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Analysis of Competitiveness in Agri-Supply Chain Logistics Outsourcing: A B2B Contractual Framework

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Abstract: COVID-19 has left some permanent effects on the Regional Agri-Supply Chain (RASC). It has single-handedly accelerated the RASC's performance through the globalization of local products and increased e-agri-business, virtual retailing trends, and smart logistics and warehousing services. The post-COVID worldwide growing demand for regional agri-products has increased the competitiveness in logistics outsourcing. Motivated by these changing notions, this paper addresses two major questions—whether the competitiveness in logistics outsourcing allows the supply chain drivers (supplier, retailer, and 3PL) to form a sustainable B2B pricing supply chain model, and what will be 3PL firms' strategic decisions to secure sustainable profit under this competitiveness? In the light of competitive literature, this paper proposes two decision-making approaches, optimistic and pessimistic, models them using the Stackelberg game theory, and solves them using the subgame perfect Nash equilibrium. The result shows that, even after competitiveness in logistics outsourcing, the supply chain drivers agree to form a contractual supply chain. However, the competitive strategy-making of 3PL firms is a little tricky. Each focal 3PL firm must have perfect information about the peer firm's strategic movement to choose its preferable strategy. Further, they can preferably constrain their core competencies (service price and quality level) to assure a sustainable profit.

Keywords: 3PL competitiveness; logistics outsourcing; agri-supply chain; B2B contract; global cashew-supply chain

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1. Introduction

With a reduced number of COVID cases throughout the world, different food processing industries, logistics firms, and international borders began to restore primarily for trade and business purposes. However, COVID-19 has left widespread effects on the agri-supply chain, business, and marketing. COVID-19 has reduced the production rate of various mass-producing food-processing industries. At the same time, it has significantly enhanced the performance of the regional agri-supply chain (RASC) [1]. Previously, the RASC performed within a small geographical boundary, and the farmers or the local retailers used to sell products in physical markets. However, with the post-COVID growth of e-commerce portals [2], regional products have gained a global platform. The RASC can better meet the economic, environmental, and socially sustainable development goals compared to conventionally produced food [3]. These RASCs can also provide consumers with more fresh, nutritious, and less-pesticide-affected agri-products [4,5]. This transformation has led to increasing worldwide demand for high-nutrient-content regional food. However, the RASC, driven by smallholder farmers and retailers, still lacks sufficient infrastructure in the logistics section to build an organized supply chain and pricing structure.

With the globalization of products, e-commerce in the agri-supply chain has been trending, even in pre-COVID times. After spreading coronavirus diseases, a significant percentage of the physical market stopped and converted into e-commerce portals. Different small and large retailers have started e-commerce portals. E-commerce is successfully

trending, even in the post-COVID situation, because it offers retailers low risk in terms of inventory loss, price declination, and bargaining loss. At the same time, it increases the geographical market region and offers consumers a wide variety and range of products [6]. Moreover, IoT and Blockchain technologies [7] offer the consumers a transparent vision of the product and its supply chain.

With the rapid increase in e-commerce retailing, the need for logistics outsourcing has achieved critical significance. Over the years, researchers have discussed and acknowledged that logistics outsourcing enhances the performance of agri-supply chains [8–10]. E-commerce giant retailers have identified the importance of logistics outsourcing and effectively invested in it. For example, Amazon in the US and JD in China increased investment in logistics outsourcing in post-COVID times by more than 80% [11]. With the up-gradation of the RASC to a global platform, different 3PL logistics firms are actively participating in global logistics of regional agri-products. This notion has given rise to the concept of pseudo 4PL in the agri-supply chain, especially for RASC. Accenture introduced the concept of 4PL (Fourth Party Logistics) in 1998. Unlike 3PL, 4PL performs as an integrator that assembles resources, capabilities, and technologies of its own organization and other organization (3PL) to design, build, and operate comprehensive supply chain solutions [12]. In recent times, a few local retailers (start-ups) have expressed themselves as virtual enterprises, having only a registered online e-commerce portal. In most cases, they use social media marketing to achieve global demand. These virtual enterprises contribute to designing, building, and operating a global supply chain through 3PL firms, but lack sufficient capital to develop their own resources and technologies. Thus, they are named pseudo-4PL. They make one B2B contract with local farmers or suppliers for the product and another B2B contract with international 3PL firms for logistics service facilities worldwide. These start-ups mostly use bootstrap funding and outsource the logistics through reputed 3PL firms. For example, in India, several bootstrap agri-companies, such as Fruit Box and co., GoFarmz, Freshokartz, and Ninjacart, effectively sell fresh agri-products throughout the world.

The growth of 3PL firms in logistics outsourcing has led to competitiveness amongst the 3PL firms. Each agri-3PL firm works with a variety of e-commerce retailers. Thus, each firm wants to maximize its market share. Previously, 3PL firms used to provide only transportation services. With the growing complexity and efficiency of the supply chain, 3PL firms have integrated a variety of services, including both conventional and refrigerated transportation [13], smart warehousing [14], and dedicated contract carriers [15]. Thus, a wide variety of diversification in strategic and service portfolios keeps the 3PL focused on competitiveness [16]. Earlier, De and Singh [17] discussed the agri-pricing and supply chain problem amongst suppliers, e-commerce retailers, and 3PL firms, considering monopoly in logistics outsourcing. However, strategy making under competitiveness is more challenging and complex. Thus, extensive literature on agricultural logistics outsourcing, competitiveness in logistics outsourcing, and e-agribusiness is necessary to highlight the research gaps and focus on primary research objectives. The rest of the paper is structured as follows. Section 2 presents the Literature review, Section 3 presents the problem statement and mathematical model, Section 4 presents the theoretical results, Section 5 presents a numerical illustration of the cashew supply chain case, Section 6 presents the discussion, and Section 7 presents the conclusion and future research scope.

2. Literature Review

As this literature review is concerned with agricultural logistics outsourcing, competitiveness in logistics outsourcing, and e-agribusiness, this section is divided into several subsections to focus on the particular domains.

2.1. Literature on Logistics Outsourcing in Agriculture

The term logistics outsourcing came into the market in the late 1970s. However, the growing B2C e-commerce in the late 1990s caused a rapid change in the market. Different production firms started outsourcing logistics to compete with their peers and achieve

greater market share. Thus, the 3PL firms earned a streamlined force in the late 1990s and early 2000s. The literature on logistics outsourcing is highly enriched. We have primarily discussed the papers with methodological contributions in logistics outsourcing in agri-pricing and the supply chain.

The primary research on logistics outsourcing application in agri-pricing and the supply chain was performed by Kuiper and Meulenberg [18]. They developed a two-stage pricing decision model for the supplier–retailer channel considering fresh vegetable logistics in the Netherlands. However, this study was bounded within a small geographical area, lacked the essence of global logistics, and did not consider qualitative aspects of logistics outsourcing. Later, various studies addressed the two main barriers in agri-logistics outsourcing, quantity loss [19,20] and quality loss [21,22]. The impact and enhancement of different service parameters, such as transportation [23], packaging [24], and distribution [25], significantly affect supply chain drivers' profits in logistics service outsourcing. Later, researchers identified and worked on enhancing sustainable service parameters, such as logistics' green service level [26], delivery timing and duration [27], and the product's freshness level [28] to capture the market demand.

Global logistics always deal with more variation in transportation mode and different transportation constraints, such as international boundary policies and delays in ports. The contribution to reducing the supplier–retailer bottleneck [29], waiting time, and carbon emission level [30] of a sustainable agri-supply chain is significant. In a developed notion, green innovation [31] and long-term B2B contracts for sustainable price evaluation [32] have contributed to forming more robust methodologies. Concerning the post-COVID disruption in the cold supply chain service, Tang et al. [33], in analyzing a suitable leadership strategy, De and Singh [17], in improving supply chain resiliency, and Yu and Xiao [13], in enhancing the sustainable logistics service level through different market attractive schemes under a B2B contract, have made significant contributions. However, most of these studies addressed a single echelon supply chain and did not consider competitiveness amongst the peer firms within the same echelon.

2.2. Literature on Competitiveness in Agri-Logistics Outsourcing

As this study concerns competitive modeling in logistics outsourcing, the extensive literature on competition in logistics outsourcing is also presented. Market competitiveness in the duopoly is a prevalent and rich topic. A significant number of researchers [34–38] used the game-theoretic model to capture competitiveness under market duopoly. However, those studies primarily incorporated the competition between independent players. There are a few research articles that consider competitiveness in the agri-supply chain. Most of them considered competitiveness from either the supplier's end [39] or the retailer's end [22]. Competitiveness in logistics outsourcing is a relatively new topic related to growing 4PL in the agri-supply chain. While different 4PL firms outsource the logistics through 3PL firms, it generates competitiveness amongst the 3PL firms. Mellat-Parasat and Spillan [40] analyzed the competitiveness in logistics outsourcing and whether it will benefit logistics firms or not. They presented an empirical study to investigate the importance of information and process updates to the competitiveness of logistics outsourcing. Sangka [41] analyzed the importance of logistics firms' individual competencies to cope with the up-growing global competition. Nematollahi et al. [15] examined the competitive and cooperative logistics outsourcing strategies in a closed-loop agri-supply chain. Barker et al. [16] conducted an empirical study to analyze the effect of service facility diversification amongst 3PL firms in a competitive logistics outsourcing environment. Thus, there have been limited studies on strategy making in the competitive logistics outsourcing environment, which hardly helps the 3PL firms to identify optimal strategies.

2.3. Literature on E-Agribusiness

There is a positive relationship between the logistics outsourcing of firms and performance in the e-agribusiness [42]. Thus, with the growing trend of logistics outsourc-

ing, e-agribusinesses rapidly seized the market. In COVID and post-COVID times [43], e-agribusinesses in the RASC gained sharp growth and started making an effective contribution to the globalization of local agri-products. E-agribusiness considers four typical transactional supply chain models, B2B (transaction between business and business), B2C (direct transaction between business and customer), C2B (transaction between customer and business), and C2C (transaction between customer and customer). Scholars conducted a comparative analysis of these supply chain models. They found that B2B in e-commerce is likely to have a promising future in agribusiness, especially in supermarket applications [44,45]. Later, different researchers discussed critical factors regarding the B2B supply chain model in e-commerce. Clarity, preciseness, and dynamicity in the portal update play essential roles in B2B transactions [46]. Yu and Zhao [47] analytically proved that logistics service quality is one of the critical factors of the B2B supply chain model of e-commerce.

Though logistics outsourcing in agri-e-commerce had early applications in the 2000s, it became widely accepted in the early and mid-2010s. Chen et al. [48] discussed the effects of logistics outsourcing in e-agribusiness. With the growing trend of globalization of local agri-products, different researchers contributed to supply chain and logistics models. Strzebicki [49] discussed the barriers of B2B contractual e-agribusiness. Gharehgozli et al. [6] discussed the sustainable strategic development of logistics outsourcing in e-agribusiness. Gupta et al. [50] empirically analyzed the impact of e-agribusiness on sustaining product freshness levels. Yadav et al. [51] investigated the importance of suitable logistics partner selection, and Priyadarshini and Avilash [52] analyzed India's post-COVID e-governance policy in light of RASC. He et al. [39], by developing a logistics resource-sharing policy between supplier and retailer, Zhao and Tian [53], by providing a service-provider-driven centralized policy to accumulate the local producer, Cristobal-Fransi et al. [54] and Liu et al. [55], by proposing a rural e-commerce policy to enhance e-agribusiness, made significant contributions to e-agribusiness policymaking. However, this sector is currently more focused on the globalization of regional products and increasing the efficiency of RASC, and there is a research deficit in e-agribusiness models capturing the post-COVID competitive socio-economic market behavior.

2.4. Research Gaps

The extant literature discusses how the B2B contractual supply chain models have developed themselves over the years and adapted to the dynamic changes in supply chain structure, pricing policy, market, and socio-economic conditions. However, in practice, especially in the post-COVID era, the models failed to integrate the growing competitiveness in the agri-supply chain.

First, the agri-logistics outsourcing literature lacks models addressing competition within the same echelon or competition within the homogenous drivers.

Second, the literature lacks a competitive strategy-making framework in logistics outsourcing and policymaking perspective in multi-echelon B2B contractual supply chains.

Third, the e-agribusiness literature also does not correctly address the high randomness in growing e-commerce portals and the lack of reliability in customers' socio-economic behavior.

2.5. Research Questions

These research gaps lead to a few questions from the perspective of competitive strategy making in agri-logistics outsourcing. These questions are the primary motivation of this research. Therefore, they were formulated and written as research questions.

RQ1: Would the drivers of the supply chain (suppliers, e-commerce retailers, and 3PL firms) collaborate to form a price equilibrium state under competitiveness in logistics outsourcing? If yes, what will be each driver's equilibrium price and service quality?

RQ2: What would be the optimal strategy of 3PL firms to avoid market share loss under competitiveness in logistics outsourcing?

RQ3: How would the 3PL firms balance their core competencies to enhance their expected profit gain under post-COVID competitive market notions?

2.6. Contribution of This Study

Our study aims to address the research gaps by contributing to the literature in three ways.

First, this study formulates a multi-echelon B2B contractual agri-pricing and supply chain framework for high-nutrient-content fresh agri-products. The proposed framework integrates a variety of products and consumer classes by incorporating different socio-economic classes into a single framework. We modeled the proposed framework using Stackelberg sequential game modeling and solved it using the sub-game perfect Nash equilibrium. The model first analyzed whether there was an equilibrium state among suppliers, retailers, and 3PL firms. Then, the model derived the pricing policy of suppliers and retailers and the service quality of 3PL firms under that equilibrium state.

Second, this study contributes to the conventional logistics outsourcing literature by adding market competition in logistics outsourcing within the same echelon. In light of duopoly market competition, we formulated two different competitive strategies, i.e., Optimistic and Pessimistic. Our developed model compared these competitive strategies with each other in terms of higher expected profit, positive market share gain, price gain of individual drivers, stochastic demand of the market, and service quality of logistics firms. This model also prescribed that the 3PL firms should have a suitable balance between the service quality level and service price to maintain sustainability under competitiveness in logistics outsourcing.

Third, this study contributes to the theoretical perspective of the B2B contractual supply chain by adapting it to the post COVID changing pattern of agribusiness. In light of changing global supply chain patterns, this study adopts the transformation of conventional e-commerce retailers to pseudo-4PL retailing firms and the transformation of the traditional logistics service to smart logistics and warehousing services.

