# Competition Under Manufacturer Service and Retail Price

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**Abstract**

This research studies a case where there are two manufacturers producing competing products and selling them through a common retailer. The consumer demand depends on two factors: (1) retail price, and (2) service level provided by the manufacturer. Game-theoretic framework is applied to obtained the equilibrium solutions for every entities. This article studies and compares results from three possible supply chain scenarios, (1) Manufacturer Stackelberg, (2) Retailer Stackelberg, and (3) Vertical Nash. Our research concludes that consumers receive more service when every channel members possess equal bargaining power (e.g., Vertical Nash). An interesting but less intuitive result shows that as market base of one product increases, the competitor also benefits but at a less amount than the manufacturer of the first product. Furthermore, when one manufacturer has some economic advantage in providing service, the retailer will act to separate market segment by selling the product with low service at a low price and selling the product with high service at a high price.

*Keywords*: Bargaining Power; Horizontal Strategic Interaction; Manufacturer Service;
Retail Pricing; Supply Chain Management; Vertical Strategic Interaction;

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## 1 Introduction

With current dynamic and competitive environment, product manufacturers must compete with more complicated strategies than lowering their price. Non-price factors such as service have become more important in affecting a consumer's decision to buy a product. In this research, service is defined as any action that the manufacturer takes to "help the customers obtain maximum value from their purchases" (Goffin 1999). Example of services include post-sale customer support, product advertising, improved product quality, on-time product delivery, responsive product repair, etc.

There are quite a few successful firms who have focused on service and quality of their products in building brand loyalty. As an example, IBM and HP are famous for their customer support. This reputation gives them an edge over their competitors. Another example can be seen in the market of electronic appliances, e.g., washer and dryer. Maytag and GE are competing to sell their appliances through common retailers such as Sears or BestBuy. One of the major concerns for end customers is not only how low the price is, but also how good the after-sale and repair service is In both of these examples, the manufacturers interact directly with the end consumers through service channel.

Because the potential impact from the service quality to consumer demands, negotiations between the manufacturer and retailer on their price and order quantity will be affected. Moreover, competitive pressure from other manufacturers and their channel coordination with retailer are issues that a manufacturer must consider in their decision processes. This article does not study the impact of retailer's service to customers due to its potential "conflict" with the service provided by the manufacturers. Issues about possible differentiation between service for competing products from the two manufacturers make the studies more complicated. To our knowledge, almost none of the literature considered all these issues of price and service interactions, manufacturers' competition and supply chain's channel coordination simultaneously; even though most consumer goods and electronics products are sold by retailers who sell multiple competing brands at the same location. See Section 2 for literature reviews.

In order to focus our study on the role of service in competition between two manufacturers in this supply chain, it is necessary to make simplification assumptions regarding vertical strategic interactions between manufacturers and retailer. In general, in a market with a monopolist or a group of oligopolists the manufacturers would possess more bargaining power than the retailers and would be able to sell their product with some premium above the competitive price. On the other hand, if the retailer possesses more negotiation power, it can bring down the manufacturer's profit and absorb the majority of profit to itself. We are interested to study how bargaining power can affect supply chain equilibrium solution. The following three scenarios were considered: Manufacturer Stackelberg (MS), Retailer Stackelberg (RS), and Vertical Nash (VN). See Section 4 for details.

In this research we use game-theoretic approach to derive equilibrium solutions for prices (and ordering quantities), service levels, and profits for each channel member. The derivations are benchmarked with results obtained in the literature (e.g., Choi 1991) without service factors. Our research concludes that consumers receive more service when every channel members possess equal bargaining power (e.g., Vertical Nash). An interesting result shows that as market base of one product increases, the competitor also benefits but at a less amount than the manufacturer for the original product. Furthermore, when one manufacturer has some economic advantage in providing service, the retailer will separate market segments by selling the product with low service at a low price and selling the product with high service at a high price.

This paper is organized as follows. Section 2 reviews relevant literature on the studied topics. Section 3 develops basic models of noncooperative games. Demand function, cost structure for each firm, and vertical strategic interactions are specified in this section. Section 4 derives and compares analytical equilibrium solutions for prices, services, and profits under three supply-chain scenarios using the game-theoretic approach. Section 5 performs sensitivity analyses on key parameters for examining their influences on equilibrium solution. The lase section summarizes major findings and delineates several possible extensions to this research.

## 2 Literature Reviews

| | Scenario | | |
|---|---|---|---|
| | MS | VN | RS |
| **Manufacturers** | | | |
| Wholesale Price | $\frac{2\eta}{A-B}(a+(E+F)c)$ | $\frac{\eta}{\Phi}\left(a+\frac{2(A'+B')+b_s(b_s+\theta_s)}{\eta}c\right)$ | $\frac{\eta}{\Psi}\left(a+\frac{2(A'+B')+\eta b_p}{\eta}c\right)$ |
| Service Level | $\frac{(b_s+\theta_s)}{A-B}(a+\Gamma c)$ | $\frac{b_s+\theta_s}{\Phi}(a-b_pc)$ | $\frac{b_s+\theta_s}{\Psi}(a-b_pc)$ |
| Profit | $\frac{\eta}{A-B}(a+\Gamma c)\left[2(\Lambda a+b_p\Theta c)-\frac{(b_s+\theta_s)^2}{2(A-B)}(a+\Gamma c)\right]$ | $\frac{\eta[A'+\eta(b_p+\theta_p)]}{2\Phi^2}(a-b_pc)^2$ | $\frac{\eta[A'+\eta(b_p+\theta_p)]}{2\Psi^2}(a-b_pc)^2$ |
| **Retailer** | | | |
| Retail Price | $\frac{1}{b_p}\left(\Lambda+\frac{2\eta b_p}{A-B}\right)a+\left(\Theta+\frac{2\eta(E+F)}{A-B}\right)c$ | $\frac{\Phi-(A'+B')}{b_p\Phi}a+\frac{(A'+B')}{\Phi}c$ | $\frac{A'+B'+2\eta b_p}{b_p\Psi}a+\frac{A'+B'}{\Psi}c$ |
| Profit | $\frac{2}{b_p}(\Lambda a-b_p\Theta c)^2$ | $\frac{2}{b_p}\left[\frac{\eta(b_p+\theta_p)}{\Phi}(a-b_pc)\right]^2$ | $\frac{\eta(b_p+\theta_p)}{b_p\Psi}(a-b_pc)^2$ |
| Demand | $\Lambda a-b_p\Theta c$ | $\frac{\eta(b_p+\theta_p)}{\Phi}(a-b_pc)$ | $\frac{\eta(b_p+\theta_p)}{\Psi}(a-b_pc)$ |

Note: $\Gamma = E+F-\frac{A-B}{2\eta}$ $\Lambda = \frac{A-B-2\eta b_p+b_s(b_s+\theta_s)}{2(A-B)}$ $\Theta = \frac{\eta(E+F)}{A-B}-\frac{b_s(b_s+\theta_s)}{2b_p}\left(\frac{E+F}{A-B}-\frac{1}{2\eta}\right)$ $\Phi = 2(A'+B')+\eta b_p+b_s(b_s+\theta_s)$
$\Psi = 2(A'+B'+\eta b_p)$

Table 1: Summary table of the existing literature

Studies on horizontal competition between two or more producers (or sellers) can be traced back to classic economic models such as Cournot, Bertrand, and Stackelberg competition. Reviews on these models and their variants can be found in Tirole (2000). However, these studies are primarily based on single-echelon environment. Early studies on multi-echelon environment can be found in Jeuland and Shugan (1983), McGuire and Staelin (1983), Moorthy (1987), Ingene and Parry (1995). Most of these studies consider only the case with single manufacturer and single retailer. They have focused on vertical coordinations among channel members through measures such as transfer pricing schemes or formal agreements. Particularly, Jeuland and Shugan (1983) shows that the supplier can use a quantity discount schedule to induce the retailer to choose the channel-optimal retailing price. Moorthy (1987) shows that channel coordination can also be achieved through a simple two-part tariff: the supplier sells the product at his own (marginal) production cost and charges the retailer a fixed side-payment.

The majority of studies mentioned above have considered price or product quantity as the only dimension of competition. Early research to include attributes such as product quality and service can be found in economics literature such as Spence (1975) and Dixit (1979). In marketing literature, Jeuland and Shugan (1983) includes nonprice variable such as quality and services in their model with the profit function as a linear function of service amount. Our model, on the other hand, have the profit function as a nonlinear function to service amount due to the decreasing return process of providing service. Moorthy (1988) examines a competition in duopoly through both price and quality. Our model considers both horizontal and vertical relationship.

Focused on price-sensitive demands, where service issues were not considered, Choi (1991) examines a supply chain with similar channel structure to the one considered in Section 3. The paper studies three noncooperative games of different bargaining power assumptions between the two manufacturers and the retailer, i.e., two Stackelberg and one Nash game. McGahan and Ghemawat (1994) studies a single-transaction, game-theoretic model in which duopolists attempt to retain old customers through service and attract new customers through price. Iyer (1998) examines a channel with one manufacturer and two retailers who compete on both price and nonprice factors. They assume that consumers are heterogeneous in spatial locations and in their willingness to pay for retail services. In the model, the manufacturer is the Stackelberg leader, while the two retailers move simultaneously.

