ABSTRACT

We consider a three-stage supply chain, consisting of a R&D, a manufacturer and a seller. By considering possible integration and decentralization of supply chain processes and different power dynamics between players, we introduce six supply chain models with different supply chain structures based on the principal-agent paradigm. Then, we investigate their distinct characteristics, and we reveal which supply chain structure yields superior R&D and market performances.

KEYWORDS: Supply chain management, Three-stage supply chain, R&D performance and Principal-agent paradigm

INTRODUCTION

In this study, we focus on investigating and comparing the R&D and market performances of various supply chain structures. We consider a triadic supply chain, consisting of a R&D company (R&D henceforth), a manufacturer and a seller. To characterize the power dynamics between players, we need the assumption below.

Assumption 1. We focus on a supply chain of which focal company is either the R&D or the manufacturer, while the bargaining power of the R&D or the manufacturer is always greater than the seller.

There exist various types of relationships between players in supply chains. A retailer can lead a supply chain, such as Walmart Stores, Inc. There is also a supply chain in which the focal company is a manufacturer such as Toyota Motor Co. On the other hand, nowadays we can often observe that a company focusing on R&D capability with patents and unique expertise in technologies has the bargaining power over a manufacturer and other supply chain players, such as Qualcomm Inc. in telecommunication industry. Among various types, we focus on a supply chain in which either the R&D or the manufacturer has the bargaining power over other players.

Assumption 2. The player with greater bargaining power acts as a Stackelberg leader. If the R&D has the power over the manufacturer, the R&D offers the royalty contract term to the manufacturer, and then the manufacturer offers the supply contract term to the seller. Otherwise, the manufacturer offers the contract terms to both the R&D and seller for technology acquisition and product supply, respectively. The Stackelberg leader can also make a decision
on the integration of supply chain processes.

We also assume that all supply chain members have access to the same information as in many previous studies based on the cooperative Stackelberg game structure (Nagarajan & Sošić 2008). The Stackelberg leader, either the R&D or the manufacturer, offers the contract terms, while using its foresight about other players’ actions, and can lead the integration of supply chain processes in this study.

Assumption 3. We consider an existing supply chain in a single-period setting.

The process integration always accompanies additional operating cost issues. However, our interest lies in comparing the performances of existing supply chains, in which its decision on supply chain structure is already made.

Based on assumptions above, we investigate six supply chain models with different combination of processes and different power dynamics, such as (1) Case FI: full integration (FI) of R&D (R), manufacturing (M) and sales (S) processes, (2) Case RM: integration of R&D and manufacturing processes, (3) Case MS-R: integration of manufacturing and sales processes with the R&D as the Stackelberg leader, (4) Case MS-M: integration of manufacturing and sales processes with the manufacturer as the Stackelberg leader, (5) Case PD-R: pure decentralization (PD) with the R&D as the Stackelberg leader, and (6) Case PD-M: pure decentralization with the manufacturer as the Stackelberg leader. Figure 1 illustrates the structures and power dynamics of six supply chain cases.

Figure 1. Supply chain models (R: R&D, M: manufacturer, S: seller; solid line: inventory or technology flow, dotted line: contract offer)
BASIC FORMULATION

In this study, we consider a supply chain dealing with consumer products such as vehicles, electronic appliances or clothes. Therefore, consumers’ buying intention is mainly affected by product quality and its price. Consumers’ demand $D$ is simply defined as follows.

$$D = \alpha - \beta p + \gamma q,$$  \hfill (1)

where $\alpha$ is the demand potential, $p$ and $q$ are the quality and sales price of the product, and $\beta$ and $\gamma$ are the respective coefficients.

In Equation (1), the sales price $p$ negatively affects consumers’ buying intention as in many previous studies, while product quality $q$ enhances the market demand. Product quality is regarded as a single composite measure as in Karmarkar and Pitbladdo (1997) and Banker (1998). Therefore, we regard the level of product quality $q$ as a sum of measurable quality attributes, such as performance, feature, reliability, durability, etc. This approach is commonly observed in continuous optimization problems, which investigate the effect of quality in conjunction with other important variables. In Shi et al (2001) and Kim and Chhajed (2002), for example, quality attributes are aggregated according to the importance weight ($w_i$) of each attribute ($q_i$), i.e., $q = \sum w_i q_i$ where $\sum w_i = 1$. Note that we do not deal with a multi-scale discrete optimization problem, which determines the levels of individual product attributes.