3. Problem Statement and Mathematical Model

3.1. Agri-Supply Chain Problem Statement and Its Modeling

This study considers a B2B contractual supply chain, where the retailers buy the suppliers' produce, sell it in their e-commerce portals, and outsource the logistics through 3PL firms. Here, we have used the term '*contractual*' to emphasize the supply chain pattern. The supply chain contains two different pricing contracts. The first one is between the supplier and the retailer over the suppliers' wholesale price. The second one is between the retailer and the 3PL firm over the service price and 3PL service quality level. The authors have used the term '*B2B (Business to Business)*' because pricing and service quality decisions only involve contractual decisions among supply chain drivers or actors (though drivers and actors reflect the same meaning in this supply chain, this paper has used the term 'Drivers' instead of 'Actors' to connect the paper with the past literature and maintain the tradition of using the particular word, 'Drivers') (suppliers, retailers, and 3PL firms). Here, the supplier supplies each unit of ith fresh agri-products to the mth retailer at a price, w_{im}. The product being fresh agri-products, the suppliers are primarily farmers. The ith product incurs a farming cost c_{si}.

The farming cost of each product is different and it depends on the product's nutrient content. The 3PL firms ensure the quality and freshness level of these agri-products during transportation through the cold logistics service. Here, the kth 3PL firm sets a service charge u_{ik} for procuring per unit of the ith product. The kth 3PL firms incur the costs of packaging, processing, transportation, cold-service, and cross-docking charges in international borders, which are accumulated and reflected through the transportation cost c_{ik}^{T}. The mth retailer sets a price of p_{im} for i^{th} product, displayed in its e-commerce portal. Figure 1 schematically represents the supply chain and pricing.

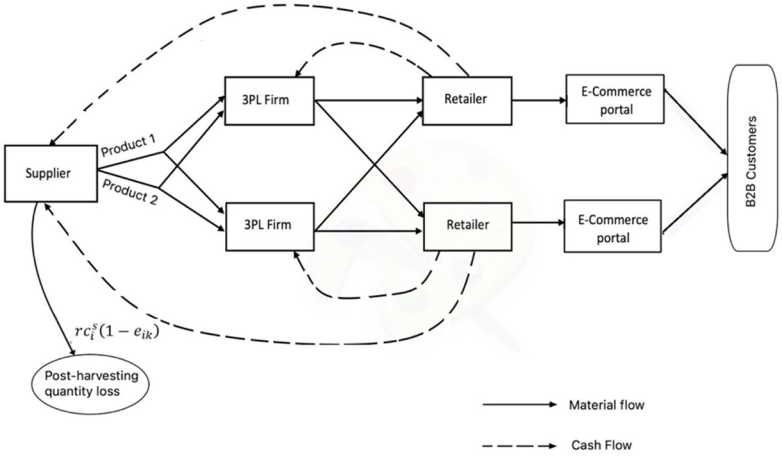

Figure 1. B2B supply chain schematic of competitiveness in logistics outsourcing.

Following the law of demand for fresh agri-products [22], consumers' demand is price and quality-sensitive. The impact of price on the consumer's demand is simply negative and can be easily represented as $b_m p_{im}$. Here, $b_m > 0$ and represents the average price sensitivity coefficient of the consumer-availing e-commerce portal of the mth retailing firm. The impact of the product's quality on consumer demand is positive. The '*quality*' term includes a mixed impact of the 3PL firm's logistics service quality and the product's freshness.

Let y measure the cold service level $y \in [0,\ 1]$, which is defined by logistic firms. For simplicity, Yu and Xiao [28] considered $e = y/\overline{y}$ to normalize the service quality level. From $y_{ik} \in [0,\ \overline{y}\ ]$, $e_{ik} \in [0,\ 1]$. Here, essentially, the service quality level is also considered as normalized.

Now, let us assume that the coefficient of cold service to the product's freshness level for the kth 3PL firm is η_k, and the quality of cold service level of the k^{th}3PL firm for the ith product is e_{ik}. Thus, the freshness level of the ith product, by considering it as outsourced by the k^{th}3PL firm, is represented in Equation (1) as follows.

$$\theta_{ik} = \eta_k e_{ik} \tag{1}$$

This function [56] indicates that the freshness level of the product (θ_{ik}) is an increasing differentiable function of service quality, e_{ik}.

We integrated the impact of the product's price and quality, and represent the stochastic demand of the ith product in the mth retailing portal through Equation (2), as follows.

$$Dem_{im} = D_{im} - b_m p_{im} + h_{mk}\theta_{ik}(\forall i, m, k) \tag{2}$$

where D_{im} represents the demand class of the ith product at the mth retailing portal, considering that the cold transportation service is conducted by the kth 3PL firm. Here, h_{mk} is the product's freshness sensitivity coefficient of the mth retailing portal, by considering that the logistics service is provided by the kth 3PL firm. $h_{mk} > 0$.

Now, the product's quality sensitivity coefficient (β_{mk}) equals the multiplication of the product's freshness sensitivity coefficient (h_{mk}) and coefficient of the cold service to the product's freshness level (η_k), which is represented in Equation (3).

$$\beta_{mk} = h_{mk}\eta_k(\forall m, k) \tag{3}$$

Now, substituting the value of θ_{ik} in Equation (2), and then substituting the value of $h_{mk}\eta_k$ in Equation (2), we obtain the modified value of the stochastic demand of the ith product in the mth retailing portal through Equation (4).

$$Dem_{im} = D_{im} - b_m p_{im} + \beta_{mk} e_{ik}(\forall i, m, k) \tag{4}$$

It is assumed that the ith suppliers, m^{th} retailers, and k^{th} 3PL firms coordinate through a pricing contract, where the supplier chooses a wholesale price w_{im}, the retailer chooses the market price p_{im}, and the 3PL firm chooses the service price u_{ik} and service quality level e_{ik}. This B2B contractual supply chain is consistent in the pricing and logistics outsourcing domain [13]. The growth of the global supply chain has given rise to competitiveness in logistics outsourcing. The competitiveness amongst the 3PL firms is described in the following section. A detailed list of parameters and variables is presented in Table A1 (Appendix A) for the ease of the readers.

3.2. Competitiveness in Logistics Outsourcing (Market Duopoly) and Its Modeling

The literature on supply chain competitiveness identifies two primary forms of competition, sequential and parallel. Sequential competition, also known as Stackelberg, occurs between two distinct drivers, and this competition mainly integrates competition over price and supply chain leadership. There is already significant research regarding Stackelberg competition. However, parallel competition, also known as perfect competition, exists between firms within the same echelon, and has been left unconsidered primarily by researchers. This paper addresses parallel competition in logistics outsourcing under a three-tier agri-supply chain, consisting of the supplier, retailer, and 3PL firms.

From the basic notion of perfect competition, 3PL firms are price-takers [57]. However, considering the market imperfectness in a real scenario [58], 3PL firms focus on maximizing their market share gain through enhancing their core competencies [59]. Barker et al. [16] also established how service portfolio diversification benefits 3PL firms' marginal profit under imperfect competition. A 3PL firm, which escalates the refrigerated logistics and procurement service, considers its service quality, goodwill, and low-price portfolio as primary core competencies and advertise their unique selling proposition (USP). Though core competency is generally a qualitative term, the authors are more concerned with the quantitative terms associated with these competencies in this paper. In this case, service quality level and price are the main parameters associated with core competency. They modify the basic definition of the service attributes of the 3PL firm to relative attribute gain and relative attribute loss under perfect competition. Figure 2 characterizes the scenario of parallel competition in logistics outsourcing.

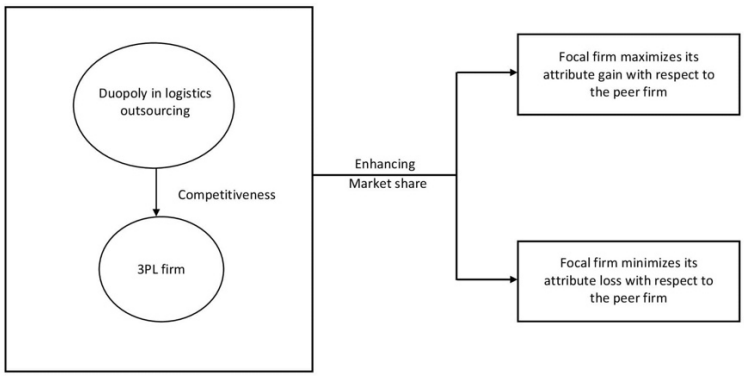

Figure 2. Competitiveness in logistics outsourcing.

In order to maximize their market share gain, 3PL firms can perform in two ways. The focal 3PL firm can either maximize its relative attribute gain (optimistic approach) or minimize its relative attribute loss (pessimistic approach) concerning its peer firm. The term '*peer*' is used instead of '*rival*' to emphasize that both 3PL firms are fulfilling the societal food need.

Thus, under the optimistic approach, the relative attribute gain of the ith product for the kth 3PL firm is represented in Equation (5).

$$A_{ik}^{G} = \frac{e_{ik}}{e_{il}} - \frac{u_{ik}}{u_{il}} (\forall i, k) \quad (5)$$

Here, the ratio $\frac{e_{ik}}{e_{il}}$ defines the gain of the kth 3PL firm in the service quality attribute, with respect to its peer l^{th} 3PL firm. Similarly, the ratio $\frac{u_{ik}}{u_{il}}$ defines the gain of the kth 3PL firm in the service price attribute, with respect to its peer l^{th} 3PL firm. Here, the core competency of the service quality level is directly, and the core competency of the service price is inversely proportional to the relative service attribute gain of the kth 3PL firm.

Thus, the market share gain of the kth 3PL firm for the ith product is represented in Equation (6). Physically, M_{ik}^{Op} defines how much additional market share the kth 3PL firm is gaining for the ith product due to its strategic value (service quality level and service price) selection under perfect competition in logistics outsourcing.

$$M_{ik}^{Op} = \frac{A_{ik}^{G}}{\sum_k A_{ik}^{G}} (\forall i, k) \tag{6}$$

Similarly, under the pessimistic approach, the relative attribute loss of the ith product for the kth 3PL firm is represented in Equation (7).

$$A_{ik}^{L} = \frac{e_{il}}{e_{ik}} - \frac{u_{il}}{u_{ik}} (\forall i, k) \tag{7}$$

The ratio $\frac{e_{il}}{e_{ik}}$ defines the loss of the kth 3PL firm in the service quality attribute, with respect to its peer l^{th} 3PL firm. Similarly, the ratio $\frac{u_{il}}{u_{ik}}$ defines the loss of the kth 3PL firm in the service price attribute with respect to its peer l^{th} 3PL firm.

Here, the market share gain of the kth 3PL firm for the ith product is represented (Equation (8)) through relative attribute loss. Physically, lower relative attribute loss results in a higher market share gain, and vice versa.

$$M_{ik}^{P} = 1 - \frac{A_{ik}^{L}}{\sum_k A_{ik}^{L}} (\forall i, k) \tag{8}$$

4. Results

Assuming that the supply chain drivers facilitate a B2B contractual approach, this paper presents two stages of the decision-making model. The first stage facilitates strategic decision making between the optimistic and the pessimistic approaches. The second stage coordinates between the supply chain drivers and facilitates the pricing and service quality decision. In the second stage, we adopted a sequential game considering the 3PL firm as the leader, where each driver sets its equilibrium pricing and service quality decisions. However, the first stage deals with selecting strategic decisions by the 3PL firms, whose profit and relative attributes are two aspects of this investigation. Therefore, the decision making in the second stage is considered and followed by the strategic decision of the first stage. We investigated and derived the decisions of the first and the second stages by applying backward induction. Thus, the derivation of the first stage was followed by the derivation of the second stage.

4.1. Derivation of Pricing Decisions of Supply Chain Drivers

This section derives the optimal pricing and service quality decisions under equilibrium by assuming that the 3PL firm's strategic decision is fixed. As the entire physical flow of the product is handled by the 3PL firms, gain or loss in their market share affects the total expected demand of the market. Thus, the stochastic demand of the ith product in the mth retailing portal (Equation (2)) modifies itself to the expected demand by multiplying by the marginal market share gain (Equation (9)).

$$Dem_{im}^{Ex} = M_{ik}(D_{im} - b_m p_{im} + \beta_{mk} e_{ik}) (\forall i, m) \tag{9}$$

Based on the previous section, the expected profit gain of each supply chain driver is the product of their expected demand and profit per unit of served demand. Therefore, the expected profit gain of the retailer, supplier, and the 3PL firm is represented in Equations (10)–(12).

Expected profit gain of the mth retailer

$$\pi_m^R = \sum_i \sum_k M_{ik}(D_{im} - b_m p_{im} + \beta_{mk} e_{ik})(p_{im} - w_{im} - u_{ik})(\forall m) \tag{10}$$

Expected profit gain of the ith supplier

$$\pi_i^s = \sum_m \sum_k M_{ik}(D_{im} - b_m p_{im} + \beta_{mk} e_{ik})\{w_{im} - c_i^s - rc_i^s(1 - e_{ik})\}(\forall i) \tag{11}$$

According to Zhang et al. [60], researchers described the total quantity loss in cold-chain logistics as $(1 - y/\overline{y})r$, where r is the basic quantity loss rate $r \in [0, 1]$ without a cold-supply logistics service. In our case, the basic quality loss rate is essentially the post-harvesting loss rate from the supplier's end. Thus, the extra cost of the supplier due to post-harvesting loss is $rc_i^s(1 - e_{ik})$.

Expected profit of the kth 3PL firm

$$\pi_k^{3PL} = \sum_m \sum_i M_{ik}(D_{im} - b_m p_{im} + \beta_{mk} e_{ik})\left(u_{ik} - c_{ik}^T\right) - \sum_i \sum_m \frac{\lambda_k e_{ik}^2}{2}(\forall k) \tag{12}$$

A service cost $\frac{\tau y^2}{2}$ is incurred by logistic firms, where τ reflects the service cost efficiency of the 3PL service level in the cold supply chain [61]. Likewise, $\tau \overline{y}^2 = \lambda$, where λ represents the service to cost ratio of the logistics firm [28]. In our case, λ_k is the service quality to service cost ratio of the kth 3PL firm, and the term $\frac{\lambda_k e_{ik}^2}{2}$ defines the cost incurred by the kth 3PL firm to establish cold-logistics-associated technology.

Now, we start to form the retailer's price p_{im}, considering a fixed post-harvesting loss rate r from the supplier. Then, sequentially, we will derive the supplier's wholesale price and the 3PL firm's service quality and service price.