Lee and Staelin (1997) examine strategic pricing policies in uncoordinated supply chain (no vertical integration or two-part tariff). Using game theoretic approach, the paper shows that the question of using linear or nonlinear demand functions is not as critical as whether the demand function imply vertical strategic substitute (VSS) or vertical strategic complement (VSC).

Kim and Staelin (1999) examine a single period profit maximizing game with two manufacturers and two retailers. They derive the optimal solutions and perform sensitivity on the results. They found that if consumers become more sensitive to differences in merchandizing activity between brands within a store, the retailers' profits increases and the manufacturers' profits decrease. Tsay and Agrawal (2000) study a distribution system in which a manufacturer supplies a common product to two independent retailers. The demand is deterministic and depends on both the retail prices and retail services. The paper shows that the intensity of competition with respect to each competitive dimension plays a key role, as does the degree of cooperation between the retailers.

Table 1 categorizes relevant literature based on assumptions made in the main model in those literature. Our model is shown in comparison with the rest of the literature in the last row. The model we study allows us to study both the horizontal and vertical interactions in supply chain, e.g., the competition between the two manufacturers and their interactions with the retailer. Moreover, this article examines the impact of different bargaining power to the supply-chain equilibrium decisions about price and service-level. The results from this research will give insights on the role of service, in addition to price, in competition and supply chain management, which has not been focused in the existing literature.

Remark: There are several less relevant literature not reviewed above. For example, Trivedi (1998) look into two manufacturers and two common retailers for pricing decisions. The paper showed that the presence of competitive effects at both retail and manufacturer levels of distribution has a significant impact on prices. Raju, Sethuranman and Dhar (1995), Sayman, Hoch and Raju (2002) and Morton and Zettelmeyer (2004) considered multiple manufacturers and one retailer for understanding differences in store brand market share. Impact of service factor was not studied. Boyaci and Ray (2003) studied the role of capacity costs in shaping the optimal differentiation strategy of a firm selling two variants of the same product, one express and another regular. The delivery time is the service factor considered in addition to the usual price based differentiation decisions. Boyaci and Gallego (2004) considered a market with two competing supply-chains, each consisting of one wholesaler and one retailer. customer service was the focused competition factor.

# 3 Model

In our supply chain structure, there are two manufacturers producing different but substitutable products. Both of these manufacturers sell their products to a common retailer, who in turn sells the products to the end consumer. We assume that there is only one retailer in the area. In other words, we assume that the distance between each retailer is so large that there is no competition among retailers. This may be a strong assumption for some markets. However, it allows us to focus on the competition between the two manufacturers. We also assume that consumer demand for each product is sensitive to two factors: (1) retail price, (2) service provided by the manufacturer. Notice that only services that are provided by the competing manufacturers are considered. Effectively, we do not take into account the effect of the services provided by the retailer to the customer demand for each product. We can think of this as the retailer providing the same level of service to both products; the only difference to the customer's perception (other than price) is the services provided by the manufacturer.

We assume also that the investment in services has a decreasing return to scale. Namely, the next dollar invested by the manufacturer returns less service than the last dollar invested, i.e., it is harder (and costs more) to provide the next unit of service than the last one. This can be reflected in the quadratic form of the cost of providing services. The same quadratic equation is also used in Tsay and Agrawal (2000).

In this section, the mathematical model of the supply chain depicted in Figure **??** is defined. In our model, we assume that all activity occurs within a single period. There are two manufacturers, indexed by $i \in \{1, 2\}$, and one retailer. Each manufacturer produces one product, also indicated by the same index as its producer, and also provides service directly to consumers. The retailer carries the products of both manufacturers and faces a deterministic consumer demand that is influenced by both the retail prices and the manufacturer's service of both products. Each manufacturer must decide on his product's wholesale price and level of service to be provided to consumers, while the retailer controls the retail price of both products.

### 3.1 Demand Function

Our model represents a generalization of the model found in Choi (1991). Given this structure, we next specify the consumer demand function and cost structure for each firm. In defining the demand function, we follow the approach by McGuire and Staelin (1983). This approach uses a set of basic characteristics of the type of demand of each product, e.g., downward sloping in its own price, increasing with respect to the competitor's price, and then specifies an analytically feasible function (e.g., linear) that captures these desired characteristics. An alternative approach would derive specific (nonlinear) functions facing the retailer. Typically, this latter approach requires making explicit assumptions concerning consumer tastes, or the existence of a few types of market segments. Examples of this latter approach can be seen in Lal and Matutes (1994).

As pointed out by Lee and Staelin (1997) and Choi (1991), although a liner demand functions do not have good forecasting properties (possibility for negative quantities), they outperform multiplicative and exponential demand functions for analysis of the primary interests such as category pricing or product line pricing. For our model, we make the following assumptions regarding demand functions:

ASSUMPTION 1. *The demand structure is symmetric between the two products. Demand for one product is decreasing in its own retail price and increasing in the competitor retail price. On the other hand, it is increasing in its own service and decreasing in the competitor service.*

ASSUMPTION 2. *Product $i$ has market base $a_i$ and production cost $c_i$. Market base $a_i$ measures the size of product $i$'s market. It is the demand of product $i$ faced by the retailer when both products are priced at zero but the manufacturers offer no service.*

ASSUMPTION 3. *Decreasing product retail price or increasing service level will trigger two phenomena. First, a group of customers will decide to switch from the other product. Second, a group of customers who otherwise would not have bought either product will purchase at this lower price or higher service. The opposite happens when price is increased or service level is decreased.*

From Assumption 1 to 3, the demand for product $i$, which is the same as the retailer ordering quantity, can be expressed as:

$$Q_i(p_i, p_j, s_i, s_j) \quad = \quad a_i - (b_p + \theta_p)p_i + \theta_p p_j + (b_s + \theta_s)s_i - \theta_s s_j \tag{1}$$

where $a_i > 0$, $b_p > 0$, $\theta_p > 0$, $b_s > 0$, $\theta_s > 0$, $i = 1, 2$, and $j = 3 - i$.

Here, $a_i$ is a non-negative constant. It can be thought of as a "market base" (Tsay and Agrawal

2000) as defined in Assumption 2. Customer buying behaviors are characterized in this market base and the slopes for the price and service level explained below. We assume that $a_i$ is large enough so that $Q_i$ will always be non-negative. We can think of $(b_p + \theta_p)$ as the measure of the responsiveness of each manufacturer's market demand to its own price. As specified in Assumption 3, when the price of product $i$ is decreased by one unit, the product will gain $b_p + \theta_p$ more customers. Amongst these customers, $\theta_p$ of them are switching from the competitor's product while $b_p$ of them are the direct result of a larger market demand due to the smaller price. In other words, $b_p$ of them would not buy the product otherwise. A similar explanation can be used for service-related parameters $b_s$ and $\theta_s$.

Note that we can rearrange the terms in Equation 1 to the following form:

$$Q_i(p_i, p_j, s_i, s_j) = a_i - b_p p_i + \theta_p(p_j - p_i) + b_s s_i - \theta_s(s_j - s_i). \tag{2}$$

This is similar to the demand function used in Tsay and Agrawal (2000), except their model was used to study a system with one manufacturer and two competing retailers in their study.

### 3.2 Cost Structure

In our model, the manufacturers can influence the demand by setting the wholesale prices and the service levels. On the other hand, the retailer can independently influence the (retail) price of each product. We do not assume any collusion or cooperation among firms. Each channel member has the same goal: to maximize his own profit. This leads us to the following assumption:

ASSUMPTION 4. *All channel members try to maximize their own profit and behave as if they have perfect information of the demand and the cost structures of other channel members.*

The state of information specified in Assumption 4 is typical in analytical modelling, although it overstates the information climate of the real world. From the model and Assumption 4, the retailer's objective is to maximize its profit function, which can be described by the following equation:

$$\Pi_R = \sum_{i=1}^{2}(p_i - w_i)Q_i(p_i, p_j, s_i, s_j) \tag{3}$$

where $Q_i(p_i, p_j, s_i, s_j)$ is as specified in Equation 2.

To specify each manufacturer's profit function, we note that manufacturers carry two types of cost: production cost and service cost. The latter includes the cost of providing service to customers. This may include the total wage of employees in the service department, the cost of training these employees, or the cost of hiring outsiders to provide customer service. Just as in Tsay and Agrawal (2000), we assume diminishing returns of service. This is specified in the next assumption.

ASSUMPTION 5. *Cost of providing service has a decreasing-return property; the next dollar invested would produce less unit of service than the last dollar - i.e., it becomes more expensive to provide the next unit of service.* $w_i - c_i$ is the difference between manufacturer's wholesale price and production cost. This diminishing return of service can be captured by the quadratic form of service cost. In our model we assume that the cost of providing $s_i$ units of service is $\eta_i {s_i}^2/2$.

This function is also used in Tsay and Agrawal (2000). Thus, the manufacturers' profit function can be written as:

$$\Pi_{M_i} = (w_i - c_i)Q_i(p_i, p_j, s_i, s_j) - \frac{\eta_i s_i^2}{2} \qquad ;\text{i} = 1,\ 2 \tag{4}$$

where $\eta_i$ is the service cost coefficient of manufacturer $i$.

