0.3$; natural disasters, Government subsidy policies, unexpected events, and other exogenous uncertain factors $x = 0.5$ with a variance $\sigma^2 = 0.9$; the covariance of investment cost, b, (front warehouse for FAP), $cov(y, b) = 0.6$. Based on these assumed parameter values, the following results could be generated.

When the loss rate of FAP and the compensation ratio of FAP suppliers are fixed values, assuming the loss rate $h = 0.2$, $\Phi = 0.9$, the shared profits of the FAP supply chain are estimated, as shown in Table 1.

Table 1. Profits of various stakeholders in the supply chain under various conditions.

Scenario	Profit (Ten Thousand CNY)			
	E-Commerce Platform	**Logistics Provider**	**FAP Supplier**	**Total**
Complete Information	0.2750	0.2000	0.2400	0.7150
Partial Information (without b)	0.0178	0.1370	0.4773	0.1442
Partial Information (with b)	0.0771	0.1609	0.65203	0.8899

From Table 1, it can be seen that under a complete information condition, the profits of e-commerce platforms and logistics service providers are higher than the profits under a partial information condition. This verifies the validity of Theorem 1. Moreover, by comparing the profits between complete and partial information conditions, it was found that under the same external factor, the profit obtained under a partial information condition is lower than under a complete information condition, which verifies Theorem 2. After adding an investment for A front warehouse, the total profit of the supply chain and profits of e-commerce platforms, logistics service providers, and FAP suppliers are all increased to some extent, indicating that Theorem 3 is valid.

Under a partial information condition, the loss of FAP and the compensation ratio of FAP suppliers have different impacts on the profit of the FAP supply chain. In this regard, to further verify the proposed models, we fixed one of the two parameters, and a sensitivity test was conducted for the other parameter to visualize the effect of the parameter on the profit of the fresh produce supply chain. The sensitivity testing results of FAP loss rate and FAP supplier compensation ratio on the profit of the supply chain are presented in Figures 2 and 3, respectively.

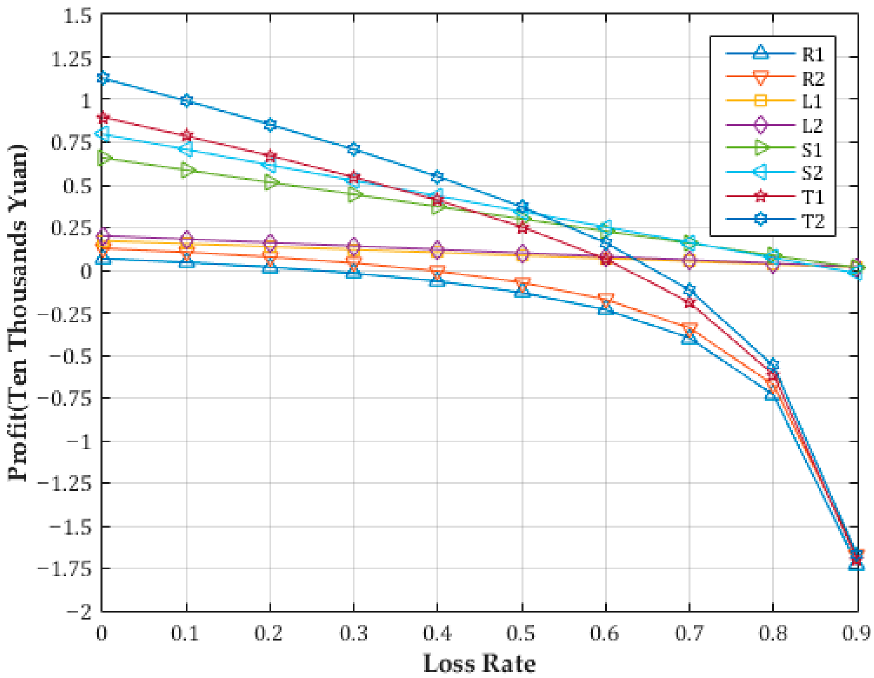

Figure 2. Effects of loss rate on the profit of the supply chain under a partial information condition.