4.1.1. Derivation of the Retailer's Price

Differentiating the expected profit gain of the mth retailer (Equation (10)) with respect to p_{im}, we get $\frac{\partial^2 \pi_m^R}{\partial p_{im}^2} < 0$, which helps to derive Lemma 1.

Lemma 1. *For any given supplier's wholesale price w_{im}, the retailer's expected profit gain π_m^R is concave over the retailer's price p_{im}, and Equation (13) represents the optimal retailer's price under equilibrium.*

$$p_{im}^*(w_{im}) = \frac{D_{im}}{2b_m} + \frac{w_{im}}{2} + \frac{\sum_k u_{ik} M_{ik}}{2} + \sum_k M_{ik} \beta_{mk} e_{ik}(\forall i, m) \tag{13}$$

Proof. Please find the proof in Appendix B. □.

Lemma 1 provides the best response of the retailer's price $p_{im}^*(w_{im})$. It is clear from Equation (13) that $\frac{\partial p_{im}^*}{\partial w_{im}} > 0$. This means that the more the supplier's wholesale price will be, the more the retailer's price. Now, the following derivation is associated with the supplier's wholesale price.

4.1.2. Derivation of the Supplier's Wholesale Price

Equation (13) shows that the retailer's optimal price is a function of the supplier's wholesale price. It means that the retailer already knew the supplier's wholesale price while choosing the optimal price. Now, we are interested to know whether the supplier's

expected profit gain function ensures an optimal supplier's wholesale price or not. This leads us to Lemma 2.

Lemma 2. *For any given service quality e_{ik} and service price u_{ik} of 3PL firms, the supplier's expected profit gain π_i^s is concave over the supplier's wholesale price w_{im}, and Equation (14) represents the optimal supplier's price under equilibrium.*

$$w_{im}^* = \frac{D_{im}}{2b_m} + \frac{c_i^s}{2}(1+r) - \frac{\sum_k M_{ik}u_{ik}}{2} + \sum_k \frac{M_{ik}e_{ik}}{2}\left(\frac{\beta_m}{b_m} - rc_i^s\right)(\forall i, m) \tag{14}$$

Proof. Please find the proof in Appendix C. □.

Lemma 2 provides the best response of the supplier's wholesale price w_{im}^*. It is clear from the contract-making point between the supplier and the retailer that the supplier's wholesale price is independent of any pricing variables. However, the market demand is stochastic and dependent upon service quality. Thus, the total profit of the supplier has indirectly become a function of the 3PL firm's service quality and service price.

4.1.3. Derivation of 3PL Firm's Service Quality and Service Price

Here we consider another contract between the retailer and the 3PL firm. It is clear from the leadership diagram that the retailer sets its price after the 3PL firm sets its service quality and service price. Thus, the retailer's optimal price reflects the 3PL firm's expected profit gain function (as mentioned in Equation (12)).

Now, we are interested in two fundamental questions: Does the 3PL firm's profit function satisfy itself as a bivariate concave function? If it satisfies, what is the necessary condition for that? These two questions give rise to Lemma 3.

Lemma 3. *The 3PL firm's profit π_k^{3PL} can only be expressed as a bivariate concave function if Equation (15) holds.*

$$\sum_m M_{ik}^2\left(\frac{\lambda_k}{2}M_{ik} + \frac{3\beta_{mk}^2 M_{ik}}{2b_m} - \frac{rc_i^s\beta_{mk}M_{ik}}{2}\right) \geq \sum_m \left\{\beta_{mk}^2 + M_{ik}^2\left(\frac{9\beta_{mk}^2}{16b_m} + \frac{r^2 c_i^{s^2}}{16} - \frac{3\beta_{mk}rc_i^s}{8b_m}\right)\right\}(\forall i,\ k) \tag{15}$$

Proof. Please find the proof in Appendix D. □.

Equation (15) is essentially the Kuhn–Tucker condition of convexity. If the condition is satisfied and the equilibrium service quality and pricing decision holds, we need to find the optimal service quality and price value under equilibrium, which leads to Theorem 1.

Theorem 1. *If a 3PL firm's expected profit gain π_k^{3PL} satisfies the Kuhn–Tucker condition and expresses itself as a bivariate concave function of the service quality level and service price, that firm essentially satisfies an equilibrium pricing contract with the retailer and the supplier as well.*

The value of the optimal service quality level (e_{ik}^*) provided by the kth 3PL firm for the ith product under equilibrium state is represented in Equation (16).

$$e_{ik}^* = \frac{(u_{ik}^* - c_{ik}^T)}{\lambda_k}\sum_m \left\{\beta_{mk} - \frac{M_{ik}}{4}M_{ik}\left(\frac{3\beta_{mk}}{b_m} - rc_i^s\right)\right\}(\forall i, k) \tag{16}$$

The value of the optimal service price (u_{ik}^*) provided by the kth 3PL firm for the ith product under equilibrium state is represented in Equation (17).

$$u_{ik}^* \leq c_{ik}^T + \frac{\lambda_k}{\sqrt{\left(\frac{\lambda}{2}M_{ik} + 3\sum_m \frac{\beta_{mk}^2 M_{ik}}{2b_m} - rc_i^s\sum_m \frac{\beta_{mk}M_{ik}}{2}\right)}}(\forall i, k) \tag{17}$$

The value of the optimal supplier's wholesale price (w^*_{im}) *of the* i^{th} *product for the* m^{th} *retailer under equilibrium state is described in Equation (18).*

$$w^*_{im} = \frac{D_{im}}{2b_m} + \frac{c^s_i}{2}(1+r) - \frac{\sum_k M_{ik}u_{ik}}{2} + \sum_k M_{ik}e_{ik}\left(\frac{\beta_m}{2b_m} - \frac{rc^s_i}{2}\right)(\forall i, m) \tag{18}$$

The value of the optimal retailer's price (p^*_{im}) *of the* i^{th} *product for the* m^{th} *retailer under equilibrium state is described in Equation (19).*

$$p^*_{im} = \frac{3D_{im}}{4b_m} + \frac{c^s_i}{4}(1+r) + \frac{\sum_k M_{ik}u_{ik}}{4} + \frac{\sum_k M_{ik}e_{ik}}{4}\left(\frac{3\beta_{mk}}{b_m} - rc^s_i\right)(\forall i, m) \tag{19}$$

Proof. Please find the proof in Appendix E. □.

Now,

$$p^*_{im} - w^*_{im} = \frac{D_{im}}{4b_m} - \frac{c^s_i}{4}(1+r) + \frac{3\sum_k M_{ik}u_{ik}}{4} + \frac{\sum_k M_{ik}e_{ik}}{4}\left(\frac{\beta_{mk}}{b_m} + rc^s_i\right) \tag{20}$$

$$\frac{\partial\left(p^*_{im} - w^*_{im}\right)}{\partial r} = \frac{c^s_i}{4}\left(\sum_k M_{ik}e_{ik} - 1\right) \tag{21}$$

Since M_{ik} and e_{ik} cover the [0–1] region, $(\sum_k M_{ik}e_{ik} - 1)$ does not have a high positive value. Thus, price competition between supplier and retailer does not have a high correlation with the post-harvesting loss rate.

Theorem 1 characterizes the optimal pricing and the service quality decisions under equilibrium state among the supplier, the retailer, and the 3PL firm. However, we are yet to analyze the impact of competitiveness among 3PL firms.

This study concerns competitiveness among 3PL firms considering duopoly in logistics outsourcing. Thus, the expected profit gain of kth focal 3PL not only depends on its service quality and price decisions, but also fluctuates due to the peer firm's strategic deviations. This concept leads us to calculate the impact of service quality and price deviation $(e^*_{il}, u^*_{il}\ ; \forall l \in k)$ of the peer firm to the focal 3PL firm's expected profit gain, considering that both the firms are already at equilibrium. This leads us to form Corollary 1. Note that the service price and the service quality have positive relations with the 3PL firm's expected profit gain; here, deviation always refers to a positive deviation. ∂u^*_{il}, $\partial e^*_{il} > 0$.

Corollary 1. *Considering all 3PL firms are at an equilibrium state, if the* l^{th} *peer firm increases its service price by a unit, the* k^{th} *focal firm can still avoid a negative impact on its expected profit gain only if it already achieves an essential market share* M^{Sp}_{ik}*, where*

$$M^{Sp}_{ik} = 1 - 2\left(\sum_m \frac{3\beta_{mk}}{b_m}\left\{\frac{\lambda_k}{(3\beta_{mk} - b_m rc^s_i)} + \sum_m \beta_{mk} + rc^s_i\right\}\right)^{\frac{1}{2}}(\forall i, k) \tag{22}$$

Proof. Please find the proof in Appendix F. □.

Corollary 1 analyzes the impact of the unit service price deviation of the focal firm on peer firms. Next, we will analyze the impact of the peer 3PL firm's unit service quality deviation to the focal firm's profit, which results in Corollary 2.

Corollary 2. *Considering all 3PL firms are at an equilibrium state, if the lth peer firm increases its service quality level by a unit, the kth focal firm still can avoid a negative impact on its profit only if it already achieves an essential market share M_{ik}^{Sq}, where*

$$M_{ik}^{Sq} = 2\left(\frac{\sum_m \beta_{mk}}{\sum_m \left(rc_i^s - \frac{3\beta_{mk}}{b_m}\right)}\right)^{\frac{1}{2}} (\forall i, k) \tag{23}$$

Proof. Please find the proof in Appendix G. □.

It is clear that 3PL firms need to ensure a high market share gain to avoid a negative impact on expected profit gain, irrespective of whether the focal firm increases its service quality level or service price. Thus, to have a secured expected profit, each 3PL firm must ensure a market share of $\max\left\{M_{ik}^{Sp}, M_{ik}^{Sq}\right\}$. Now, it is also the case that market share gain is not an independent parameter and is closely related to the competitive strategic approach and the values of service quality level and service price. The next section focuses on the strategic decisions of 3PL firms.

4.2. Competitiveness Strategies of 3PL Firms

As discussed in Section 2, competitiveness strategies hold importance for individual focal 3PL firms to gain more market share and profit margin than the peer firm. Section 2 describes the theory of optimistic and pessimistic strategies. The study has already shown that the supply chain drivers satisfy a price equilibrium state. Thus, it is assumed that the focal and the peer 3PL firms are initially at their particular equilibrium strategic values of the service price and quality. This section is interested in deriving the impact of the peer logistics firm's strategic movement (from the equilibrium state) on the focal firm's market share change and vice versa. The formulation and derivation of both strategies will help the 3PL firms to facilitate the right strategic decisions.

4.2.1. Optimistic Strategy

As described in Section 3.2, Equation (5) shows the relative attribute gain of the kth focal 3PL firm for the ith product, considering an optimistic strategy in the logistics outsourcing duopoly. Equation (6) shows the market share gain for the same strategy. Now, the derivation shows the impact on the market share and suggests to the focal firm a wise selection of strategic parameters to avoid market share loss under the optimistic strategy.

Lemma 4.

(a) Under the optimistic strategy, a unit increase in the peer firm's strategic value regarding service quality and service price will never have a unidirectional (positive or negative) impact on the kth focal 3PL firm's market share gain.

(b) Under the optimistic strategy, when the kth focal firm chooses the service quality level and service price,

$$u_{il}^*\left(u_{ik}^* - c_{ik}^T\right)\sum_m \beta_{mk} > \lambda_k e_{il}^* u_{ik}^*; \tag{24}$$

(i) Percentile deviation of the kth focal 3PL firm's market share gain is negative with respect to the unit change of the peer's service quality from equilibrium state.

(ii) Percentile deviation of the kth focal 3PL firm's market share gain is positive with respect to the unit change of the peer's service price from equilibrium state.

Proof. Please find the proof in Appendix H. □.

4.2.2. Pessimistic Strategy

As shown in Section 3.2, Equation (7) shows the relative attribute loss of the kth focal 3PL firm for the ith product, considering a pessimistic strategy in the logistics outsourcing duopoly. Equation (8) shows the market share for the same strategy. Now, the derivation shows the impact on the market share and suggests the focal firm a wise selection of strategic parameters to avoid market share loss under the pessimistic strategy.

Lemma 5.

(a) Under the pessimistic strategy, a unit increase in the peer firm's strategic value regarding service quality and service price will never have a unidirectional (positive or negative) impact on the kth focal 3PL firm's market share gain.

(b) Under the pessimistic strategy, when the kth focal firm chooses the service quality level and service price,

$$\frac{M_{ik}^{P^*2}\left(2u_{il}^{*}+3M_{ik}^{P^*}u_{ik}^{*}\right)}{4} > \frac{u_{ik}^{*}\sum_m \beta_{mk}}{\sum_m\left(\frac{3\beta_{mk}}{b_m}-rc_i^s\right)}; \tag{25}$$

(i) Percentile deviation of the kth focal 3PL firm's market share gain is positive with respect to the unit change of the peer firm's service quality from the equilibrium state.

(ii) Percentile deviation of the kth focal 3PL firm's market share gain is negative with respect to the unit change of the peer firm's service price from the equilibrium state.

Proof. Please find the proof in Appendix I. □.

Lemmas 4 and 5 summarize the effect of the peer firm's service quality and pricing strategy change on the focal firm's market share gain. The lemmas help to establish a wise selection of competitive strategy. The selection of competitive strategy and supply chain parameters is summarized in Theorem 2.

Theorem 2.

- *If the peer firms are more concerned about positive changes in service quality, the focal firm must choose the pessimistic strategy over the optimistic strategy and set its service price and service quality level to satisfy Equation (24) to have a positive impact on the market share gain.*
- *If the peer firms are more concerned about positive changes in service price, the focal firm must choose the optimistic strategy over the pessimistic strategy and set its service price and service quality level to satisfy Equation (25) to have a positive impact on the market share gain.*

Note that the value of the service price and quality are interlinked and formulated as an inequality. Thus, deriving a direct proposition to test the superiority of a competitive strategy over another is not possible. In the later sections, the simulation is formulated and a case study is presented to compare and justify the competitive strategies with a real-life problem.

4.3. Model

The simulation model is concerned about maximizing each 3PL firm's market share in this competitive duopoly environment. The simulation is formulated as a Non-Linear Programming Problem and coded and solved in LINGO. The formulation is as follows.