### 3.3 Strategic Interactions

Note that so far we have not made any assumptions regarding the bargaining power possessed by each channel member. The assumption regarding bargaining power possessed by each firm can influence how the pricing game is solved in our model. Depending on the situation in any particular industry, the bargaining power of retailers and manufacturers can vary significantly. In the last few decades there are widely accepted notion that retailers are gaining "power" over the manufacturers. However, the validity of the notion that retailers are gaining power at the expense of the manufacturers is being questioned and studied by researchers in recent years (Ailawadi *et al.* 1995, Messinger and Narasimhan 1995, Kim and Staelin 1999).

Following the notions in Choi (1991), variation in bargaining power in a particular supply chain can create one of the following three scenarios:

1) Manufacturer Stackelberg (MS): The two manufacturers have equal bargaining power. They possess more bargaining power than the retailer and thus are the Stackelberg leader.

2) Retailer Stackelberg (RS): The retailer has more bargaining power than the manufacturers and is the Stackelberg leader. Again, the two manufacturers possess equal bargaining power.

3) Vertical Nash (VN): Every firm in the system has equal bargaining power.

In modelling the problem, the level of bargaining power possessed by each firm (as compared to the other firms) is translated into whether the firm is a leader or a follower. In the game-theoretical approach, the firm with more bargaining power has the first-mover advantage (Stackelberg leader). The firm with less power would have to respond to the leader's decisions. For example, in the Manufacturer Stackelberg game, both manufacturers simultaneously select wholesale prices and service levels in the first step. The retailer observes the decisions made by the manufacturers and makes his response to those decisions in the second step (by choosing retail prices). In the Retailer Stackelberg game the events take place in reverse, while every firm moves simultaneously in the

Vertical Nash game. In this research, we analyze our model with all three scenarios of different power structures. We are interested to see the effect of bargaining power on the results.

# 4 Analytical Results (Manufacturer Stackelberg, Retailer Stackelberg, Vertical Nash)

To analyze our model, we follow a game-theoretical approach. The leader in each scenario makes his decisions to maximize his own profit, conditioned on the follower's response function. The problem can be solved backwards. We begin by first solving for the reaction function of the follower of the game, given that he has observed the leader's decisions. For example, in Manufacturer Stackelberg, the retailer reaction function is derived first, given that the retailer has observed the decisions made by the manufacturers (on wholesale prices and service levels). Then, each manufacturer solves his problem given that he knows how the retailer would react to his decisions.

## 4.1 Manufacturer Stackelberg

### 4.1.1 Retailer Reaction Function

The retailer in this game must choose retail prices $p_1^*$ and $p_2^*$ to maximize his equilibrium profit. That is,

$$p_i^* \in arg \max_{p_i} \Pi_R(p_i, p_j^* | w_1, w_2, s_1, s_2) \tag{5}$$

where $\Pi_R(p_i, p_j | w_1, w_2, s_1, s_2)$ denotes the profit to the retailer at this stage when he sets retail prices $p_i, p_j$, given earlier decisions by the manufacturers are $w_1, w_2, s_1, s_2$. The first order condition can be shown as

$$\begin{aligned} 0 = \frac{\partial \Pi_R}{\partial p_i} \quad &= \quad a_i - 2b_p p_i + \theta_p(p_j - 2p_i) + b_s s_i - \theta_s(s_j - s_i) + w_i b_p + w_i \theta_p \\ &\quad\; + p_j \theta_p - w_j \theta_p \end{aligned} \tag{6}$$

where $i \in \{1, 2\}$ and $j = 3 - i$. We then check the Hessian for optimality. We have $\partial \Pi_R^2 / \partial p_i^2 = -2b_p - 2\theta_p$, and
$\partial \Pi_R^2 / \partial p_i \partial p_j = \partial \Pi_R^2 / \partial p_j \partial p_i = 2\theta_p$.

Assuming that $b_p > 0$ and $\theta_p > 0$, we have a negative definite Hessian. Therefore, the $p_1$ and $p_2$ calculated above are the optimal reaction functions for the retailer.

Using the first and second order optimality conditions above, we have the following expression for the retailer's reaction function

$$p_i^* = \frac{w_i}{2} + \frac{(b_p+\theta_p)a_i + \theta_p a_j}{2b_p(b_p+2\theta_p)} - \frac{\theta_s(s_j - s_i)}{2(b_p+2\theta_p)} + \frac{(b_p+\theta_p)b_s s_i + \theta_p b_s s_j}{2b_p(b_p+2\theta_p)} \tag{7}$$

where $i \in \{1,2\}$ and $j = 3-i$. From equation (7) and (1), we can also obtain the demand quantities for products 1 and 2 as

$$Q_i^* = \frac{a_i}{2} - \frac{(b_p+\theta_p)}{2}w_i + \frac{\theta_p}{2}w_j + \frac{(b_s+\theta_s)}{2}s_i - \frac{\theta_s}{2}s_j \tag{8}$$

where $i = 1, 2$ and $j = 3-i$. We can see that the equilibrium quantities $p_i^*$ and $Q_i^*$ for each product are linear functions of the wholesale prices and service levels by the manufacturers, and the market bases ($a_1$ and $a_2$). Note that the wholesale price and service levels are a function of production costs and other model parameters as described in the next section.

### 4.1.2 Manufacturers Decisions

Using the retailer's reaction function, we can derive each manufacturer's optimal wholesale price and service level. This is carried out by maximizing each manufacturer's profit shown in Equation (4), given the retailer reaction function. The manufacturer $i$ chooses the wholesale prices $w_i^*$ and service level $s_i^*$ to maximize his own individual profit. Recall that the manufacturers move simultaneously. Thus, a Nash Equilibrium exists between them. That is,

$$w_i^* \in arg\max_{w_i} \Pi_{M_i}(w_i, w_j^*, s_i^*, s_j^*), \tag{9}$$

$$s_i^* \in arg\max_{s_i} \Pi_{M_i}(w_i^*, w_j^*, s_i, s_j^*) \tag{10}$$

where $\Pi_{M_i}(w_i, w_j, s_i, s_j)$ is the profit of manufacturer $i$ at this stage when manufacturers set their wholesale prices at $w_i, w_j$ and service levels at $s_i, s_j$. To find the optimal wholesale price, $w_i$, we first look at the first order condition.

$$\begin{aligned} 0 = \frac{\partial \Pi_{M_i}}{\partial w_i} &= a_i - b_p\left[w_i + \frac{(b_p+\theta_p)a_i + \theta_p a_j}{2b_p(b_p+2\theta_p)} - \frac{\theta_s(s_j - s_i)}{2(b_p+2\theta_p)} + \frac{(b_p+\theta_p)b_s s_i + \theta_p b_s s_j}{2b_p(b_p+2\theta_p)}\right] \\ &+\theta_p\left[\frac{a_j - a_i}{2(b_p+2\theta_p)} + \frac{w_j - 2w_i}{2} + \frac{(2\theta_s + b_s)(s_j - s_i)}{2(b_p+2\theta_p)}\right] \\ &+b_s s_i - \theta_s(s_j - s_i) + \frac{c_i b_p}{2} + \frac{c_i \theta_p}{2} \end{aligned}$$

$$0 = \frac{\partial \Pi_{M_i}}{\partial s_i} = (w_i - c_i)\left[-\frac{b_p\theta_s}{2(b_p+2\theta_p)} - \frac{b_p(b_p+\theta_p)b_s}{2b_p(b_p+2\theta_p)} - \frac{\theta_p(b_s+2\theta_s)}{2(b_p+2\theta_p)} + b_s + \theta_s\right] - \eta_i s_i$$

The second order condition is then calculated to check the optimality. We have $\partial\Pi_{M_i}^2/\partial w_i^2 = -b_p - \theta_p$,
$\partial\Pi_{M_i}^2/\partial w_i \partial s_i = b_s + \theta_s/2$, and $\partial\Pi_{M_i}^2/\partial s_i^2 = -\eta_i$.

Assuming that $b_p > 0$ and $\theta_p > 0$, we have a negative definite Hessian. Therefore, the $w_i$ and $s_i$ calculated above are the optimal reaction functions for the manufacturer $i$.

The following proposition gives the closed form solution of wholesale price and service level.

**PROPOSITION 4.1.** *The manufacturer's equilibrium wholesale price and service level are:*

$$w_i^* = \frac{2\eta_i A_j}{A_1A_2 - B_1B_2}\Big[a_i + D_ja_j + (E_i + F_iD_j)c_i + (F_j + E_jD_j)c_j\Big] \tag{11}$$

$$\begin{aligned} s_i^* &= (b_s + \theta_s)\Big\{\frac{A_j}{A_1A_2 - B_1B_2}\Big[a_i + D_ja_j + (F_j + E_jD_j)c_j\Big] \\ &\quad + \Big[\frac{A_j(E_i + F_iD_j)}{A_1A_2 - B_1B_2} - \frac{1}{2\eta_i}\Big]c_i\Big\} \end{aligned} \tag{12}$$

*where* $i = 1, 2$ *and* $j = 3 - i$ *and* $A_i = 4\eta_i(b_p + \theta_p) + (b_s + \theta_s)^2, B_i = 2\eta_i\theta_p - \theta_s(b_s + \theta_s)[(b_p - b_s + 2\theta_p)/(b_p + 2\theta_p)], D_i = B_i/A_i, E_i = (b_p + \theta_p) - (b_s + \theta_s)^2/2\eta_i, F_i = [\theta_s(b_s + \theta_s)/2\eta_i] - [\theta_p b_s(b_s + \theta_s)/2\eta_i(b_p + 2\theta_p)]$.