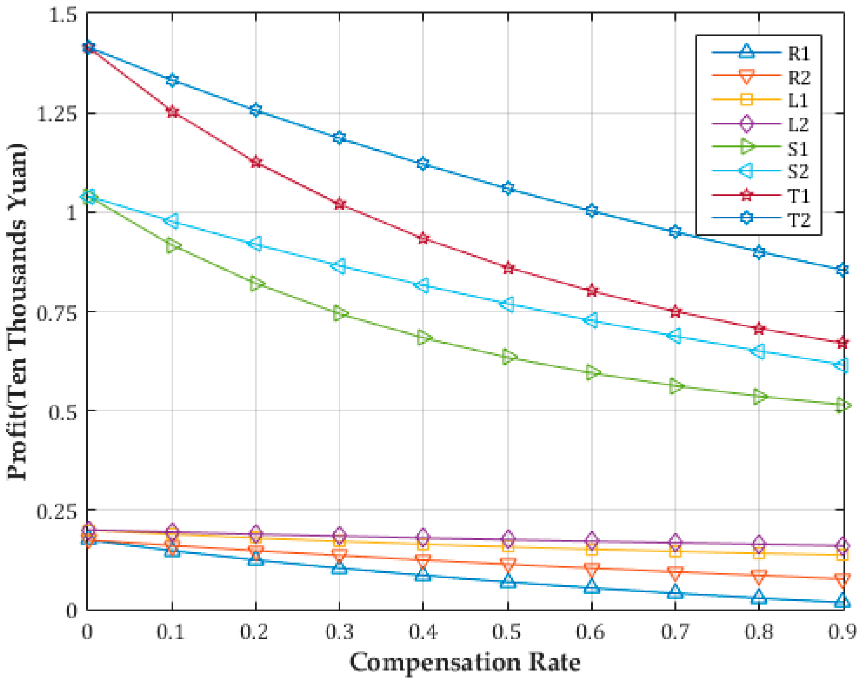

Figure 3. Effects of compensation ratio on the profit of the supply chain under a partial information condition.

Results show that when the fresh produce supplier's compensation ratio is fixed, with the increase in the loss rate, that is, the freshness decreases or the time increases, the total profit of the supply chain, as well as the profits of fresh produce suppliers, logistics service providers, and e-commerce platforms, have a decreasing trend. Similarly, when the loss rate is fixed, as the compensation ratio increases, decreasing trends in the profits were observed. In comparison, after adding the investment cost, b, the overall cost is reduced, so the profit of each stakeholder in the supply chain and the total profit are increased. This is in line with the conclusion from Theorem 4.

When the FAP supplier compensation ratio and the product loss rate change simultaneously, the profits of the FAP supply chain will also change accordingly, as shown in Table 2.

Table 2. Effects of parameters on the profit of various stakeholders under a partial information condition.

Profit (Ten Thousand CNY)							
E-Commerce Platform		**Logistics Provider**		**FAP Supplier**		**Total**	
Without *b*	**With *b***	**Without *b***	**With *b***	**Without *b***	**With *b***	**Without *b***	**With *b***
0.0784	0.1356	0.1769	0.2053	0.6865	0.8381	0.9422	1.1789
0.0562	0.1133	0.1592	0.1848	0.6116	0.7429	0.8274	1.0409
0.0284	0.0856	0.1415	0.1642	0.5367	0.6506	0.7070	0.9004
−0.0073	0.0498	0.1238	0.1437	0.4618	0.5568	0.6144	0.7504
−0.0549	0.0022	0.1061	0.1232	0.3869	0.4631	0.4385	0.5885
−0.1216	−0.0644	0.0885	0.1026	0.3120	0.3693	0.2792	0.4075
−0.2216	−0.1644	0.0708	0.0821	0.2371	0.2756	0.0866	0.1932
−0.3883	−0.3311	0.0531	0.0616	0.1622	0.1818	−0.1726	−0.0877
−0.7216	−0.6644	0.0354	0.0411	0.0873	0.0881	−0.5985	−0.5353
−1.7216	−1.6644	0.0177	0.0205	0.0124	−0.0057	−1.6911	−1.6496

It can be seen from Table 2 that when the loss rate of FAP and the compensation ratio of FAP suppliers change simultaneously, after adding an investment, b, for installing a front warehouse to improve the freshness of agricultural products, the profits of e-commerce platforms, logistics service providers, and FAP suppliers have all been increased, and this trend of change is in line with Theorem 3. The effect of these two parameters on the profit of the FAP supply chain is illustrated in Figure 4.

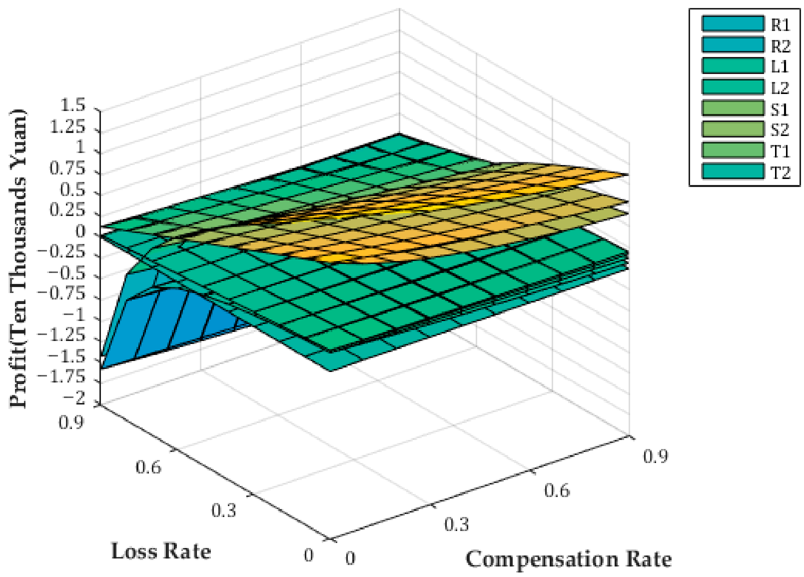

Figure 4. Combined effect of loss rate and compensation ratio on the profit of the supply chain under a partial information condition.