4.3.1. Formulation for Optimistic Approach

Objective function:

Maximizing the focal 3PL firm's relative attribute gain with respect to the peer firm represented in Equation (26).

$$A^G = \sum_i \sum_k \left(\frac{e_{ik}^{op}}{e_{il}^{op}} - \frac{u_{ik}^{op}}{u_{il}^{op}} \right) \tag{26}$$

Subject to constraints:

$$M_{ik}^{Op} = \frac{e_{ik}^{op} u_{il}^{op} - u_{ik}^{op} e_{il}^{op}}{u_{il}^{op}\left(e_{ik}^{op} + e_{il}^{op}\right) - e_{il}^{op}\left(u_{ik}^{op} + u_{il}^{op}\right)} (\forall i,k) \tag{27}$$

$$M_{ik}^{Op} + M_{il}^{Op} = 1 (\forall i) \tag{28}$$

$$e_{ik}^{op} = \frac{\left(u_{ik}^{Op} - c_{ik}^{T}\right)}{\lambda_k} \sum_m \left\{ \beta_{mk} - \frac{M_{ik}^{op}}{4} M_{ik}^{op} \left(\frac{3\beta_{mk}}{b_m} - rc_i^s \right) \right\} (\forall i,k) \tag{29}$$

$$e_{il}^{op} = \frac{\left(u_{il}^{Op} - c_{il}^{T}\right)}{\lambda_l} \sum_m \left\{ \beta_{ml} - \frac{M_{il}^{op}}{4} M_{il}^{op} \left(\frac{3\beta_{ml}}{b_m} - rc_i^s \right) \right\} (\forall i,l) \tag{30}$$

$$u_{ik}^{op} \le c_{ik}^{T} + \frac{\lambda_k}{\sqrt{\left(\frac{\lambda_k}{2} M_{ik} + 3\sum_m \frac{\beta_{mk}^2 M_{ik}^{op}}{2b_m} - rc_i^s \sum_m \frac{\beta_{mk} M_{ik}^{op}}{2} \right)}} (\forall i,k) \tag{31}$$

$$u_{il}^{op} \le c_{il}^{T} + \frac{\lambda_l}{\sqrt{\left(\frac{\lambda_l}{2} M_{il} + 3\sum_m \frac{\beta_{ml}^2 M_{il}^{op}}{2b_m} - rc_i^s \sum_m \frac{\beta_{ml} M_{il}^{op}}{2} \right)}} (\forall i,k) \tag{32}$$

$$u_{il}^{op}\left(u_{ik}^{op} - c_{ik}^{T}\right) \sum_m \beta_{mk} > \lambda_k e_{il}^{op} u_{ik}^{op} (\forall i,k) \tag{33}$$

Here, the objective (Equation (26)) is for maximizing each of the kth focal 3PL firm's relative gain in optimistic strategy with respect to the lth peer firm. Equation (27) describes the market share of the kth focal 3PL firm for the ith product. Equation (28) depicts that the total market share of the kth focal 3PL firm and its lth peer firm will be equal to one. Equations (29) and (30) describe the service quality of the kth focal 3PL firm and the lth peer firm, respectively. Equations (31) and (32) describe the maximum service price of the kth focal 3PL firm and l^{th} peer firm, respectively. Equation (33) directs the market share gain of the kth focal 3PL firm toward a positive value.

4.3.2. Formulation for the Pessimistic Approach

Objective function:

Minimizing the focal 3PL firm's relative attribute loss with respect to the peer firm represented in Equation (34).

$$A^L = \sum_i \sum_k \left(\frac{e_{il}^{P}}{e_{ik}^{P}} - \frac{u_{il}^{P}}{u_{il}^{P}} \right) \tag{34}$$

Subject to constraints:

$$M_{ik}^{P} = \frac{\left(e_{ik}^{P} + e_{il}^{P}\right)\left(u_{ik}^{P} + u_{il}^{P}\right)\left(e_{il}^{P} u_{ik}^{P} - e_{ik}^{P} u_{il}^{P}\right)}{e_{ik}^{P} u_{ik}^{P}\left\{e_{il}^{P}\left(u_{ik}^{P} + u_{il}^{P}\right) - u_{il}^{P}\left(e_{ik}^{P} + e_{il}^{P}\right)\right\}} (\forall i,k) \tag{35}$$

$$M_{ik}^{P} + M_{il}^{P} = 1 (\forall i) \tag{36}$$

$$e_{ik}^{P} = \frac{\left(u_{ik}^{P} - c_{ik}^{T}\right)}{\lambda_k} \sum_m \left\{ \beta_{mk} - \frac{M_{ik}^{P}}{4} M_{ik}^{P} \left(\frac{3\beta_{mk}}{b_m} - rc_i^s \right) \right\} (\forall i, k) \tag{37}$$

$$e_{il}^{P} = \frac{\left(u_{il}^{P} - c_{il}^{T}\right)}{\lambda_l} \sum_m \left\{ \beta_{ml} - \frac{M_{il}^{P}}{4} M_{il}^{P} \left(\frac{3\beta_{ml}}{b_m} - rc_i^s \right) \right\} (\forall i, l) \tag{38}$$

$$u_{ik}^{P} \le c_{ik}^{T} + \frac{\lambda_k}{\sqrt{\left(\frac{\lambda_k}{2} M_{ik}^{P} + 3 \sum_m \frac{\beta_{mk}^2 M_{ik}^{P}}{2b_m} - rc_i^s \sum_m \frac{\beta_{mk} M_{ik}^{P}}{2} \right)}} (\forall i, k) \tag{39}$$

$$u_{il}^{P} \le c_{il}^{T} + \frac{\lambda_l}{\sqrt{\left(\frac{\lambda_l}{2} M_{il}^{P} + 3 \sum_m \frac{\beta_{ml}^2 M_{il}^{P}}{2b_m} - rc_i^s \sum_m \frac{\beta_{ml} M_{il}^{P}}{2} \right)}} (\forall i, k) \tag{40}$$

$$\frac{M_{ik}^{P\,2} \left(2u_{il}^{P} + 3M_{ik}^{P} u_{ik}^{P}\right)}{4} > \frac{u_{ik}^{P} \sum_m \beta_{mk}}{\sum_m \left(\frac{3\beta_{mk}}{b_m} - rc_i^s \right)} (\forall i, k) \tag{41}$$

Here, the objective (Equation (34)) is for minimizing each of the kth focal 3PL firm's relative losses in pessimistic strategy with respect to the lth peer firm. Equation (35) describes the market share of the kth focal 3PL firm for the ith product. Equation (36) depicts that the total market share of the focal 3PL firm and its lth peer firm will be equal to one. Equations (37) and (38) describe the service quality of the kth focal 3PL firm and l^{th} peer firm, respectively. Equations (39) and (40) describe the maximum service price of the kth focal 3PL firm and l^{th} peer firm respectively. Equation (41) directs the market share gain of the kth focal 3PL firm towards positive values.

5. Numerical Illustration: A Case of the Indian Cashew Supply Chain

This section illustrates the proposed theorem and lemmas with numerical values, compares the results, and presents them in graphical form. The main motive of this section is to establish a bridge between theory and practice so that the e-agribusiness drivers gain a new direction toward their profitability and sustainability. However, this study is not a mere numerical exercise, but rather an accumulation of data from open internet sources [62,63] and pseudo value generation.

Cashew, a popular ingredient of luxurious sweets and beverages, has also fulfilled the need for protein and vitamin consumption for years. According to medical research, cashew helps to decrease body cholesterol and reduces the chances of heart diseases. Thus, in the post-COVID scenario, the increasing high-nutrient-content dry fruit demand has converted cashew into essential food from a luxurious food and caused a spike in the trend of cashew consumption (38.6% increment from 2012–2019) throughout the world [64]. India is one of the top cashew-producing countries, followed by Ghana and Vietnam. However, unlike the West African countries, India lags in cashew export and value chain [65]. The main reasons behind India's inefficient cashew value chain are the impreciseness in fetching local producers in the 'Cashew Development Corporation of India' platform, limited investments in global cashew logistics [66], inadequate refrigeration during long-duration transportation, and growth of bacterial and fungal infections [67]. Thus, this study is concerned about upgrading the cashew global logistics service by enhancing competitiveness in logistics outsourcing and ensuring a sustainable profit to each driver.

India produces two highly productive cashew seeds, BPP6 and VRI2. The BPP6 seed (average yield of 9–11 kg per tree and 4–5 g nut weight) primarily produces W400 kernel grade (24% shelling). The VRI2 seed (average yield of 6–8 kg per tree and 4–6 g nut weight) primarily produces W320 kernel grade (28.30% shelling). These cashew kernels, produced and supplied by suppliers (S1 and S2), are sold on the global online platform by two virtual retailing firms (R1 and R2) after being procured, processed, and packaged by two giant smart logistics firms (L1 and L2). Figure 3 illustrates the cashew supply chain.

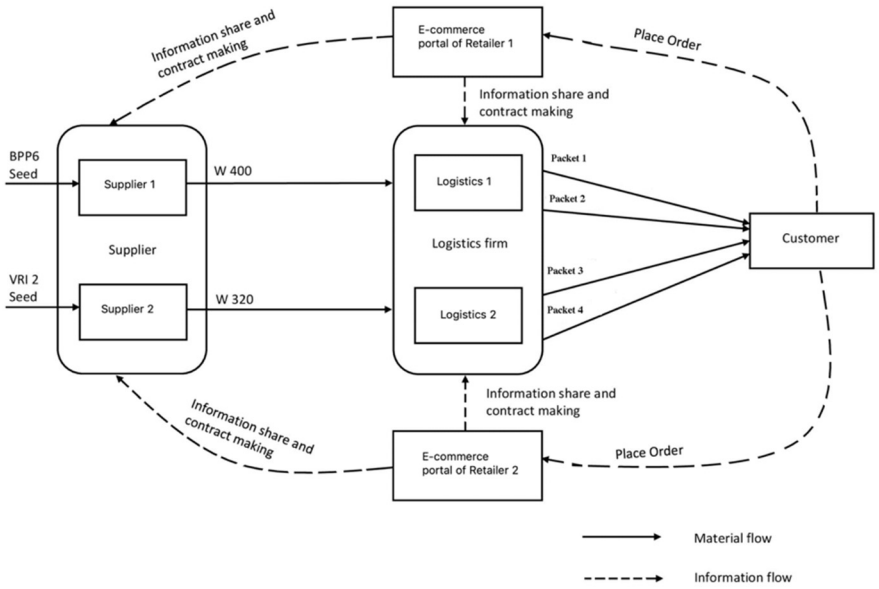

Figure 3. Schematic of the Indian cashew supply chain.

There are several cost and market parameters associated with each driver of the supply chain, which are already described in Table A1 (Appendix A). For this case study, the values of these parameters are noted in Table 1.

Table 1. Values of different parameters.

Parameter	Value				
Demand (D_{im})		W400		W320	
	Retailer R1	1000		700	
	Retailer R2	800		1400	
Price sensitivity coefficient (b_m)	Retailer R1	0.505			
	Retailer R2	0.595			
Quality sensitivity coefficient (β_{mk})		Logistics L1		Logistics L2	
	Retailer R1	17.2		15.8	
	Retailer R2	16.5		13.6	
Service to cost factor (λ_k)	Logistics L1		Logistics L2		
	0.5		0.6		
Post-harvesting loss rate (r)	[0–0.45]				
Farming cost of product (c_i^s)	BPP6 seed to W400 grade		VRI2 seed to W320 grade		
	500		400		
Transportation cost (c_{ik}^T)		Packet 1	Packet 2	Packet 3	Packet 4
	Logistics 1	80	65	-	-
	Logistics 2	-	-	72	45

6. Discussion

Traditional literature has already informed us about the benefits of the competitive market over the monopoly. This result enriches the literature by analyzing the effect of imperfect competition in logistics outsourcing and prescribing suitable strategies for 3PL firms. This result also identifies the impact of the post-harvesting loss rate on all of the supply chain drivers. The detailed output data set is presented in Appendix J.

6.1. Effect of Retailer's Price on Retailer's Expected Profit Function

As depicted in Equation (10), the retailer's expected profit is a concave function of the retailer's price variable (Lemma 1). In simple words, profit starts increasing with price. At a particular price point, the profit is highest and then decreases. That particular price point is essentially the retailer's price under equilibrium. Figure 4 shows the retailer's profit function.

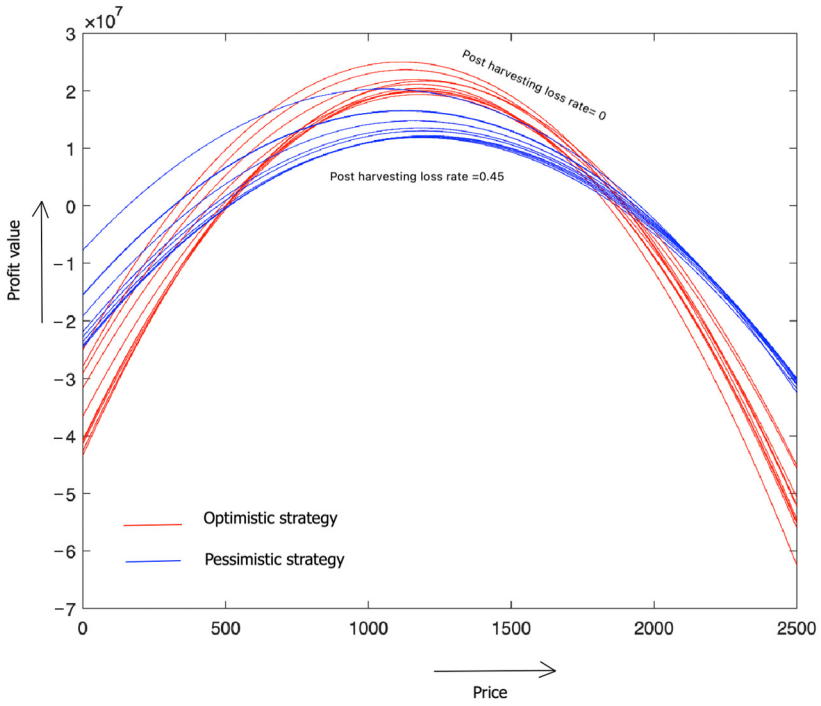

Figure 4. Total retailer's profit in various strategies.

The post-harvesting loss rate has an impact on the retailer's expected profit function. The figure also shows that, despite the retailer's price under equilibrium being fixed, the retailer's expected profit starts decreasing with increasing post-harvesting loss rate.

6.2. Retailer's Price under Equilibrium

The retailer's price under equilibrium is essentially the price at which the retailer's expected profit is highest. The market is not an absolute price-taker. The products have different farming costs, service quality levels, and processing costs. Thus, the market price varies for different products. Under equilibrium, the post-harvesting loss rate negatively impacts the retailer's price (Equation (21)). However, the equilibrium price tries to maintain stability, even in a high post-harvesting loss rate, to gain a sustainable profit. Figure 5a–d represents the retailer's prices under equilibrium for different products and different retailers.