**Proof:** See the Appendix.

Note that if service is not taken into account or is assumed to be zero, equation (7), (8), and (11) reduce to

$$p_i^{NS*} = \frac{w_i}{2} + \frac{(b_p + \theta_p)a_i + \theta_p a_j}{2b_p(b_p + 2\theta_p)} \tag{13}$$

$$Q_i^{NS*} = \frac{a_i}{2} - \frac{(b_p + \theta_p)w_i}{2} + \frac{\theta_p w_j}{2} \quad \text{and} \tag{14}$$

$$w_i^{NS*} = \frac{1}{4(b_p + \theta_p)^2 - \theta_p^2}\Big[2(b_p + \theta_p)a_i + \theta_p a_j + 2(b_p + \theta_p)^2 c_i + \theta_p(b_p + \theta_p)c_j\Big] \tag{15}$$

for $i \in \{1, 2\}$ and $j = 3 - i$. These are the results derived by Choi (1991). Choi (1991) defines a linear duopoly demand function as $Q_i = a - bp_i + \gamma p_j$ where $b = b_p + \theta_p$ and $\gamma = \theta_p$. His model does not take into account the service provided by manufacturers and assumes that the two products have equal market base ($a_1 = a_2 = a$). Thus, his model is a special case of our model.

Comparing equations (8) and (14), we can see that ${Q_i}^*$ (demand of product $i$ when both manufacturers provide service) will be greater than $Q_i^{NS*}$ (demand of product $i$ when no service is provided) if

$$\frac{s_i}{s_j} \geq \frac{\theta_s}{(b_s + 2\theta_s)}. \tag{16}$$

Thus, when manufacturer $i$ provides its service $s_i \geq \frac{\theta_s}{(b_s+2\theta_s)} s_j$, product $i$ can capture a bigger market than its competitor.

Now, comparing equations (7) and (13), $p_i{}^*$ (retail price of product $i$ when both manufacturers provide service) will be greater than $p_i^{NS^*}$ (retail price of product $i$ when no service is provided) if the following condition is satisfied

$$w_i^* - w_i^{NS*} \quad \geq \quad \frac{[b_p\theta_s + \theta_p b_p]s_j - [(b_p+\theta_p)b_s + b_p\theta_s]s_i}{b_p(b_p+2\theta_p)}. \tag{17}$$

In other words, if

$$s_j \quad \leq \quad \frac{b_p(b_p+2\theta_p)(w_i^* - w_i^{NS*})}{b_p\theta_s + \theta_p b_p} + \frac{[(b_p+\theta_p)b_s + b_p\theta_s]}{b_p\theta_s + \theta_p b_p} s_i, \tag{18}$$

then $p_i{}^*$ will be greater than $p_i^{NS^*}$.

### 4.2 Retailer Stackelberg

The Retailer Stackelberg scenario arises in markets where retailers' sizes are large compared to their suppliers. For example, large retailers like Walmart and Target can influence each product's sales by lowering price. Because of their sizes, the retailers can maintain their margin on sales while squeezing profit from their suppliers. The suppliers are mostly concerned with receiving orders from the retail giants. Similar game-theoretic framework as applied in the Manufacturer Stackelberg case is implemented to solve this problem; i.e., the problem is solved backwards. First, the suppliers' problem is solved to derive the response function conditional on the retail prices chosen by the retailer. The retailer problem is then solved given that the retailer knows how the manufacturers would react to the retail prices he sets.

#### 4.2.1 Manufacturers Reaction Functions

To cope with competition, manufacturer $i$ chooses equilibrium wholesale price $w_i$ and service level $s_i$. That is, for each manufacturer $i$

$$w_i^* \quad \in \quad arg\max_{w_i} \Pi_{M_i}(w_i, w_j^*, s_i^*, s_j^* | p_1, p_2), \tag{19}$$

$$s_i^* \quad \in \quad arg\max_{s_i} \Pi_{M_i}(w_i^*, w_j^*, s_i, s_j^* | p_1, p_2) \tag{20}$$

where $\Pi_{M_i}(w_1, w_2, s_1, s_2 | p_1, p_2)$ is the profit to manufacturer $i$ at this stage when manufacturers set wholesale prices $w_1, w_2$ and service levels $s_1, s_2$, given earlier decisions on retail price $p_1, p_2$ by the retailer.

The first order conditions are

$$\begin{aligned}0 = \frac{\partial \Pi_{M_i}}{\partial w_i} &= Q_i + (w_i - c_i)(-b_p - \theta_p)\\ 0 = \frac{\partial \Pi_{M_i}}{\partial s_i} &= (w_i - c_i)(b_s + \theta_s) - \eta_i s_i\end{aligned}$$

We can check for optimality by calculating the second order condition. We then have $\partial \Pi_{M_i}^2/\partial w_i^2 = -b_p - \theta_p$,
$\partial \Pi_{M_i}^2/\partial w_i \partial s_i = b_s + \theta_s$, and $\partial \Pi_{M_i}^2/\partial s_i^2 = -\eta_i$. Thus, the Hessian is negative definite and the second order condition is satisfied. Therefore, the $w_i$ and $s_i$ calculated above are the optimal reaction functions for the manufacturer $i$.Using the first and second order conditions above, the response wholesale price and service level for each manufacture can be derived and are given in the next proposition.

**PROPOSITION 4.2.** *The manufacturer's response function given retail prices $p_i$ and $p_j$ are:*

$$w_i^* = \frac{\eta_i H_j}{H_1 H_2 - K^2}\Bigg[a_i - L_j a_j - (\theta_p L_j + G)p_i + (GL_j + \theta_p)p_j + (M_i - L_j N_i)c_i\Bigg].$$

$$s_i^* = \frac{H_j(b_s + \theta_s)}{H_1 H_2 - K^2}\Bigg[a_i - L_j a_j - (\theta_p L_j + G)p_i + (GL_j + \theta_p)p_j\Bigg] \tag{21}$$

*where* $G = b_p + \theta_p, H_i = \eta_i(b_p + \theta_p) - (b_s + \theta_s)^2, K = \theta_s(b_s + \theta_s), L_i = K/H_i, M_i = H_i/\eta_i = (b_p + \theta_p) - (b_s + \theta_s)^2/\eta_i, N_i = K/\eta_i = \theta_s(b_s + \theta_s)/\eta_i$

**Proof:** See the Appendix.

We can see that the optimal service responses for both manufacturers do not depend on the production cost. Even for the optimal wholesale price responses, the manufacturers do not need to know the production cost of their competitors. Retail prices can be easily observed in the market. The value of market bases can be estimated by the manufacturers by conducting a market survey.

### 4.2.2 Retailer Decision

Having the information about the reaction functions of manufacturers, the retailer would then use them to maximize his profit

$$\Pi_R = (p_1 - w_1(p_1, p_2))Q_1(p_1, p_2) + (p_2 - w_2(p_1, p_2))Q_2(p_1, p_2). \tag{22}$$

The retailer in this game must choose retail prices $p_1^*$ and $p_2^*$ to maximize his equilibrium profit. That is,

$$p_i^* \in arg\max_{p_i} \Pi_R(p_i, p_j^*) \tag{23}$$

where $\Pi_R(p_1, p_2)$ denotes the profit to the retailer at this stage when he set retail prices $p_1, p_2$. The first order condition can be shown as

$$\begin{aligned} 0 = \frac{\partial \Pi_R}{\partial p_i} &= \left(1 - \frac{\partial w_i(p_i,p_j)}{\partial p_i}\right) Q_i(p_i,p_j) + (p_i - w_i(p_i,p_j))\frac{\partial Q_i(p_i,p_j)}{\partial p_i} \\ &\quad + \left(-\frac{\partial w_j(p_i,p_j)}{\partial p_i}\right) Q_j(p_i,p_j) + (p_j - w_j(p_i,p_j))\frac{\partial Q_j(p_i,p_j)}{\partial p_i} \end{aligned} \tag{24}$$

where

$$\frac{\partial w_i(p_i,p_j)}{\partial p_i} = \frac{2\eta_i H_j}{H_i H_j - K^2}(\theta_p L_j - G) \tag{25}$$

$$\frac{\partial w_j(p_i,p_j)}{\partial p_i} = \frac{2\eta_j H_i}{H_i H_j - K^2}(G L_i - \theta_p) \tag{26}$$

$$\frac{\partial w_i(p_i,p_j)}{\partial p_j} = \frac{2\eta_i H_j}{H_i H_j - K^2}(G L_j - \theta_p) \tag{27}$$

$$\frac{\partial w_j(p_i,p_j)}{\partial p_j} = \frac{2\eta_j H_i}{H_i H_j - K^2}(\theta_p L_i - G) \tag{28}$$

To check for optimality, the second order condition is checked. We then have $\partial\Pi_R^2/\partial p_i^2 = -2b_p - 2\theta_p$, and
$\partial\Pi_R^2/\partial p_i \partial p_j = \partial\Pi_R^2/\partial p_j \partial p_i = 2\theta_p$. Assuming that $b_p > 0$ and $\theta_p > 0$, we have a negative definite Hessian. Therefore, the $p_1$ and $p_2$ calculated above are the optimal reaction functions for the retailer.

Using the first and second order optimization conditions, the equilibrium retail prices can be derived and are given in the following proposition.