Under a partial information condition, due to the combined effects of loss rate and compensation ratio, the profits of various stakeholders in the supply chain have also been changed. From Figure 3, it was found that the profits decrease with the increase in the product loss rate. When the product loss rate is fixed, the profits of the supply chain decrease with the increase in compensation ratio. If both parameters change simultaneously, fluctuations in the profit of the FAP supply chain were observed. Therefore, the stakeholders in the FAP supply chain should negotiate and determine a reasonably expected degree of freshness and compensation ratio based on their expected revenues.

5. Concluding Remarks

This paper employs the freshness of FAP and logistics spatio-temporal cost as variables to develop FAP supply chain analytical models for modeling the profit-sharing contracts between the E-commerce platform, FAP suppliers, and logistics service providers. Three scenarios were considered: (1) complete information, (2) partial information, and (3) considering logistics spatio-temporal cost (intentionally including increases in logistics spatio-temporal costs to accommodate customer requirements). For each scenario, sales profits assigned to each of the three stakeholders in the supply chain were calculated, and the changes in sales profits were analyzed.

This paper reveals that in comparison with the two-level FAP supply chain that contains a supplier and a retailer, the three-level FAP supply chain under a direct sale mode has the potential to reduce the cost of logistics services and the loss of FAP, which eventually increases customer satisfaction. In general, it was found that the coordination between the various stakeholders in the FAP supply chain reduces the loss of FAP, improves the logistics services of FAP, and increases the profits of all stakeholders in the FAP supply chain. Details of the major findings from this research are presented as follows:

(1) Under a complete information condition, the relevant business information of all stakeholders in the FAP supply chain can be obtained, so there is no information asymmetry. The profit-sharing contract mechanism could allow all stakeholders in the FAP supply chain to obtain the maximum profits and could help with making the optimal investment decisions to maximize the shared profits of all stakeholders in the supply chain.

(2) In the case of partial information, due to consumers' ability to access marketing data, the quantity and quality of products supplied by FAP suppliers, and the sorting, packaging, transportation, and distribution capabilities of logistics service providers, etc., there are information asymmetries in the FAP supply chain. Moreover, each stakeholder in the FAP supply chain has a corresponding share of profit, which will also result in an uncertainty in information asymmetry. In practice, e-commerce platforms generally sign purchase and sales contracts prior to the production of FAP. Due to the existence of information asymmetry and the various stochastic factors that may affect the production of FAP, the amount of products produced may not match expectations. This will lead to compensation costs that need to be paid by the supplier. As a contrast, under a complete information condition, consumers are able to know the expected production of a certain agricultural product. Since there are many alternative varieties of the agricultural product, so consumers have multiple choices, which could help with eliminating additional costs due to the insufficient supply of the agricultural product. Obviously, the complete information condition tends to result in higher benefits to all the stakeholders of the supply chain. This also shows that the Internet of Things and Information Technology have been playing a significant role in promoting economic development and can make the FAP supply chain more coordinated.

(3) Under a partial information condition, to improve customer satisfaction, the e-commerce platform requires FAP suppliers to add front warehouses to ensure the freshness of the FAP. This option increases the cost of logistics services, while it has the potential to increase the profit of the e-commerce platform. Moreover, the profits of the logistics service providers and FAP suppliers could also be increased. The improvements in the overall profits of the entire supply chain show that improving customer satisfaction could increase the sales volume without reducing the price, thus increasing the revenue of the supply chain and optimizing the coordination of the supply chain. Findings from this research have the potential to direct capital investment to the FAP supply chain, such as having the supplier install a front warehouse to increase the profit of the supply chain.

(4) By analyzing the effects of the increases in the freshness of FAP on the shared profits of the supply chain, this research found that when the loss rate is fixed, the shared profit of the FAP supply chain shows a decreasing trend with the increase of the FAP supplier compensation ratio. On the other hand, when the FAP supplier compensation ratio remains unchanged, the shared profit reduces with the increase in the loss rate. Based on the above results, e-commerce platforms can purchase products with different degrees of freshness to accommodate various consumers and choose logistics service providers and FAP suppliers that meet their expectations. FAP suppliers can also choose the most suitable e-commerce that could maximize their profit.

It is worth pointing out that this research was based on a three-level FAP supply chain composed of a FAP supplier, a fixed logistics service provider, and an e-commerce platform. Future works may investigate more complex supply chains with multiple FAP suppliers, multi-level logistics service providers, and multiple e-commerce platforms. Besides this, this research assumes that exogenous factors, such as government policies, weather conditions, unforeseen events, etc. that may affect FAP suppliers and market demands follow a normal distribution, while in reality, these factors are more complicated. Moreover, this paper assumes that the profit share of logistics service providers is not less than 20%, but in practice, this profit share may be less than 20%. Future research works need to calibrate these factors based on real-world data, and conduct sensitivity analysis to quantify the effects of each factor on FAP supply chain operations.

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