6.3. Effect of Supplier's Price on Supplier's Expected Profit Function

As depicted in Equation (14), the supplier's expected profit is a concave function of the supplier's wholesale price (Lemma 2). Essentially, the supplier's wholesale price under equilibrium serves as the best-expected profit to the supplier. Figure 6 represents the supplier's profit function.

The supplier's profit is much more affected by a high post-harvesting loss rate, as they have to pay an extra cost to compensate for the quantity loss or fulfill the supply chain's required demand. This is well represented in Figure 6, as we can see that the profit bunch contains a bit more of a gap as compared to the retailer's expected profit.

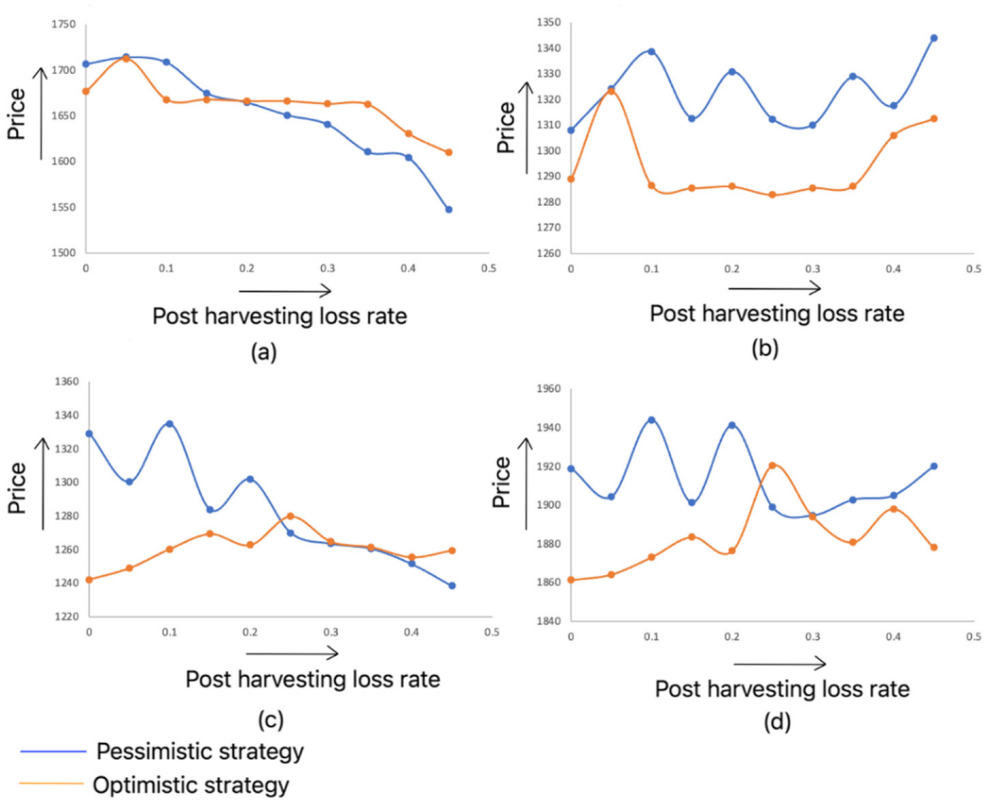

Figure 5. Retailer's price for different products under different strategies. (**a**) Price of packet 1 on the online portal of Retailer 1; (**b**) Price of packet 2 on the online portal of Retailer 2; (**c**) Price of packet 3 on the online portal of Retailer 1; (**d**) Price of packet 4 on the online portal of Retailer 2.

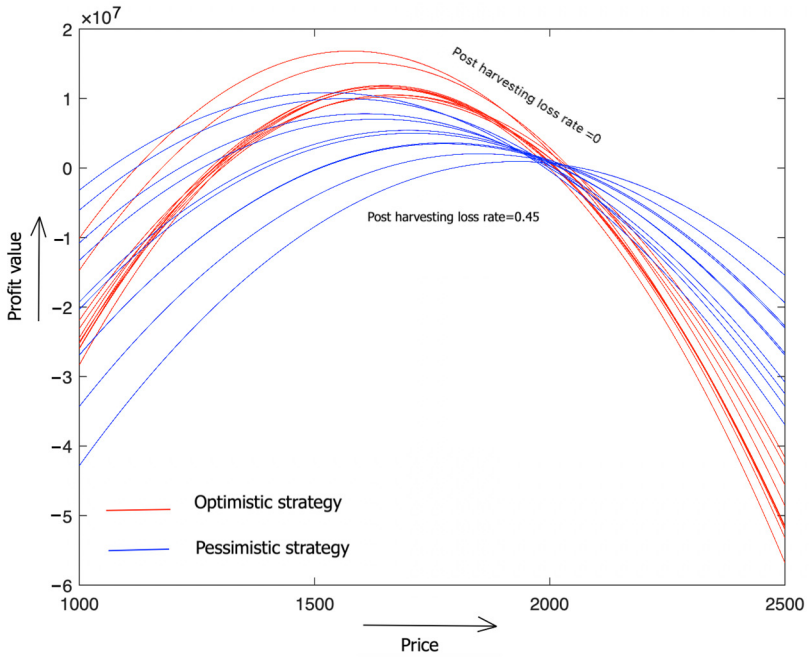

Figure 6. Total supplier's profit in various strategies.

6.4. Supplier's Price under Equilibrium

In the current B2B and B2C market, price competition between drivers does not have a very good competitive advantage. Our mathematics (Equations (22) and (23)) also indicate this. Thus, practically, the supplier's wholesale price is almost a replica of the retailer's

wholesale price under equilibrium. Figure 7a–d represents the supplier's wholesale prices for different product and different retailers.

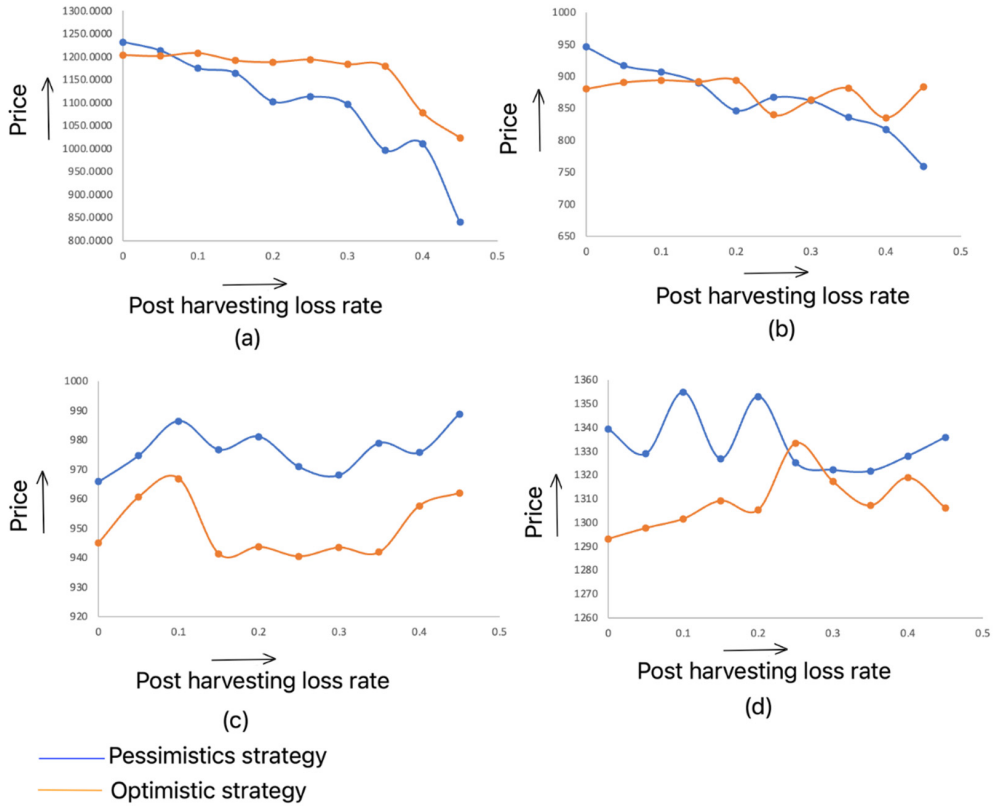

Figure 7. Supplier's wholesale prices for different products in different strategies. (**a**) Price of 'W400' Cashew nut to Retailer 1; (**b**) Price of 'W320' Cashew nut to Retailer 1; (**c**) Price of 'W400' Cashew nut to Retailer 2; (**d**) Price of 'W320' Cashew nut to Retailer 2.

6.5. 3PL Firm's Service Quality under Equilibrium

The 3PL firm's service quality is subject to the product's nature and quality. For example, more perishable products require a higher cold service level than less perishable products. Competitiveness in logistics outsourcing encourages the firms to have a more attractive and balanced relation with the service quality level and service, so that each focal firm assures a gain in market share. Thus, the relation between service quality and service price is quite distinguishable for different competitive strategies. Figure 8 reflects the relation between service quality and service price, and establishes the philosophy of different competitive strategies.

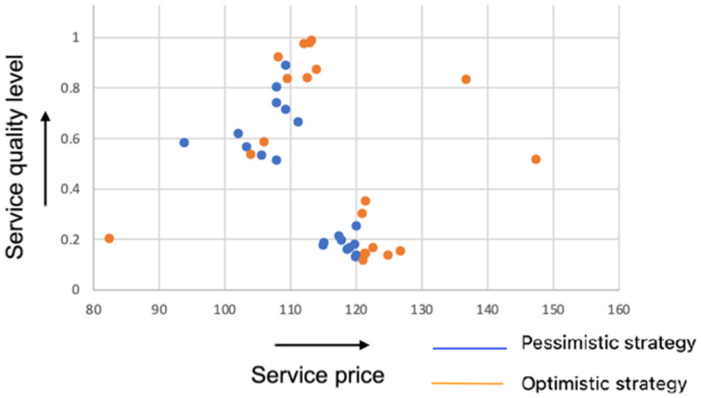

Figure 8. 3PL firm's service quality level.

The two clusters reflect the service quality and price of 3PL firms for cashew kernels W400 and W320. Despite the product-wise clusters, this scatterplot indicates that the pessimistic strategy recommends a more concentrated output than the optimistic strategy. In the practical scenario, a concentrated output is better than a random output because a highly random output increases firms' cold chain establishment costs. Thus, from the strategic point of view, the pessimistic strategy offers a better recommendation.

6.6. Demography of 3PL Firm's Profit

In our model, the logistic firm's service price is endogenous. Thus, the logistic firm's profit depends on two independent variables: service quality level and the logistics firm's service price. As depicted in Theorem 1, the 3PL firm's profit function satisfies the Kuhn–Tucker condition of convexity (Equation (19)) and expresses itself as a bivariate concave function. Figure 9a,b shows the surface demography of the 3PL firm's profit function.

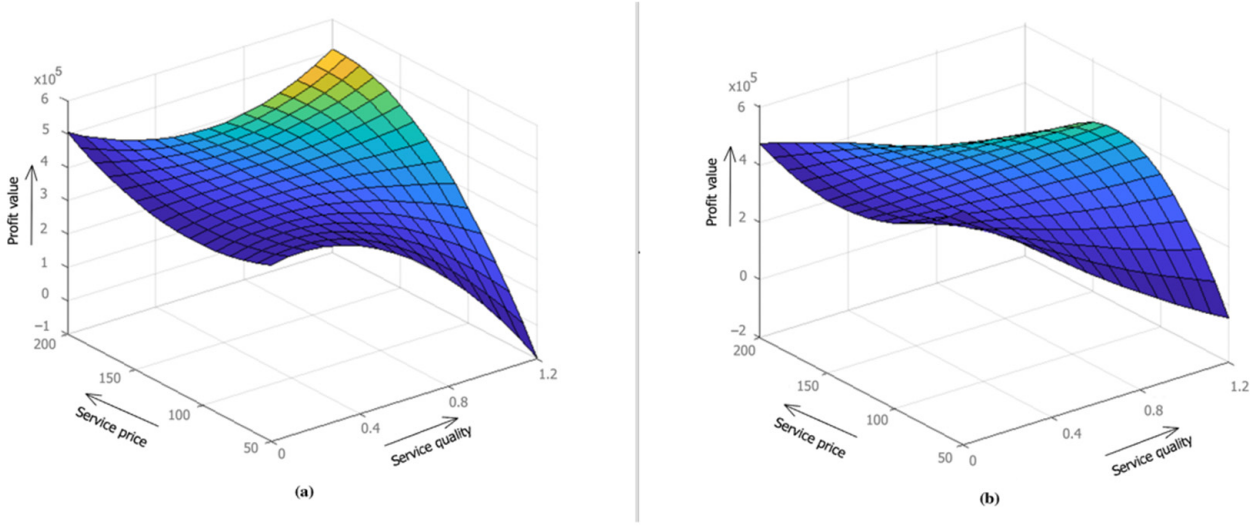

Figure 9. 3PL firm's total profit for different strategies. (**a**) 3PL firm's total profit under the optimistic approach; (**b**) 3PL firm's total profit under the pessimistic approach.

From the strategy comparison point of view, the optimistic approach ensures a higher total profit to the 3PL firm than the pessimistic strategy. However, the pessimistic strategy ensures higher stability to the total profit of 3PL firms. Essentially, due to competition, the optimal service quality level and service price point are not the same in the two strategies. The effect of imperfect competition is discussed in the following subsection.

6.7. Effect of Imperfect Competitiveness in Logistics Outsourcing

This paper has analyzed the effect of imperfect competitiveness in logistics outsourcing by considering logistics duopoly. The numerical case considers each firm as focal and its competitor as the peer. The results support Theorem 2, which physically means that each focal firm's profitable strategic move needs perfect information regarding the peer firm's strategy making. Figure 10a–d represents the effect of competition on the market share gain of logistics firms.