**PROPOSITION 4.3.** *In the Retailer Stackelberg case, the equilibrium retail price $p_1^*$ and $p_2^*$ chosen by the retailer are*

$$\begin{aligned} p_1^* &= \frac{(X_2U_1 - YV_1)a_1 + (YV_2 - X_2U_2)a_2 + (X_2\rho_1 - Y\sigma_1)Wc_1 + (Y\rho_2 - X_2\sigma_2)Wc_2}{X_1X_2 - Y^2} \\ p_2^* &= \frac{(YU_1 - X_1V_1)a_1 + (X_1V_2 - YU_2)a_2 + (Y\rho_1 - X_1\sigma_1)Wc_1 + (X_1\rho_2 - Y\sigma_2)Wc_2}{X_1X_2 - Y^2}. \end{aligned}$$

*where $\rho_i$, $\sigma_i$, $X_i$, $Y$, $U_i$, $V_i$ and $W$ for $i \in \{1, 2\}$ and $j = 3-i$ are constants defined in the Appendix.*

**Proof:** See the Appendix.

This proposition shows linear relationship between retail price and market bases and production costs. When $b_s = \theta_s = 0$, the expressions are reduced to the results given in Choi (1991).

### 4.3 Vertical Nash

The Vertical Nash model is studied as a benchmark to both the Manufacturer Stackelberg and Retailer Stackelberg cases. In this model, every firm has equal bargaining power and thus makes his decisions simultaneously. This scenario arises in a market in which there are relatively small to medium-sized manufacturers and retailers. In this market it is reasonable to assume that a manufacturer may not know the competitor's wholesale price but can observe its retail price. Since a manufacturer cannot dominate the market over the retailer, his price decision is conditioned on how the retailer prices the product. On the other hand, the retailer must also condition its retail price decisions on the wholesale price.

Again, game-theoretic framework is employed to derive the reaction function of each firm in the supply chain. Fortunately, the reaction functions for the retailer and the manufacturers were already derived in the Manufacturer Stackelberg game and the Retailer Stackelberg game respectively. From the Manufacturer Stackelberg game, the retailer reaction function for given wholesale prices $w_1, w_2$ and service levels $s_1, s_2$ is given in Equation (7) as

$$p_i^* = \frac{w_i^*}{2} + \frac{(b_p+\theta_p)a_i + \theta_p a_j}{2b_p(b_p+2\theta_p)} - \frac{\theta_s(s_j^* - s_i^*)}{2(b_p+2\theta_p)} + \frac{(b_p+\theta_p)b_s s_i^* + \theta_p b_s s_j^*}{2b_p(b_p+2\theta_p)}$$

where $i \in \{1,2\}$ and $j = 3-i$. From the Retailer Stackelberg game, the manufacturers reaction function for given retail prices $p_1, p_2$ are given in Equations (44) and (45) as

$$w_i^* = \frac{\eta_i H_j}{H_1 H_2 - K^2}\left[a_i - L_j a_j - (\theta_p L_j + G)p_i + (GL_j + \theta_p)p_j + (M_i - L_j N_i)c_i\right]$$

$$s_i^* = \frac{H_j(b_s+\theta_s)}{H_1 H_2 - K^2}\left[a_i - L_j a_j - (\theta_p L_j + G)p_i + (GL_j + \theta_p)p_j\right]$$

for wholesale price and service level respectively. $H_i, K, L_i, M_i, N_i$, and $G$ for $i \in \{1,2\}$ and $j = 3-i$ are defined as in the Retailer Stackelberg game. Solving the above equations simultaneously yields the Nash equilibrium solution. The equilibrium retail prices can be derived and are given in the following proposition.

**PROPOSITION 4.4.** *In Vertical Nash case, the equilibrium retail price $p_1^*$ and $p_2^*$ chosen by the retailer are*

$$p_i = \frac{(\gamma_j\kappa_i + \lambda_i\kappa_j)a_1 + (\gamma_j\nu_i + \lambda_i\nu_j)a_2 + \gamma_j\psi_i c_1 + \lambda_i\psi_j c_2}{\gamma_i\gamma_j - \lambda_i\lambda_j} \tag{29}$$

*where $\kappa_i$, $\lambda_i$, $\nu_i$ and $\psi_i$ for $i \in \{1,2\}$ and $j = 3-i$ are constants.*

**Proof:** See the Appendix.

## 4.4 Comparison of Results

In this section, we compare the results from the three different scenarios to focus on the effect of power structure on prices, service levels, and profits of each channel member. However, when the two manufacturers are not identical (in production cost or market base), it is difficult to compare the results from different scenarios since there will be a market leader and a follower. In order to separate the effects of different power structures from the effects of cost differences, we assume identical manufacturers (same market base, production cost and service cost coefficient). This assumption simplifies the results given previously by setting $a_i = a_j = a$, $c_i = c_j = c$, and $\eta_i = \eta_j = \eta$. The following theorem summarizes the results with the identical manufacturers assumption.

**THEOREM 4.1.** *When the two manufacturers are identical (same market base, production cost and service cost coefficient), the retail price, wholesale price, service level, demand quantity, and profit can be calculated as shown in Table 4.1*

| | Scenario | | |
|---|---|---|---|
| | MS | VN | RS |
| **Manufacturers** | | | |
| Wholesale Price | 22.227 | 20.870 | 19.039 |
| Service Level | 4.307 | 7.935 | 7.0192 |
| Profit | 221.649 | 188.882 | 147.809 |
| **Retailer** | | | |
| Retail Price | 42.146 | 43.540 | 45.110 |
| Profit | 555.480 | 719.552 | 732.006 |
| Demand | 13.943 | 15.870 | 14.039 |

Table 2: Comparison of results from three scenarios

**Proof:** See the Appendix.

When $b_s = \theta_s = 0$, the results given in Table 2 reduce to the results given by Choi (1991) in which competition in service is not taken into account. The results in Table 2 show that the equilibrium wholesale and retail price, service level, and demand quantity are a linear function of both market base and production cost. From Table 2, we have the following corollary.

**COROLLARY 4.1.** *When the two manufacturers are identical (same market base, production cost and service cost coefficient) and $\eta b_p > b_s(b_s + \theta_s)$ and $a > b_p c$, then $s^{MS} < s^{RS} < s^{VN}$.*

**Proof:** See the Appendix.

This proposition states that when the manufacturers possess the most bargaining power, consumers receive the least benefit from service. The proposition shows that the consumers are better off when there is no dominant power between the retailer and manufacturers. This is reflected in higher service levels and greater demand quantity in the VN scenario as compared to those in MS and RS.

We next compares other quantities among the three scenarios. We find that the results of comparison depend on the value of $b_s$ and $\theta_s$. When $b_s$ and $\theta_s$ are greater than zero, the results from Manufacturer Stackelberg can vary, depending on the values of the parameters. Thus, they can not be compared to the results from the other two cases. However, when $b_s = \theta_s = 0$, the results from all three scenarios in Table 2 can be simplified and compared. The following corollary states these findings.

**COROLLARY 4.2.** *When the two manufacturers are identical (same market base, production cost and service cost coefficient) and $\eta b_p > b_s(b_s + \theta_s)$ and $a > b_p c$, we have the following results*

| | *(a)* *If $b_s$ and $\theta_s > 0$* | *(b)* *If $b_s$ and $\theta_s = 0$* |
|---|---|---|
| *Retail Price* | *N/A* | $p^{MS} < p^{VN} < p^{RS}$ |
| *Demand* | $Q^{RS} < Q^{VN}$ | $Q^{MS}, Q^{RS} < Q^{VN}$ |
| *Wholesale Price* | $w^{VN} > w^{RS}$ | $w^{MS} > w^{VN} > w^{RS}$ |
| *Manufacturer Profit* | $\Pi_M^{VN} > \Pi_M^{RS}$ | $\Pi_M^{MS} > \Pi_M^{VN} > \Pi_M^{RS}$ |
| *Retailer Profit* | $\Pi_R^{VN} < \Pi_R^{RS}$ | $\Pi_R^{MS} < \Pi_R^{VN} < \Pi_R^{RS}$ |

**Proof:** See the Appendix.

Part (b) of Corollary 4.2 is similar to the results given by Choi (1991) and Lee and Staelin (1997). Their models do not include the service component (i.e., $b_s = \theta_s = 0$ in their models). Thus, Corollary 4.2 provides more general results than those in existing literature.

Note that when $b_s$ and $\theta_s > 0$, it is not possible to compare the results from the Manufacturer Stackelberg case with the other two cases. This is because the values of $b_s$ and $\theta_s$ can influence the nature of competition. When $b_s$ and $\theta_s$ are significant larger than $b_p$ and $\theta_p$, the two manufacturers will focus on service competition. On the other hand, if $b_p$ and $\theta_p$ are significant larger than $b_s$ and $\theta_s$, manufacturers will concentrate on price competition. Thus, the relative amount of price and service level in the Manufacturer Stackelberg case as compared to the other two cases can vary.

Note also that we can not compare the retail price among the three cases. This is also due to the nature of competition in the industry. When $b_p$ and $\theta_p$ are significant larger than $b_s$ and $\theta_s$, the result will be close to that given in part (b) (i.e., $p^{MS} < p^{VN} < p^{RS}$). However, if $b_s$ and $\theta_s$ are significant larger than $b_p$ and $\theta_p$, the manufacturers will focus on service competition. In this case, no definite statement can be concluded from the comparison of the retail price between the three cases.