It is clear from Theorem 2 that, when choosing the optimistic strategy, a firm will try to satisfy Equation (24), while choosing a pessimistic strategy will cause them to try to satisfy Equation (25). Thus, perfect information regarding the peer strategic movement plays an essential role in obtaining a positive market share gain for each 3PL firm. Figure 10a assumes that Logistics 2 (peer) firm is looking to increase their service quality by a unit. Now, Logistic 1 firm (focal) can have perfect information about it (will choose the pessimistic strategy) or have imperfect information about it (will choose the optimistic strategy). Figure 10b assumes that the Logistic 2 (peer) firm is looking to increase its service price

by a unit. Now, Logistic 1 firm (focal) can have perfect information about it (will choose the optimistic strategy) or have imperfect information about it (will choose the pessimistic strategy). Figure 10c assumes that Logistics 1 (peer) firm is looking to increase its service quality by a unit. Now, Logistic 2 firm (focal) can have perfect information about it (will choose the pessimistic strategy) or have imperfect information about it (will choose the optimistic strategy). Figure 10d assumes that Logistics 1 (peer) firm is looking to increase its service price by a unit. Now, Logistic 2 firm (focal) can have perfect information about it (will choose the optimistic strategy) or have imperfect information about it (will choose the pessimistic strategy). The four graphs combinedly show that having perfect information always results in a positive gain in market share under competitiveness.

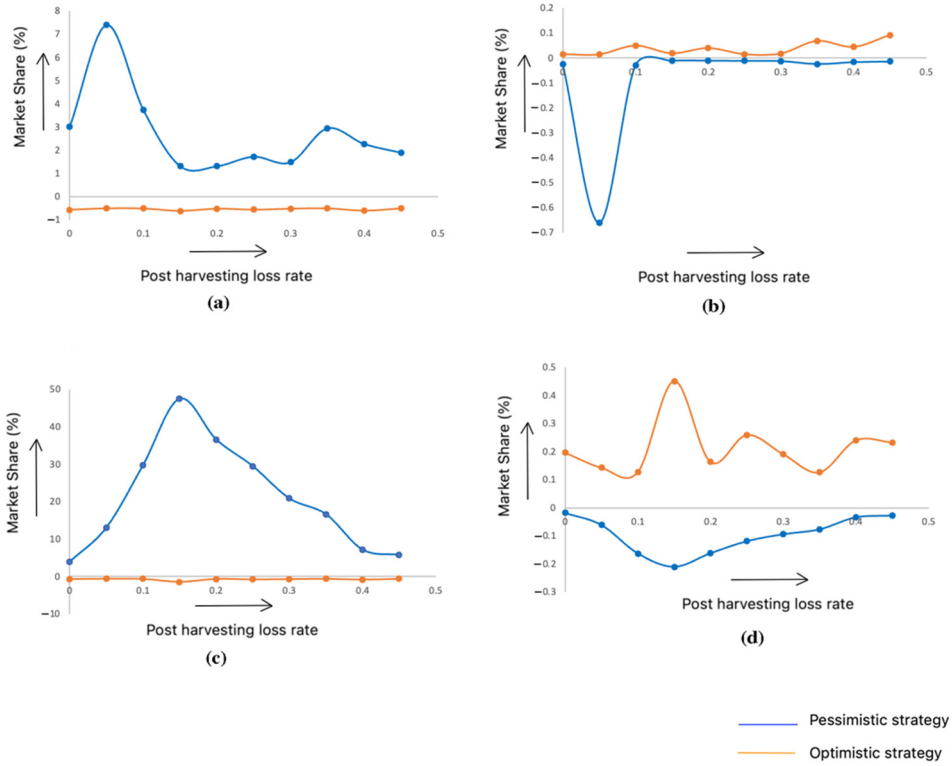

Figure 10. Effect of the peer firm's strategy change on the focal firm's market share. (**a**) Percentile deviation of Logistics 1 firm's market share gain due to a unit increase in the service quality of Logistics 2 firm; (**b**) Percentile deviation of Logistics 1 firm's market share gain due to a unit increase in the service price of Logistics 2 firm; (**c**) Percentile deviation of Logistics 2 firm's market share gain due to a unit increase in the service quality of Logistics 1 firm; (**d**) Percentile deviation of Logistics 2 firm's market share gain due to a unit increase in the service price of Logistics 1 firm.

6.8. Effect of 3PL Firm's Competitiveness on Market Demand

Here, the primary concern is to analyze the effect of different competitive strategies on the stochastic market demand. Stochastic demand in the e-commerce portal is dependent on the retailer's price and the freshness of the product. The product's freshness depends on the 3PL firm's service quality level. Thus, analyzing the effectiveness of competitive strategies on stochastic demand is similar to analyzing the effect of competitiveness on market sustainability. Figure 11 illustrates the effect graphically. The comparison does not carry any absolute answer. Although the optimistic strategy provides an excellent output at low post-harvesting loss rates, the pessimistic strategy holds higher stability.

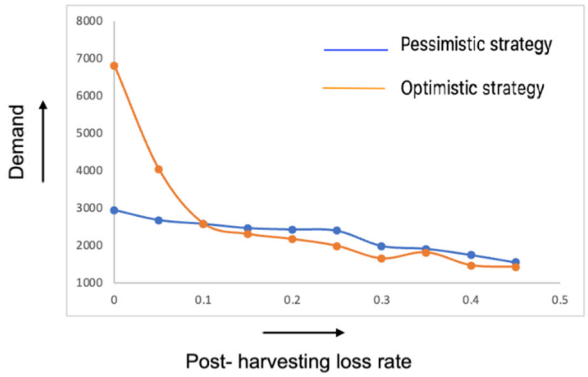

Figure 11. Total stochastic demand of e-commerce portals in various strategies.

7. Conclusions

The repetitive waves of COVID left some permanent effects on the agri-supply chain. However, food-processing industries restarted efficiently and the international borders for agri-product transportation reopened. Currently, agri-industries are coping with changing market patterns, recapturing their market share, and satisfying global demand. The 'new normal' boosted the regional agri-supply chain efficiently, with demand growth for high-quality, high-nutrient-content food through e-agribusiness. At the same time, it turned the RASC into a global platform through increasing e-commerce, smart 3PL, and virtual enterprise retailing firms. Thus, growing e-agri-business challenges the agri-supply chain with high randomness in channel partner selection, price in equilibrium among supply chain drivers, and competitiveness in global agri-logistics. As a result, the supply chain faces price decline, demand drop from the retailer's end, and a reduction in the logistics service efficiency.

7.1. Implications for Domestic and Global Agri-Supply Chain

Due to the post-COVID changing market notion, 3PL firms assure a very low-profit margin [11]. Since 2020, the situation has been worsening due to economic recession and trade wars. For example, China faced a total of a 10.1 percent container volume drop in ocean freight and a 19 percent volume drop in air freight [68]. With the post-COVID growth of e-commerce, the 3PL firms seek to manage their profit. In the US, the expected growth of logistics in 2021–2025 is more than 6% [69]. However, most of the market share is occupied by giant logistics firms. For example, in the US, FedEx, UPS, and USPS alone occupy a total of 73% market share, whereas the regional carriers only possess 16% market share [70]. These scenarios have made researchers worldwide think about a preferable solution to enhance the profit margin of small 3PL firms under such competitive market conditions.

Thus, the current situation seeks to address these limitations by developing an agri-supply chain model considering competitiveness in logistics outsourcing, making strategic decisions of the supply chain, and adapting market changes, such as e-commerce and the pseudo-4PL smart-warehousing service of logistics firms. Motivated by these challenges, this study develops a multi-echelon pricing and supply chain model, considering competitiveness among logistics firms in a market duopoly environment. This supply chain model considers two varieties of products from different suppliers, retailed by two different virtual retailing firms (with their e-commerce portals), outsourced by two different logistics firms. This model develops equilibrium pricing and service quality decisions under market monopoly, and optimistic and pessimistic competitive strategies, and compares them to assure higher gain of individual supply chain drivers and higher robustness of logistic firms.

7.2. Theoretical Implications

First, this study proposes a B2B contractual multi-echelon supply chain framework that contains two contracts between the supplier and retailer regarding the supplier's wholesale

price, and between the logistics firm and retailer regarding the logistics firm's service quality level and service price (Theorem 1). B2B contract making in the multi-echelon supply chain and incorporating competitiveness within the same echelon significantly contributes to the post-COVID pricing and supply chain domain. This model simultaneously allows cooperative strategy-making among the supply chain channel partners and competitive strategy-making with the peers within the same supply chain.

Second, this study significantly concerns competitiveness in logistics outsourcing and mathematically derives the constraints that 3PL firms should maintain to positively impact their market share gain. This study emphasizes that each focal 3PL firm needs perfect information regarding the peer firm's strategic movement. The focal 3PL firm can choose a competitive approach accordingly and balance between the service quality level and service price to positively impact its market share gain, even if its peer firm deviates from its equilibrium strategic values (Theorem 2). This study also mathematically derives the importance of lowering the post-harvesting loss rate to achieve a higher price gain of suppliers and retailers and the higher service quality level of logistics firms. This contribution in the agri-logistics domain is significant, because it helps the logistics firms strategize under market competitiveness.

Third, the study adopts the post-COVID changing patterns of the market by considering the model for e-agribusiness, encouraging the regional agri-supply chain through virtual retailing firms, and integrating the logistics service with the smart logistics warehousing service. This contribution to the smart supply chain domain is significant, as it enriches the theoretical and managerial aspects of the global supply chain.

7.3. Future Research Direction

This study provides some valuable directions for future research scope. First, researchers can integrate the idea of 4PL with the ongoing concept of virtual retailing and prepare methodological developments in bootstrapping in the agri-supply retailing section. Second, researchers can modify the model to contract farming to improve the supply chain and satisfy the global demand for agri-products. Third, researchers can incorporate yield uncertainty and modify the current stochastic model to a probabilistic one. Fourth, logistics outsourcing is nowadays undergoing widespread research. However, researchers can emphasize the point of smart logistics and warehousing, and develop models in technology outsourcing.

This study also contributes to the literature by declaring its limitations and depicting future research perspectives. Thus, we believe that the developed model and its suggested extensions can better handle the global logistics and pricing and supply chain of agri-products and efficiently boost the post-COVID agri-supply chain.

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Appendix A

Table A1. List of parameters and variables.

Parameter	Description
D_{im}	Demand for i^{th} product at m^{th} retailer's e-commerce portal
b_m	Average price sensitivity coefficient of mth retailer's portal
β_{mk}	Average quality sensitivity coefficient of kth 3PL firm for m^{th} retailer's portal
λ_k	Service-to-cost factor of kth 3PL firm
r	Post-harvesting loss of supplier
c_i^s	Production cost per unit of ith product
c_{ik}^T	Transportation (includes processing and packaging also) cost per unit of ith product
Variables	**Description**
p_{im}	Price of a unit of ith product at m^{th} retailer's portal
w_{im}	Supplier's wholesale price of a unit of ith product to m^{th} retailer
e_{ik}	Service quality level of kth 3PL firm for i^{th} product
u_{ik}	Service price of kth 3PL firm for i^{th} product
M_{ik}^P	Market share of kth 3PL firm for i^{th} product under pessimistic strategy
M_{ik}^{Op}	Market share of kth 3PL firm for i^{th} product under optimistic strategy
A_{ik}^G	Attribute gain of kth focal 3PL firm for i^{th} product
A_{ik}^L	Attribute loss of kth focal 3PL firm for i^{th} product

Appendix B

Proof of Lemma 1. Differentiating π_m^R (Equation (10)) with respect to p_{im}, we get

$$\frac{\partial \pi_m^R}{\partial p_{im}} = \sum_k M_{ik}(D_{im} - 2b_m p_{im} + \beta_m e_{ik} + b_m w_{im} + b_m u_{ik})(\forall i, m) \tag{A1}$$

and

$$\frac{\partial^2 \pi_m^R}{\partial p_{im}^2} = -2b_m \sum_k M_{ik}(\forall i, m) \tag{A2}$$

$$\frac{\partial^2 \pi_m^R}{\partial p_{im}^2} = -2b_m, \text{ as } \sum_k M_{ik} = 1(\forall i, m) \tag{A3}$$

As $\frac{\partial^2 \pi_m^R}{\partial p_{im}^2} < 0$, it implies that the profit function of retailer π_m^R is concave over p_{im}.

We need to equate $\frac{\partial \pi_m^R}{\partial p_{im}} = 0$ to get the optimal value of p_{im}

$$p_{im}^*(w_{im}) = \frac{D_{im}}{2b_m} + \frac{w_{im}}{2} + \frac{\sum_k u_{ik} M_{ik}}{2} + \sum_k M_{ik}\beta_{mk} e_{ik}(\forall i, m) \tag{A4}$$

□

Appendix C

Proof of Lemma 2. We need to express the supplier's expected profit gain as a function of only the supplier's wholesale price to eliminate the retailer's optimal price. Substituting the value of p_{im}^* (Equation (A4)) to Equation (11), we get the retailer's-price-independent supplier's expected profit gain function, represented in Equation (A5).

$$\pi_i^s = \sum_m \sum_k M_{ik} \left\{ \frac{D_{im}}{2} - \frac{b_{im}}{2}(w_{im} + u_{ik}) + \frac{\beta_m e_{ik}}{2} \right\} \{w_{im} - c_i^s - r c_i^s (1 - e_{ik})\} \tag{A5}$$

Differentiating π_i^s (Equation (A5)) with respect to w_{im} gives

$$\frac{\partial \pi_i^s}{\partial w_{im}} = \sum_k M_{ik}\left\{\frac{D_{im}}{2} - b_m w_{im} - \frac{b_m u_{ik}}{2} + \frac{\beta_m e_{ik}}{2} + \frac{b_m c_i^s}{2} + \frac{b_m r c_i^s}{2}(1 - e_{ik})\right\}(\forall i, m) \quad \text{(A6)}$$

And,

$$\frac{\partial^2 \pi_i^s}{\partial w_{im}^2} = -b_m \sum_k M_{ik}(\forall i, m) \quad \text{(A7)}$$

$$\frac{\partial^2 \pi_i^s}{\partial w_{im}^2} = -b_m, \text{ as } \sum_k M_{ik} = 1(\forall i, m) \quad \text{(A8)}$$

As, $\frac{\partial^2 \pi_i^s}{\partial w_{im}^2} < 0$, it implies that the supplier's profit function π_i^s is concave over the supplier's wholesale price w_{im}.

We need to equate $\frac{\partial \pi_i^s}{\partial w_{im}} = 0$ to determine the optimal value of the supplier's wholesale price, which gives w_{im}^*, as stated in Equation (14). □

Appendix D

Proof of Lemma 3. The retailer's optimal price (Equation (A4)) is still dependent on the supplier's wholesale price. We substitute the value of w_{im}^* (Equation (14)) into Equation (12) to get the supplier's-price-independent value of the retailer's price p_{im}^*, which is later presented in Equation (19) (Theorem 1).

We substitute the value of p_{im}^* (Equation (19)) into Equation (12) to get the retailer's-price-independent 3PL's profit function in Equation (A9).

$$\pi_k^{3PL} = \sum_m \sum_i M_{ik}\left\{\frac{D_{im}}{4} - \frac{c_i^s}{4}(1 + r) - \frac{\sum_k M_{ik} u_{ik}}{4} - \frac{\sum_k M_{ik} e_{ik}}{4}\left(\frac{3\beta_{mk}}{b_m} - r c_i^s\right) + \beta_{mk} e_{ik}\right\}\left(u_{ik} - c_{ik}^T\right) - \sum_i \sum_m \frac{\lambda_k e_{ik}^2}{2}(\forall k) \quad \text{(A9)}$$

Here, the 3PL firm's profit is a function of the service quality and service level. The function is increasing over the service price and decreasing over the service quality.

Now, π_k^{3PL} is a bivariate function of the service quality (e_{ik}) and service price (u_{ik}). Thus, in order to satisfy the concavity in nature, the function must satisfy the Kuhn–Tucker conditions, which are as follows.

The first-order principal minor of the Hessian matrix D_1 must be negative.

The second-order principal minor of the Hessian matrix D_2 must be positive.

The Hessian matrix of $\pi(f_1, f_2)$ is

$$H = \begin{bmatrix} \frac{\partial^2 \pi}{\partial f_1^2} & \frac{\partial^2 \pi}{\partial f_1 \partial f_2} \\ \frac{\partial^2 \pi}{\partial f_2 \partial f_1} & \frac{\partial^2 \pi}{\partial f_2^2} \end{bmatrix} \quad \text{(A10)}$$

$$D_1 = \frac{\partial^2 \pi}{\partial f_1^2}; \text{ and } D_2 = \left(\frac{\partial^2 \pi}{\partial f_1^2}\right)\left(\frac{\partial^2 \pi}{\partial f_2^2}\right) - \left(\frac{\partial^2 \pi}{\partial f_2 \partial f_1}\right)\left(\frac{\partial^2 \pi}{\partial f_1 \partial f_2}\right) \quad \text{(A11)}$$

In this case, the Hessian matrix is

$$H = \begin{bmatrix} -\sum_i \sum_m \frac{M_{ik}^2}{2} & \sum_i \sum_m \left\{\beta_{mk} - \frac{M_{ik}^2}{4}\left(\frac{3\beta_{mk}}{b_m} - r c_i^s\right)\right\} \\ \sum_i \sum_m \left\{\beta_{mk} - \frac{M_{ik}^2}{4}\left(\frac{3\beta_{mk}}{b_m} - r c_i^s\right)\right\} & -\lambda_k \end{bmatrix}(\forall i,\ k) \quad \text{(A12)}$$

Thus,

$$D_1 = -\sum_i \sum_m \frac{M_{ik}^2}{2} < 0; \quad \text{(A13)}$$

and

$$D_2 = \sum_i \sum_m \left[\lambda \frac{M_{ik}^2}{2} - \beta_{mk}^2 - \frac{3\beta_{mk}^2 M_{ik}^2}{2b_m} - \frac{9\beta_{mk}^2 M_{ik}^2}{16b_m^2} + \frac{6\beta_{mk} r c_i^s M_{ik}^2}{16b_m} - \frac{\beta_{mk} r c_i^s M_{ik}^2}{2} - \frac{r^2 c_i^{s2} M_{ik}^2}{16} \right] (\forall i,\ k) \tag{A14}$$

Now, equating $D_2 = 0$ gives the condition as stated in Equation (15). □

Appendix E

Proof of Theorem 1. Differentiating π_k^{3PL} with respect to e_{ik}, we get

$$\frac{\partial \pi_k^{3PL}}{\partial e_{ik}} = \sum_m \left\{ \beta_{mk} - \frac{M_{ik}^2}{4} \left(\frac{3\beta_{mk}}{b_m} - r c_i^s \right) \right\} \left(\left(u_{ik} - c_{ik}^T \right) \right) - \lambda_k e_{ik} (\forall i,\ k) \tag{A15}$$

Now, equating $\frac{\partial \pi_k^{3PL}}{\partial e_{ik}} = 0$, we get e_{ik}^*, as stated in Equation (16).

We equate the optimal service quality (e_{ik}^*) with Equation (15), and get the equation of the maximum service price, as stated in Equation (17). □

Appendix F

Proof of Corollary 1. We can characterize the expected profit gain of the kth 3PL firm of the ith product for the mth retailer under equilibrium by substituting the values of e_{ik}^* (Equation (16)) and p_{im}^* (Equation (19)) into Equation (12). After conducting some more algebra, we get π_{imk}^{3PL} as a function of the service price u_{ik}^* only, as represented in Equation (A16).

$$\begin{aligned} \pi_{imk}^{3PL} = {} & \lambda_k \left(u_{ik}^* - c_{ik}^T \right) \left[\frac{D_{im}}{4} - \frac{c_i^S b_m}{4} (1 + r) - \frac{\sum_k M_{ik} u_{ik}^*}{4} - \left(3\beta_{mk} - b_m r c_i^S \right) \left\{ \frac{\sum_k M_{ik} \left(u_{ik}^* - c_{ik}^T \right) \sum_m \beta_{mk}}{4} - \right. \right. \\ & \left. \frac{\sum_k M_{ik}^3}{16\lambda_k} \sum_m \frac{3\beta_{mk}}{b_m} \left(u_{ik}^* - c_{ik}^T \right) + \frac{r c_i^s \sum_k M_{ik} \left(u_{ik}^* - c_{ik}^T \right)}{4\lambda_k} \right\} + \left(u_{ik}^* - c_{ik}^T \right) \beta_{mk} \sum_m \beta_{mk} - \frac{\left(u_{ik}^* - c_{ik}^T \right)}{4} \beta_{mk} M_{ik}^2 \sum_m \frac{3\beta_{mk}}{b_m} + \\ & \left. \left(u_{ik}^* - c_{ik}^T \right) \beta_{mk} r c_i^S \right] - \frac{\lambda}{2} \left\{ \left(u_{ik}^* - c_{ik}^T \right) \sum_m \beta_{mk} - \frac{\left(u_{ik}^* - c_{ik}^T \right)}{4} M_{ik}^2 \sum_m \frac{3\beta_{mk}}{b_m} + \left(u_{ik}^* - c_{ik}^T \right) \beta_{mk} r c_i^S \right\}^2 (\forall i, m, k) \end{aligned} \tag{A16}$$

Clearly, the focal 3PL firm's expected profit gain has a non-negative impact over the peer firm's service price deviation if $\frac{\partial \pi_{imk}^{3PL}}{\partial u_{il}^*} > 0$; and a negative impact if $\frac{\partial \pi_{imk}^{3PL}}{\partial u_{il}^*} < 0$; otherwise, zero. Differentiating π_{imk}^{3PL} with respect to u_{il}^*, we get the impact of the service price strategy deviation $(u_{il}^*\ \forall l)$ of the peer firm on the kth focal 3PL firm's profit.

$$\frac{\partial \pi_{imk}^{3PL}}{\partial u_{il}^*} = -\frac{M_{il}}{4} \left\{ 1 + \frac{\left(3\beta_{mk} - b_m r c_i^s \right)}{\lambda_k} \left(\sum_m \beta_{mk} - \frac{M_{il}^2}{4} \sum_m \frac{3\beta_{mk}}{b_m} + r c_i^s \right) \right\} (\forall i, m, k) \tag{A17}$$

The right-hand-side of Equation (A17) is non-negative, only if

$$1 + \frac{\left(3\beta_{mk} - b_m r c_i^s \right)}{\lambda_k} \left(\sum_m \beta_{mk} - \frac{M_{il}^2}{4} \sum_m \frac{3\beta_{mk}}{b_m} + r c_i^s \right) \leq 0 \tag{A18}$$

$$\frac{\sum_m \beta_{mk}}{\lambda_k} - \left(\frac{M_{il}^2}{4} \sum_m \frac{3\beta_{mk}}{b_m} + r c_i^s \right) \geq -\frac{1}{\left(3\beta_{mk} - b_m r c_i^s \right)} \tag{A19}$$

Here, as duopoly in 3PL is considered,

$$M_{il} + M_{ik} = 1 (\forall i) \tag{A20}$$

Thus, substituting the value of M_{il} with M_{ik}, and after some algebra, we get the M_{ik}^{Sp} value as stated in Equation (22). □

Appendix G

Proof of Corollary 2. Substituting the value of u_{ik}^* (Equation (17)) and p_{im}^* (Equation (19)) into Equation (12), and doing some algebra, we get π_{imk}^{3PL} as a function of the service price e_{ik}^* only, as represented in Equation (A21).

$$\pi_{imk}^{3PL} = \left[\frac{D_{im}}{4} + \beta_{mk}e_{ik}^* - \frac{b_m c_i^s}{4}(1+r) - \frac{b_m M_{ik}}{4}\left\{D_{im} - c_i^S(1+r) + M_{ik}c_{ik}^T - \sum_k M_{ik}e_{ik}^*\left(\frac{3\beta_{mk}}{b_m} - rc_i^s\right) + 4\beta_{mk}e_{ik}^* - c_{ik}^T - \frac{\lambda_k e_{ik}^*}{\sum_m \beta_{mk} - \sum_m \frac{M_{ik}^2}{4}\left(\frac{3\beta_{mk}}{b_m} - rc_i^s\right)}\right\} - \sum_k M_{ik}e_{ik}^*\left(\frac{3\beta_{mk}}{b_m} - rc_i^s\right)\right]\left[\frac{\lambda_k e_{ik}^*}{\sum_m \beta_{mk} - \sum_m \frac{M_{ik}^2}{4}\left(\frac{3\beta_{mk}}{b_m} - rc_i^s\right)}\right] - \frac{\lambda_k e_{ik}^*}{2} \quad (\forall i, m, k) \tag{A21}$$

Clearly, the focal 3PL firm's profit has a non-negative impact over the peer firm's service quality deviation if $\frac{\partial \pi_{imk}^{3PL}}{\partial e_{il}^*} > 0$; and negative if $\frac{\partial \pi_{imk}^{3PL}}{\partial e_{il}^*} < 0$; otherwise, zero. Differentiating π_{imk}^{3PL} with respect to e_{il}^*, we get the impact of the service price deviation $(e_{il}^* \ \forall l)$ of the peer firm to the kth focal 3PL firm, as represented in Equation (A22).

$$\frac{\partial \pi_{imk}^{3PL}}{\partial e_{il}^*} = \left\{\left(\frac{b_m M_{ik}}{4} - 1\right)\left(\frac{3\beta_{mk}}{b_m} - rc_i^s\right)M_{il}\right\}\left\{\frac{\lambda_k e_{ik}^*}{\sum_m \beta_{mk} - \sum_m \frac{M_{ik}^2}{4}\left(\frac{3\beta_{mk}}{b_m} - rc_i^s\right)}\right\}(\forall i, m, k) \tag{A22}$$

Here, let

$$\frac{3\beta_{mk}}{b_m} - rc_i^s = Z; \tag{A23}$$

Now, the right-hand-side of Equation (A22) is non-negative, only if

$$\frac{4\lambda_k e_{ik} b_m}{\frac{\sum_m \beta_{mk}}{ZM_{il}} - \frac{M_{ik}^2}{4M_{il}}} \geq 0 \tag{A24}$$

$$\frac{\sum_m \beta_{mk}}{ZM_{il}} - \frac{M_{ik}^2}{4M_{il}} \leq 0 \tag{A25}$$

$$\frac{4\sum_m \beta_{mk} - ZM_{ik}^2}{4ZM_{il}} \leq 0 \tag{A26}$$

Here, as duopoly in 3PL is considered,

$$M_{il} + M_{ik} = 1(\forall i) \tag{A27}$$

Thus, substituting the value of M_{il} with M_{ik}, and after some algebra, we get Equation (22). □

Appendix H

Proof of Lemma 4. Now, substituting Equation (5) with Equation (6), we get the elaborated value of the market share gain in Equation (A28).

$$M_{ik}^{Op} = \frac{e_{ik}u_{il} - u_{ik}e_{il}}{u_{il}(e_{ik} + e_{il}) - e_{il}(u_{ik} + u_{il})}(\forall i, k) \tag{A28}$$

Considering the focal and the peer firm in the equilibrium state, we substitute the value of e^*_{ik} as per Equation (17) and get the value of the market share gain of the focal 3PL firm for the ith product at equilibrium, represented in Equation (A29).

$$M^{op^*}_{ik} = 2\left[\frac{\frac{\lambda_k e^*_{il} u^*_{ik}}{u^*_{il}\left(u^*_{ik} - c^T_{ik}\right)} - \sum_m \beta_{mk}}{\sum_m \left(\frac{3\beta_{mk}}{b_m} - rc^s_i\right)}\right]^{\frac{1}{2}} (\forall i, k) \tag{A29}$$

Taking log_e and differentiating with respect to e^*_{il} and u^*_{il} respectively results in Equations (A30) and (A31).

$$\frac{\frac{\partial M^{op^*}_{ik}}{\partial e^*_{il}}}{M^{op^*}_{ik}} = \frac{-\lambda_k u^*_{ik}}{\left(u^*_{ik} - c^T_{ik}\right)\sum_m \beta_{mk} - \lambda_k e^*_{il} u^*_{ik} - u^*_{il}} (\forall i, k) \tag{A30}$$

$$\frac{\frac{\partial M^{op^*}_{ik}}{\partial u^*_{il}}}{M^{op^*}_{ik}} = \frac{\frac{\lambda_k e^*_{il} u^*_{ik}}{u^*_{il}}}{\left(u^*_{ik} - c^T_{ik}\right)\sum_m \beta_{mk} - \lambda_k e^*_{il} u^*_{ik} - u^*_{il}} (\forall i, k) \tag{A31}$$

Clearly, when Equation (24) is satisfied, we can derive lemma 4 from Equation (A29)–(A31). □

Appendix I

Proof of Lemma 5. Now, substituting Equation (7) with Equation (8), we get the elaborated value of market share as Equation (A32).

$$M^P_{ik} = 1 - \frac{(e_{ik} + e_{il})(u_{ik} + u_{il})((e_{il} u_{ik} - e_{ik} u_{il}))}{e_{ik} u_{ik}\{e_{il}(u_{ik} + u_{il}) - u_{il}(e_{ik} + e_{il})\}} (\forall i, k) \tag{A32}$$

Now, by considering that the focal and the peer firm are both in equilibrium state, we substitute the value of e^*_{ik} as per Equation (16) and get the value of the market share of the kth focal 3PL firm for the ith product at equilibrium, as represented in Equation (A33).