# 5 Numerical Studies

In this section, we use numerical approach to studies the behavior of firms when facing changing environment. We follow existing literature (e.g., Tsay and Agrawal (2000) and Vilcassin *et al.* (1999)) in defining the range of some parameters. We explore how retail prices, wholesale prices, service levels, and profits are affected by changes arisen from the individual company. This is because prices or services can change over time due to continuing improvement in production technology in the industry. Thus, the results in this section can help us understand the robustness of our results to either firm-specific or industry-wide changes.

From the results in the last section, we found that, regardless of power structure, as market base of manufacturer $i$ increases, the firm can sell its product at a higher price and with larger quantity. This brings in more revenue and makes it affordable for the manufacturer to provide more services. This in turn creates even more demand for the product and increases profit. We also found out that as the market base of product $i$ increases, manufacturer $j$'s profit also increases. This might be counterintuitive but can be explained as follows: the increase in competitor's profit is due to the factor $\theta_p$ in demand function which reflects the fact that some fixed proportion of customers will switch from product $i$ to product $j$ due to competition. However, the increase in price, service level and profit of product $j$ will be smaller than those of product $i$. This result is summarized in the next proposition.

**OBSERVATION 5.1.** *Regardless of power structure, an increase in market base in one company benefits its competitor as well but at a lesser extent. Namely, (a)* $0 < \frac{\partial w_j}{\partial a_i} < \frac{\partial w_i}{\partial a_i}$*, (b)* $0 < \frac{\partial s_j}{\partial a_i} < \frac{\partial s_i}{\partial a_i}$*, (c)* $0 < \frac{\partial p_j}{\partial a_i} < \frac{\partial p_i}{\partial a_i}$*, (d)* $0 < \frac{\partial Q_j}{\partial a_i} < \frac{\partial Q_i}{\partial a_i}$*, (e)* $0 < \frac{\partial \Pi_{M_j}}{\partial a_i} < \frac{\partial \Pi_{M_i}}{\partial a_i}$*, (f)* $0 < \frac{\partial \Pi_R}{\partial a_i}$

Similar phenomenon also occurs when $c_i$ increases, except that now the increase has adverse effect on demand quantity, service level and profit of product $i$. The result shows that firm $i$ will sell its product at a higher price and provide less service. This brings the firm less profit. We found out that as $c_i$ increases, $p_j$ also increases. However, this increase in $p_j$ is at a smaller magnitude than the increase in $p_i$. As $s_i$ decreases due to a higher $c_i$, $s_j$ increases. Thus, demand and profit for product $j$ increase while those for product $i$ decrease. Note that the retailer is also hurt if the production cost of one of the manufacturers increases; this is because of the decrease in total demand due to a higher price. The next proposition states this result.

**OBSERVATION 5.2.** *Regardless of power structure, an increase in production cost in one company decreases its profit while increases its competitor's profit, but at a lesser extent. Namely, (a)* $0 < \frac{\partial w_j}{\partial c_i} < \frac{\partial w_i}{\partial c_i}$*, (b)* $0 < \frac{\partial s_j}{\partial c_i} < -\frac{\partial s_i}{\partial c_i}$*, (c)* $0 < \frac{\partial p_j}{\partial c_i} < \frac{\partial p_i}{\partial c_i}$*, (d)* $0 < \frac{\partial Q_j}{\partial c_i} < -\frac{\partial Q_i}{\partial c_i}$*, (e)* $0 < \frac{\partial \Pi_{M_j}}{\partial c_i} < -\frac{\partial \Pi_{M_i}}{\partial c_i}$*, (f)* $0 > \frac{\partial \Pi_R}{\partial c_i}$

We also found that when manufacturer $i$ has an advantage on service cost coefficient (i.e.,

$\eta_i < \eta_j$), it will provide more service, and sell the product at lower wholesale price. However, its product will have a higher retail price. This leads us to the following result.

**OBSERVATION 5.3.** *When $\eta_i < \eta_j$, the retailer will act as a market segmenter and sell the product with high service at high (retail) price and sell the product with low service at low (retail) price. Namely, $s_i > s_j$ and $p_i > p_j$ even though $w_i < w_j$.*

When manufacturer $i$ has an advantage on service cost coefficient (i.e., $\eta_i < \eta_j$), he can sell at a lower price since his service cost is less than that of his competitor. However, the retailer will sell product $i$ at a higher retail price. The retailer makes up for the smaller profit from the low service product by a bigger profit from the higher service product. This result emphasizes the role of the retailer as an intermediary. The consumers can not enjoy better service and lower price offered by manufacturer $i$ due to the existence of the retailer. In order to receive high service offered by manufacturer $i$, they must pay a higher price.

# 6 Conclusions

Our primary objective is to highlight the importance of service from manufacturers in the interactions between two competing manufacturers and their common retailer, facing end consumers who are sensitive to both retail price and manufacturer service. We also explore the role of bargaining power by examining the problem through three different scenarios. Using game theoretic approach, our analysis found a number of insights into economic behavior of firms, which could serve as the basis for empirical study in the future.

In this paper, we derive expressions for equilibrium retail and wholesale prices, service levels, profits, and demand quantity for each product. We then analyze the results and give some insights on the influence of each parameters. Our results show that it is more beneficial to consumers when there is no dominant player(s) in vertical strategic interaction. In such case, the consumers receive more manufacturer service and can buy product at a lower price. A counterintuitive result shows that as market base of one product increases, the competitor also benefit but at a less amount. Furthermore, when one manufacturer has economic advantage in providing service, the retailer will act to separate market segment by selling product with low service at low price and selling product with high service at high price.

In this paper we study the effect of changes in each parameters to cope with rapidly changing environment. Another approach is to extend the model over multiple periods to specifically study temporal dynamics in the supply chain. One possibility is to study learning effect. The new model can analyze how firms and consumers can make use of their experiences and learn over repeated transactions. One can start by first extend the problem to two periods and analyze model before extending the model to longer horizon.

Furthermore, the retailer in our model enjoys regional monopolistic advantage. One alternative is to build a model with two competing retailers. Each sells competing products from two manufacturers. Other possibilities may include the situation where one manufacturer owns and controls a retailer as a "company store" and compete with regular channel. One can also build a more general model to have the service components both from the manufacturers and from the retailer. Lastly, we examine the problem without coordination within the supply chain. One possible extension is to examine the mechanism such as vertical integration or two-part tariffs.

# APPENDIX A: Final Expressions for Retail Price

## A1: Retailer Stackelberg

Using the first and second order optimization technique, the equilibrium retail price is

$$\begin{aligned}
p_1 &= \frac{(X_2M_1 - YN_1)a_1 + (YN_2 - X_2M_2)a_2 + (X_2\rho_1 - Y\sigma_1)Kc_1 + (Y\rho_2 - X_2\sigma_2)Kc_2}{X_1X_2 - Y^2} \\
p_2 &= \frac{(YM_1 - X_1N_1)a_1 + (X_1N_2 - YM_2)a_2 + (Y\rho_1 - X_1\sigma_1)Kc_1 + (X_1\rho_2 - Y\sigma_2)Kc_2}{X_1X_2 - Y^2}
\end{aligned}$$

where

$$\begin{aligned}
K &= A_1^{'}A_2^{'} - B^{'2} \\
M_1 &= \xi_1\rho_1 + \omega_1\gamma_1 + \xi_2D_1^{'}\sigma_2 + \psi_2\phi_2 \\
M_2 &= \xi_2\sigma_2 + \omega_1\phi_1 + \xi_1D_2^{'}\rho_1 + \psi_2\gamma_2 \\
N_1 &= \psi_1\gamma_1 + \xi_1\sigma_1 + \omega_2\phi_2 + \xi_2D_1^{'}\rho_2 \\
N_2 &= \psi_1\phi_1 + \xi_2\rho_2 + \omega_2\gamma_2 + \xi_1D_2^{'}\sigma_1 \\
X_1 &= 2(\omega_1\rho_1 + \psi_2\sigma_2) \\
X_2 &= 2(\omega_2\rho_2 + \psi_1\sigma_1) \\
Y &= \psi_1\rho_1 + \psi_2\rho_2 + \omega_1\sigma_1 + \omega_2\sigma_2 \\
\xi_i &= \eta_iA_j^{'} \\
\omega_i &= A_1^{'}A_2^{'} - B^{'2} + \eta_iA_j^{'}(G^{'} + \theta_pD_j^{'}) \\
\psi_i &= \eta_iA_j^{'}(G^{'}D_j^{'} + \theta_p) \\
\gamma_i &= \eta_iA_j^{'}G^{'} \\
\phi_i &= \eta_iB^{'}G^{'} \\
\rho_i &= \eta_iG^{'}(A_j^{'}G^{'} + \theta_pB^{'}) \\
\sigma_i &= \eta_iG^{'}(G^{'}B^{'} + \theta_pA_j^{'})
\end{aligned} \tag{30}$$

## A2: Vertical Nash

The above equations can then be solved simultaneously to derive Nash equilibrium solution. The final expressions for retail prices are

$$
\begin{aligned}
p_1 &= \frac{(K_1+K_4L_1)a_1+(K_2+K_4L_2)a_2+K_3c_1+K_4L_3c_2}{1-K_4L_4} && (31)\\
p_2 &= \frac{(L_1+L_4K_1)a_1+(L_2+L_4K_2)a_2+L_3c_1+L_4K_3c_2}{1-K_4L_4} && (32)
\end{aligned}
$$

where

$$
\begin{aligned}
K_0 &= 2b_p(b_p+2\theta_p)(A_1^{'}A_2^{'}-B^{'2})+\eta_1A_2^{'}(\theta_pD_2^{'}+G^{'})b_p(b_p+2\theta_p)+[\theta_sb_p+b_s(b_p+\theta_p)]A_2^{'}(b_s+\theta_s)(\theta_pD_2^{'}+G^{'})\\
&\quad -(\theta_pb_s-b_p\theta_s)(b_s+\theta_s)A_1^{'}(G^{'}D_1^{'}+\theta_p)\\
K_1 &= \frac{\eta_1A_2^{'}b_p(b_p+2\theta_p)+(b_p+\theta_p)(A_1^{'}A_2^{'}-B^{'2})+[\theta_sb_p+b_s(b_p+\theta_p)]A_2^{'}(b_s+\theta_s)-(\theta_pb_s-b_p\theta_s)(b_s+\theta_s)A_1^{'}D_1^{'}}{K_0}\\
K_2 &= \frac{-\eta_1A_2^{'}D_2^{'}b_p(b_p+2\theta_p)+\theta_p(A_1^{'}A_2^{'}-B^{'2})-[\theta_sb_p+b_s(b_p+\theta_p)]A_2^{'}D_2^{'}(b_s+\theta_s)+(\theta_pb_s-b_p\theta_s)(b_s+\theta_s)A_1^{'}}{K_0}\\
K_3 &= \frac{\eta_1b_p(b_p+2\theta_p)A_2^{'}(E_1^{'}-D_2^{'}F_1^{'})}{K_0}\\
K_4 &= \frac{\eta_1A_2^{'}(G^{'}D_1^{'}+\theta_p)b_p(b_p+2\theta_p)+[\theta_sb_p+b_s(b_p+\theta_p)]A_2^{'}(b_s+\theta_s)(G^{'}D_2^{'}+\theta_p)-(\theta_pb_s-b_p\theta_s)A_1^{'}(b_s+\theta_s)(\theta_pD_1^{'}+G^{'})}{K_0}
\end{aligned}
$$

$$
\begin{aligned}
L_0 &= 2b_p(b_p+2\theta_p)(A_1^{'}A_2^{'}-B^{'2})+\eta_2A_1^{'}(\theta_pD_1^{'}+G^{'})b_p(b_p+2\theta_p)+[\theta_sb_p+b_s(b_p+\theta_p)]A_1^{'}(b_s+\theta_s)(\theta_pD_1^{'}+G^{'})\\
&\quad -(\theta_pb_s-b_p\theta_s)(b_s+\theta_s)A_2^{'}(G^{'}D_2^{'}+\theta_p)\\
L_1 &= \frac{-\eta_2A_1^{'}D_1^{'}b_p(b_p+2\theta_p)+\theta_p(A_1^{'}A_2^{'}-B^{'2})-[\theta_sb_p+b_s(b_p+\theta_p)]A_1^{'}D_1^{'}(b_s+\theta_s)+(\theta_pb_s-b_p\theta_s)(b_s+\theta_s)A_2^{'}}{L_0}\\
L_2 &= \frac{\eta_2A_1^{'}b_p(b_p+2\theta_p)+(b_p+\theta_p)(A_1^{'}A_2^{'}-B^{'2})+[\theta_sb_p+b_s(b_p+\theta_p)]A_1^{'}(b_s+\theta_s)-(\theta_pb_s-b_p\theta_s)(b_s+\theta_s)A_2^{'}D_2^{'}}{L_0}\\
L_3 &= \frac{\eta_2b_p(b_p+2\theta_p)A_1^{'}(E_2^{'}-D_1^{'}F_2^{'})}{L_0}\\
L_4 &= \frac{\eta_2A_1^{'}(G^{'}D_1^{'}+\theta_p)b_p(b_p+2\theta_p)+[\theta_sb_p+b_s(b_p+\theta_p)]A_1^{'}(b_s+\theta_s)(G^{'}D_1^{'}+\theta_p)-(\theta_pb_s-b_p\theta_s)A_2^{'}(b_s+\theta_s)(\theta_pD_2^{'}+G^{'})}{L_0}
\end{aligned}
$$

# APPENDIX B: Detail Derivation of Equilibrium Solutions

## B1: Supplier Stackelberg

We first look at the retailer's reaction function after he has the information about prices and service levels announced by the suppliers. Retailer's profit function can be expressed as the following:

$$
\begin{aligned}
\Pi_R &= (p_1-w_1)[a_1-b_pp_1+\theta_p(p_2-p_1)+b_ss_1-\theta_s(s_2-s_1)]\\
&\quad +(p_2-w_2)[a_2-b_pp_2+\theta_p(p_1-p_2)+b_ss_2-\theta_s(s_1-s_2)].
\end{aligned}
$$

$$
\begin{aligned}
0 = \frac{\partial \Pi_R}{\partial p_i} &= (p_j - w_j)\theta_p + a_i - 2b_p p_i + \theta_p(p_j - 2p_i) + b_s s_i - \theta_s(s_j - s_i) + w_i b_p + w_i \theta_p \\
p_i &= \frac{a_i + b_s s_i - \theta_s(s_j - s_i) + w_i(b_p + \theta_p) + \theta_p(2p_j - w_j)}{2(b_p + \theta_p)}. \qquad (33)
\end{aligned}
$$

To check the optimality, we check the Hessian matrix:

$$
\begin{aligned}
\frac{\partial \Pi_R^2}{\partial p_1^2} &= -2b_p - 2\theta_p \\
\frac{\partial \Pi_R^2}{\partial p_2 \partial p_1} = \frac{\partial \Pi_R^2}{\partial p_1 \partial p_2} &= 2\theta_p \\
\frac{\partial \Pi_R^2}{\partial p_2^2} &= -2b_p - 2\theta_p.
\end{aligned}
$$

Assuming that $b_p \geq 0$ and $\theta_p \geq 0$, we have a negative definite Hessian. Therefore, the $p_1$ and $p_2$ calculated above are the optimal reaction functions for the retailer. Solving for $p_1$ and $p_2$ by plugging $p_1$ into $p_2$ we have:

$$
p_i^* = \frac{w_i}{2} + \frac{(b_p + \theta_p)a_i + \theta_p a_j}{2b_p(b_p + 2\theta_p)} - \frac{\theta_s(s_j - s_i)}{2(b_p + 2\theta_p)} + \frac{(b_p + \theta_p)b_s s_i + \theta_p b_s s_j}{2b_p(b_p + 2\theta_p)}. \qquad (34)
$$

To find the optimal wholesale price, $w_1$, we first look at the first order condition.

$$
\begin{aligned}
0 = \frac{\partial \Pi_{M_1}}{\partial w_1} &= a_1 - b_p\left[w_1 + \frac{(b_p + \theta_p)a_1 + \theta_p a_2}{2b_p(b_p + 2\theta_p)} - \frac{\theta_s(s_2 - s_1)}{2(b_p + 2\theta_p)} + \frac{(b_p + \theta_p)b_s s_1 + \theta_p b_s s_2}{2b_p(b_p + 2\theta_p)}\right] \\
&\quad + \theta_p\left[\frac{a_2 - a_1}{2(b_p + 2\theta_p)} + \frac{w_2 - 2w_1}{2} + \frac{(2\theta_s + b_s)(s_2 - s_1)}{2(b_p + 2\theta_p)}\right] \\
&\quad + b_s s_1 - \theta_s(s_2 - s_1) + \frac{c_1 b_p}{2} + \frac{c_1 \theta_p}{2}
\end{aligned}
$$

Finally,

$$
w_1 = \frac{1}{2(b_p + \theta_p)}\left\{\theta_p w_2 + a_1 + c_1(b_p + \theta_p) + (b_s + \theta_s)s_1 + \left(\frac{\theta_p b_s}{(b_p + 2\theta_p)} - \theta_s\right)s_2\right\} \qquad (35)
$$

To find the optimal level of services, we also find the first order condition:

$$
\begin{aligned}
0 = \frac{\partial \Pi_{M_1}}{\partial s_1} &= (w_1 - c_1)\left[-\frac{b_p \theta_s}{2(b_p + 2\theta_p)} - \frac{b_p(b_p + \theta_p)b_s}{2b_p(b_p + 2\theta_p)} - \frac{\theta_p(b_s + 2\theta_s)}{2(b_p + 2\theta_p)} + b_s + \theta_s\right] - \eta_1 s_1 \\
s_1^* &= \frac{(w_1 - c_1)(b_s + \theta_s)}{2\eta_1} \qquad (36)
\end{aligned}
$$

Let

$$
\begin{aligned}
A_i &= 4\eta_i(b_p + \theta_p) + (b_s + \theta_s)^2 \\
B_i &= 2\eta_i\theta_p - \theta_s(b_s + \theta_s)\left(\frac{b_p - b_s + 2\theta_p}{b_p + 2\theta_p}\right)
\end{aligned}
$$

$$
\begin{aligned}
D_i &= \frac{B_i}{A_i} \\
E_i &= (b_p + \theta_p) - \frac{(b_s + \theta_s)^2}{2\eta_i} \\
F_i &= \frac{\theta_s(b_s + \theta_s)}{2\eta_i} - \frac{\theta_p b_s (b_s + \theta_s)}{2\eta_i (b_p + 2\theta_p)}
\end{aligned}
$$