$$\left(u^*_{il} + M^{P^*}_{ik} u^*_{ik}\right)\left\{\frac{M^{P^*2}_{ik}}{4}\sum_m \left(\frac{3\beta_{mk}}{b_m} - rc^s_i\right) - \sum_m \beta_{mk}\right\} = \frac{\lambda_k u^*_{ik} e^*_{il}}{\left(u^*_{ik} - c^T_{ik}\right)} (\forall i, k) \tag{A33}$$

Taking log_e and differentiating with respect to e^*_{il} and u^*_{il} respectively results in Equations (A34) and (A35).

$$\frac{\frac{\partial M^{p*}_{ik}}{\partial e^*_{il}}}{M^{P*}_{ik}} = \frac{(u^*_{il} + M^{P*}_{ik} u^*_{ik})\left\{\frac{M^{P*2}_{ik}}{4}\sum_m \left(\frac{3\beta mk}{b_m} - rc^s_i\right) - \sum_m \beta_{mk}\right\}}{e^*_{il}\left[\frac{M^{P*}_{ik} u^*_{ik}}{4}\sum_m \left(\frac{3\beta mk}{b_m} - rc^s_i\right) - \frac{u^*_{ik}\sum_m \beta_{mk}}{M^{P*}_{ik}} + \frac{u^*_{il} + M^{P*}_{ik} u^*_{ik}}{2}\sum_m \left(\frac{3\beta mk}{b_m} rc^s_i\right)\right]} (\forall i, k) \tag{A34}$$

$$\frac{\frac{\partial M^{p*}_{ik}}{\partial u^*_{il}}}{M^{P*}_{ik}} = -\frac{\frac{M^{P*2}_{ik}}{4}\sum_m \left(\frac{3\beta mk}{b_m} rc^s_i\right) - \sum_m \beta_{mk}}{\frac{M^{P*}_{ik} u^*_{ik}}{4}\sum_m \left(\frac{3\beta mk}{b_m} - rc^s_i\right) - \frac{u^*_{ik}\sum_m \beta_{mk}}{M^{P*}_{ik}} + \frac{(u^*_{il} + M^{P*}_{ik} u^*_{ik})}{2}\sum_m \left(\frac{3\beta mk}{b_m} rc^s_i\right)\right]} (\forall i, k) \tag{A35}$$

Clearly, when Equation (25) is satisfied, we can derive Lemma 5 from Equations (A33)–(A35). □

Appendix J

Table A2. Comparison of pricings.

Post-Harvesting Loss Rate (r)		Pessimistic Strategy				Optimistic Strategy			
		Supplier's Price		Retailer's Price at Online Portal		Supplier's Price		Retailer's Price at Online Portal	
	Retailers	Product 1	Product 2	Product 1	Product 2	Product 1	Product 2	Product 1	Product 2
0	M1	1231.6532	946.0421	1706.71095	1329.08631	1203.6578	880.2631	1676.94545	1242.02245
	M2	965.8646	1339.1927	1308.02803	1918.81222	945.0661	1293.1403	1289.05794	1861.33818
0.05	M1	1212.9148	916.8516	1714.21384	1300.25622	1201.2419	890.2570	1712.3612	1248.83841
	M2	974.7625	1328.9103	1324.27705	1904.26163	960.6292	1297.6889	1323.19181	1864.17823
0.1	M1	1174.8636	907.1082	1708.48933	1334.82133	1207.8005	893.8581	1667.49788	1260.27503
	M2	986.4607	1354.8371	1338.50689	1943.79702	966.8865	1301.5585	1286.42168	1873.09092
0.15	M1	1164.3150	889.6266	1674.69677	1283.70261	1191.5020	891.5742	1667.86456	1269.24831
	M2	976.7476	1326.9254	1312.65673	1901.29762	941.2488	1309.1656	1285.48865	1883.52164
0.2	M1	1102.1656	846.5106	1664.63801	1301.86126	1188.0268	893.4336	1665.99298	1262.65857
	M2	981.1489	1353.0024	1330.87075	1941.10331	943.6628	1305.3136	1286.11292	1876.3143
0.25	M1	1113.0299	867.0305	1650.72465	1269.93563	1193.5923	839.5456	1665.95664	1279.83591
	M2	970.8967	1325.2275	1312.2245	1898.79986	940.3982	1333.3643	1282.85892	1920.25614
0.3	M1	1096.0496	862.1548	1640.59533	1263.44618	1183.3892	862.8506	1662.99426	1264.64103
	M2	968.0589	1322.1025	1310.04759	1894.59825	943.4046	1317.2427	1285.48856	1893.80508
0.35	M1	996.8472	835.6519	1610.31294	1260.5135	1178.6923	881.1614	1662.30028	1261.3695
	M2	978.9820	1321.6438	1328.87576	1902.74701	941.8146	1307.1055	1286.33532	1880.75061
0.4	M1	1010.8279	816.8801	1604.3733	1251.45688	1077.9630	835.1155	1630.40843	1255.35132
	M2	975.7591	1327.9507	1317.51355	1904.92361	957.5685	1318.8989	1305.94862	1897.98407
0.45	M1	839.9857	759.2731	1547.05808	1238.36497	1023.3192	883.1981	1609.63952	1259.38752
	M2	988.8145	1335.8572	1344.04579	1919.93997	961.9385	1306.1760	1312.53673	1878.05902

Table A3. Comparison of supplier's expected profit.

Post-Harvesting Loss Rate (r)		Pessimistic Strategy Supplier's Profit			Optimistic Strategy Supplier's Profit		
	Retailers	Product 1	Product 2	Total	Product 1	Product 2	Total
0	M1	270,895.751	512,851.166	2,175,710.74	448,436.985	1,094,319.48	4,770,471.72
	M2	129,400.702	1,262,563.12		211,374.736	3,016,340.52	
0.05	M1	457,310.927	385,383.42	1,945,147.15	112,237.907	722,598.656	2,899,739.11
	M2	199,898.707	902,554.096		48,862.488	2,016,040.06	
0.1	M1	800,056.725	308,560.969	1,958,505.52	482,490.676	291,834.834	1,780,666.88
	M2	307,198.409	542,689.419		218,844.267	787,497.103	
0.15	M1	361,928.366	442,575.137	1,867,548.01	600,392.395	183,087.371	1,505,389.3
	M2	141,416.291	921,628.22		272,424.067	449,485.466	
0.2	M1	667,678.456	463,723.019	1,997,859.57	633,144.353	136,843.472	1,406,671.26
	M2	219,339.512	647,118.579		280,667.215	356,016.221	
0.25	M1	363,642.598	472,420.379	1,860,131.2	634,255.68	145,386.802	129,6289.57
	M2	126,391.189	897,677.034		288,798.043	227,849.045	
0.3	M1	412,428.386	335,871.391	1,527,169.14	554,098.177	92,213.6097	1,071,670.22
	M2	138,456.677	640,412.683		241,962.747	183,395.683	
0.35	M1	982,741.65	123,323.906	1,573,089.98	327,940.922	234,277.551	1,254,800.06
	M2	258,732.296	208,292.132		143,461.967	549,119.615	
0.4	M1	609,941.504	266,126.779	1,441,070.35	410,445.51	218,860.393	1,131,490.24
	M2	167,517.254	397,484.81		130,946.901	371,237.438	
0.45	M1	931,367.249	175,305.918	1,489,751.72	457,952.697	147,066.791	1,089,169.72
	M2	180,817.646	202,260.903		127,400.262	356,749.967	

Table A4. Comparison of retailer's expected profit.

Post-Harvesting Loss Rate (r)	Retailers	Pessimistic Strategy Retailer's Profit			Optimistic Strategy Retailer's Profit		
		Product 1	Product 2	Total	Product 1	Product 2	Total
0	M1	135,522.1769	256,658.867	1,238,855.89	224,451.7852	547,343.944	2,766,287
	M2	64,759.10063	781,915.749		105,871.8323	1,888,619.43	
0.05	M1	228,127.1788	187,002.269	1,075,469.15	56,164.46243	364,132.955	1,705,649.89
	M2	100,051.5941	560,288.106		24,472.25201	1,260,880.23	
0.1	M1	397,947.3519	137,219.477	1,024,008.3	236,993.225	145,711.403	983,547.024
	M2	153,822.7061	335,018.764		108,727.2705	492,115.125	
0.15	M1	18,0274.534	204,644.253	1,028,220.15	295,978.6833	88,689.5419	801,608.175
	M2	70,914.95572	572,386.404		136,562.4	280,377.55	
0.2	M1	330,723.0016	189,928.03	1,030,168.58	309,332.9057	67,659.362	739,807.354
	M2	109,839.9277	399,677.625		140,533.2515	222,281.835	
0.25	M1	180,561.9564	210,736.878	1,012,343.28	309,385.5764	61,520.2413	656,239.832
	M2	63,314.02495	557,730.417		144,061.6594	141,272.355	
0.3	M1	204,637.8946	149,533.597	821,717.108	269,863.4466	41,739.5014	546,952.053
	M2	69,350.59137	398,195.024		121,208.3292	114,140.776	
0.35	M1	484,708.8979	52,923.8921	796,663.309	161,937.8946	110,420.737	686,997.867
	M2	129,559.9788	129,470.541		71,935.88988	342,703.346	
0.4	M1	36,059.84337	18,618.2723	385,432.583	199,040.863	92,952.6335	588,612.925
	M2	83,903.63411	246,850.833		65,575.18315	231,044.245	
0.45	M1	53,250.17882	32,994.1765	302,149.315	220,915.8216	70,619.3127	578,067.479
	M2	90,585.79901	125,319.161		63,845.2564	222,687.089	

Table A5. Comparison of logistics firms' expected profit.

Post-Harvesting Loss Rate (r)	Retailers	Pessimistic Strategy Retailer's Profit			Optimistic Strategy Retailer's Profit		
		Logistics 1	Logistics 2	Total	Logistics 1	Logistics 2	Total
0	P1	2344.32792	21,784.4607	54,622.853	35,953.8684	4458.11597	89,308.7464
	P2	2172.02034	28,322.0441		42,988.5179	5908.24407	
0.05	P1	2502.91973	28,562.5827	62,789.4058	9740.19619	2903.59997	27,381.9638
	P2	2185.67428	29,538.2291		11,620.3255	3117.84221	
0.1	P1	2527.02065	36,135.0888	69,765.8719	4297.47795	5125.31285	23,257.2717
	P2	2060.83307	29,042.9294		7040.66547	6793.81542	
0.15	P1	2440.18729	16,645.9068	41,837.0711	35,155.3971	4055.37147	71,945.7131
	P2	2053.39917	20,697.5779		27,794.2945	4940.64997	
0.2	P1	3053.00164	29,959.815	60,022.2483	32,920.891	4269.85162	69,357.3668
	P2	2448.50581	24,560.9259		25,606.8053	6559.81894	
0.25	P1	2846.34148	19,313.8384	46,111.2694	32,902.0298	7892.59764	75,826.402
	P2	2213.60055	21,737.489		24,927.0685	10,104.706	
0.3	P1	3054.94763	19,178.3521	43175.1649	28,010.6209	4099.70827	58,384.0654
	P2	2310.12759	18,631.7376		21,023.3311	5250.405	
0.35	P1	4589.55548	33,599.9382	62083.5917	19,603.1901	3205.76826	43,098.9028
	P2	3675.28501	20,218.813		16,617.2513	3672.69305	
0.4	P1	3198.4965	19,690.9442	40295.3366	16,057.4746	5192.40484	38,934.39
	P2	2394.34043	15,011.5555		11,518.0375	6166.47306	
0.45	P1	4223.82275	26,267.7111	46970.3613	16,367.151	4803.70042	38,286.1375
	P2	2392.82206	14,086.0054		11,126.5805	5988.70564	

Table A6. Service quality and service price under the pessimistic strategy.

Post-Harvesting Loss Rate (r)	Service Quality				Service Price			
	Logistics 1		Logistics 2		Logistics 1		Logistics 2	
	Product 1	Product 2	Product 1	Product 2	Product 1	Product 2	Product 1	Product 2
0	0.18695117	0.0959439	0.51385783	0.66219167	115.0251	71.93622	107.875	59.1422
0.05	0.16100328	0.10330847	0.66729033	0.519238	118.6484	71.90769	111.1819	59.73669
0.1	0.13126533	0.33945367	0.805817	0.96527017	119.9001	72.70315	107.8	59.3462
0.15	0.1980705	0.09450395	0.585145	0.48725417	117.7796	71.94719	93.83181	59.77898
0.2	0.16641063	0.26707217	0.74068767	0.9198495	118.9875	76.98767	107.8577	59.3345
0.25	0.213753	0.0915876	0.56700783	0.4615285	117.3212	71.95669	103.2405	59.80329
0.3	0.18117167	0.1179359	0.53437883	0.42499917	119.7532	71.95019	105.5556	59.84067
0.35	0.13699798	0.47904883	0.71703383	0.40195683	119.993	79.8704	109.1853	59.8753
0.4	0.17929717	0.24411267	0.62138017	0.5411335	114.9867	75.98735	101.9841	59.69616
0.45	0.2522585	0.641701	0.8912425	0.59765233	119.9836	72.87962	109.2622	59.67723

Table A7. Service quality and service price under the optimistic strategy.

Post-Harvesting Loss Rate (r)	Service Quality				Service Price			
	Logistics 1		Logistics 2		Logistics 1		Logistics 2	
	Product 1	Product 2	Product 1	Product 2	Product 1	Product 2	Product 1	Product 2
0	0.16760383	0.02492913	0.841287	0.4571065	122.5029	71.95721	112.4682	59.34474
0.05	0.518629	0.0500669	0.58626033	0.6047425	147.3732	67.98373	105.9723	59.96722
0.1	0.20485017	0.11084555	0.99100783	0.51577833	82.45052	71.98977	113.17133	60
0.15	0.1388689	0.1985365	0.92242483	0.51343217	124.8753	71.97804	108.1135	59.97904
0.2	0.14540587	0.15560633	0.97947933	0.3313315	121.2831	72.17075	112.85	52.50528
0.25	0.11820853	0.57428367	0.83489	0.66354783	121.009	72.08837	136.6835	67.6978
0.3	0.14406927	0.35670517	0.837582	0.36617617	121.4455	74.57897	109.4582	59.33727
0.35	0.15421478	0.17237367	0.536649	0.549575	126.6876	71.90653	103.9837	59.75349
0.4	0.30276217	0.31927883	0.8739945	0.6649175	120.8642	72.44677	113.8763	60
0.45	0.35402	0.167042	0.977058	0.34981267	121.3782	72.24485	112.0153	55.92051

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