Substitute (36) into (35), we get:

$$
w_1^* = \frac{2\eta_1 A_2}{A_1 A_2 - B_1 B_2} \left[ (a_1 + D_2 a_2) + (E_1 + F_1 D_2) c_1 + (F_2 + E_2 D_2) c_2 \right] \tag{37}
$$

Substitute (37) into (36) we get:

$$
s_1^* = (b_s + \theta_s) \left\{ \frac{A_2}{A_1 A_2 - B_1 B_2} \left[ (a_1 + D_2 a_2) + (F_2 + E_2 D_2) c_2 \right] + \left[ \frac{A_2(E_1 + F_1 D_2)}{A_1 A_2 - B_1 B_2} - \frac{1}{2\eta_1} \right] c_1 \right\} \tag{38}
$$

## B2: Retailer Stackelberg

Since the retailer moves first in this game, we need to calculate for the suppliers'reaction function. Note that the suppliers move simultaneously. Therefore, we need to calculate the Nash equilibrium between them. The profit function for supplier $i$ can be expressed as:

$$
\begin{aligned}
\Pi_{M_i} &= (w_i - c_i) Q_i - \frac{\eta_i s_i^2}{2}; \text{where} \\
Q_i &= a_i - b_p p_i + \theta_p (p_j - p_i) + b_s s_i - \theta_s (s_j - s_i)
\end{aligned}
$$

To find the suppliers' reaction function, we need to find the first order condition which can be expressed as:

$$
\begin{aligned}
0 = \frac{\partial \Pi_{M_i}}{\partial w_i} &= Q_i + (w_i - c_i) \frac{\partial Q_i}{\partial p_i} \frac{\partial p_i}{\partial w_i}; \text{where} && (39) \\
\frac{\partial Q_i}{\partial p_i} &= -b_p - \theta_p && (40) \\
\frac{\partial p_i}{\partial w_i} &= 1 && (41)
\end{aligned}
$$

Therefore,

$$
0 = a_i - (b_p + \theta_p) p_i + \theta_p p_j + (b_s + \theta_s) s_i - \theta_s s_j - (b_p + \theta_p)(w_i - c_i) \tag{42}
$$

To find the optimal level of service for supplier $i$, we also find the first order condition:

$$
\begin{aligned}
0 = \frac{\partial \Pi_{M_i}}{\partial s_i} &= (w_i - c_i) \frac{\partial Q_i}{\partial s_i} - \eta_i s_i \\
s_i^* &= \frac{(w_i - c_i)(b_s + \theta_s)}{\eta_i}
\end{aligned}
$$

Substitute (43) into (42), we get:

$$
\begin{aligned}
w_i^* &= \frac{\eta_i}{\eta_i(b_p+\theta_p)-(b_s+\theta_s)^2}\Bigg\{a_i-(b_p+\theta_p)p_i+\theta_p p_j+\left[(b_p+\theta_p)-\frac{(b_s+\theta_s)^2}{\eta_i}\right]c_i \\
&\quad +\frac{\theta_s(b_s+\theta_s)}{\eta_j}c_j-\frac{\theta_s(b_s+\theta_s)}{\eta_j}w_j\Bigg\} \qquad (43)
\end{aligned}
$$

Let

$$
\begin{aligned}
A_i^{'} &= \eta_i(b_p+\theta_p)+(b_s+\theta_s)^2 \\
B^{'} &= \theta_s(b_s+\theta_s) \\
D_i^{'} &= \frac{B^{'}}{A_i^{'}} \\
E_i^{'} &= \frac{A_i^{'}}{\eta_i}=(b_p+\theta_p)-\frac{(b_s+\theta_s)^2}{\eta_i} \\
F_i^{'} &= \frac{B^{'}}{\eta_i}=\frac{\theta_s(b_s+\theta_s)}{\eta_i} \\
G^{'} &= b_p+\theta_p.
\end{aligned}
$$

Using the above notation, (43) we have:

$$
w_i^* = \frac{\eta_i A_j^{'}}{A_i^{'}A_j^{'}-B^2}[a_i-D_j^{'}a_j-(\theta_p D_j^{'}+G^{'})p_i+(G^{'}D_j^{'}+\theta_p)p_j+(E_i^{'}-D_j^{'}F_i^{'})c_i]. \qquad (44)
$$

Using 43 and 44, we get the following:

$$
s_i^* = \frac{A_j^{'}(b_s+\theta_s)}{A_i^{'}A_j^{'}-B^j}\left[a_i-D_j^{'}a_j-(\theta_p D_j^{'}+G^{'})p_i+(G^{'}D_j^{'}+\theta_p)p_j\right] \qquad (45)
$$

These are the manufacturers' response function. Now, to solve retailer problem, recall that retailer makes decision about $p_1$ and $p_2$ after observing $w_1, w_2, s_1$ and $s_2$. His profit function can be expressed as:

$$
\Pi_R = (p_1-w_1(p_1,p_2))Q_1(p_1,p_2)+(p_2-w_2(p_1,p_2))Q_2(p_1,p_2) \qquad (46)
$$

To calculate for his optimal actions, we need to use the first order condition:

$$
\begin{aligned}
0=\frac{\partial \Pi_R}{\partial p_i} &= \left(1-\frac{\partial w_i(p_i,p_j)}{\partial p_i}\right)Q_i(p_i,p_j)+(p_i-w_i(p_i,p_j))\frac{\partial Q_i(p_i,p_j)}{\partial p_i} \\
&\quad +\left(-\frac{\partial w_j(p_i,p_j)}{\partial p_i}\right)Q_j(p_i,p_j)+(p_j-w_j(p_i,p_j))\frac{\partial Q_j(p_i,p_j)}{\partial p_i} \qquad (47)
\end{aligned}
$$

where

$$\frac{\partial w_i(p_i,p_j)}{\partial p_i} = -\frac{\eta_i A_j^{'}}{A_i^{'}A_j^{'}-B^2}(\theta_p D_j^{'} + G^{'}) \tag{48}$$

$$\frac{\partial w_j(p_i,p_j)}{\partial p_i} = \frac{\eta_j A_i^{'}}{A_i^{'}A_j^{'}-B^2}(G^{'}D_i^{'} + \theta_p) \tag{49}$$

Substitute (45) into the formula for $Q_1$ and $Q_2$, and then using the above condtions to solve for $p_1$ and $p_2$. We finally have:

$$p_1 = \frac{(X_2M_1 - YN_1)a_1 + (YN_2 - X_2M_2)a_2 + (X_2\rho_1 - Y\sigma_1)Kc_1 + (Y\rho_2 - X_2\sigma_2)Kc_2}{X_1X_2 - Y^2}$$

$$p_2 = \frac{(YM_1 - X_1N_1)a_1 + (X_1N_2 - YM_2)a_2 + (Y\rho_1 - X_1\sigma_1)Kc_1 + (X_1\rho_2 - Y\sigma_2)Kc_2}{X_1X_2 - Y^2}$$

where all parameters are as specified in Appendix A.

## B3: Vertical Nash

For Vertical Nash, we solve the problem using response functions that were already derived in Manufacturer Stackelberg case and Retailer Stackelberg case respectively. From Manufacturer Stackelberg case, the retailer reaction function for given wholesale price $w_1, w_2$ and service levels $s_1, s_2$ is

$$p_i^* = \frac{w_i^*}{2} + \frac{(b_p+\theta_p)a_i + \theta_p a_j}{2b_p(b_p+2\theta_p)} - \frac{\theta_s(s_j^* - s_i^*)}{2(b_p+2\theta_p)} + \frac{(b_p+\theta_p)b_s s_i^* + \theta_p b_s s_j^*}{2b_p(b_p+2\theta_p)}$$

where $i = 1, 2$ and $j = 3 - i$. On the other hand, the manufacturers reaction function for given retail prices $p_1, p_2$ is

$$w_i^* = \frac{\eta_i A_j^{'}}{A_1^{'}A_2^{'}-B^2}\Big[a_i - D_j^{'}a_j - (\theta_p D_j^{'} + G^{'})p_i^* + (G^{'}D_j^{'} + \theta_p)p_j^* + (E_i^{'} - D_j^{'}F_i^{'})c_i\Big].$$

$$s_i^* = \frac{A_j^{'}(b_s+\theta_s)}{A_1^{'}A_2^{'}-B^2}\Big[a_i - D_j^{'}a_j - (\theta_p D_j^{'} + G^{'})p_i^* + (G^{'}D_j^{'} + \theta_p)p_j^*\Big]$$

where $A_i^{'}, B^{'}, D_i^{'}, E_i^{'}, F_i^{'}$, and $G^{'}$ are defined as in the Retailer Stackelberg case. Solving the above equations simultaneously yield the Nash equilibrium solution.

$$p_1 = \frac{(K_1 + K_4L_1)a_1 + (K_2 + K_4L_2)a_2 + K_3c_1 + K_4L_3c_2}{1 - K_4L_4} \tag{50}$$

$$p_2 = \frac{(L_1 + L_4K_1)a_1 + (L_2 + L_4K_2)a_2 + L_3c_1 + L_4K_3c_2}{1 - K_4L_4} \tag{51}$$

where $K_i$ and $L_i$ for $i = 1 - 4$ are as defined in Appendix A.

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