In the supply chain, there are three main processes, including research and development (R&D), manufacturing and sales, which jointly determine product quality $q$ and its sales price $p$ in order to control consumers’ buying intention and maximize profit. Based on the profit functions of three processes in this section, we will characterize the profits of supply chain players in the next section by considering the integration of processes.

The R&D process invests in product or process technology enhancing the quality level of the product $q$ and delivers the result to the manufacturing process, such as new product technology, know-how, engineering skills or exterior designs which in turn determine consumers’ buying intention. Therefore, the profit of the R&D process $\Pi_r$ is defined simply as follows.

$$\Pi_r = T_{mr} - \lambda q^2,$$ \hfill (2)

where $\lambda q^2$ is the R&D expenditure due to the investment in product quality $q$ with the coefficient $\lambda$, which represents the magnitude of the cost. We define the R&D cost is increasing and convex in $q$ as in many previous literature related to quality investment, such as Karmarkar and Pitbladdo (1997) and Banker et al (1998). $T_{mr}$ is the transfer payment from the manufacturing process to the R&D process, which is the compensation for the R&D result. We will define $T_{mr}$ differently with respect to the supply chain structure and power dynamics between players in the next section.

The manufacturing process does not have all the technology, know-how and skills for new product development and production as in practice, so it utilizes the complementary capability of the R&D process, and it delivers the item produced to the sales process. Then, the sales process determines the sales price of the new item $p$ and sells it to consumers. Therefore, the profits of the manufacturing and selling processes $\Pi_m$ and $\Pi_s$ can be defined respectively as:
where \( c \) is the unit production cost and \( p \) is the unit sales price of the new item. \( T_{sm} \) is the transfer payment from the selling process to the manufacturing process, incurred due to the supply of the product. To describe the interaction between the manufacturing and selling processes, we utilize the wholesale price contract among various contract schemes in practice, which is most basic but one of the most popular supply contract forms due to its simplicity. Therefore, \( T_{sm} \) can be defined as follows, where \( w \) is the unit wholesale price of the new item.

\[
T_{sm} = wD. \tag{5}
\]

Based on the profits of supply chain processes in Equations (2), (3), and (4), we characterize various supply chain models in the next section, involving different combination of processes and power dynamics between players.

**SUPPLY CHAIN MODELS**

**Case FI: Full Integration of R&D, Manufacturing and Selling processes**

Case FI deals with a fully integrated supply chain. We can consider Case FI an ideal supply chain situation where a supply chain leader, either the R&D or the manufacturer, perfectly monitors and controls the other players’ actions. Therefore, there are no opportunistic behaviors of players, so we regard this coordinated Case FI as a benchmark for decentralized cases. The player integrating overall processes plays the roles of the R&D, manufacturer and seller at the same time (RMS), and its profit \( \Pi_{RMS}^{FI} \) becomes the same as the profit of the entire supply chain \( \Pi^{FI} \), where the superscript \( FI \) denotes Case FI.

\[
\Pi_{RMS}^{FI} = \Pi^{FI} = \Pi_r + \Pi_m + \Pi_s = (p - c)D - \lambda q^2, \tag{6}
\]

where the demand \( D \) is in Equation (1) and \( \Pi_r, \Pi_m, \) and \( \Pi_s \) are the profits of supply chain processes in Equations (2), (3) and (4). In this fully integrated situation, we do not have to consider the interaction between players. Therefore, the problem of Case FI can be simply defined as:

\[
\text{Maximize } \Pi_{RMS}^{FI}(p, q). \tag{7}
\]

By simultaneously solving the first-order necessary conditions (FONCs) of the optimization problem (7), we obtain the optimal \( p^{FI^*} \) and \( q^{FI^*} \) as closed-form solutions as:

\[
p^{FI^*} = \frac{2\lambda(\alpha - \beta c)}{4\beta \lambda - \gamma^2} + c, \text{ and } \tag{8}
\]

\[
q^{FI^*} = \frac{\gamma(a - \beta c)}{4\beta \lambda - \gamma^2}. \tag{9}
\]

To ensure \( p^{FI^*} > 0 \) and \( q^{FI^*} > 0 \) and the concavity of \( \Pi_{RMS}^{FI} \), we need the conditions below.

\[
\alpha > \beta c, \text{ and } \tag{10}
4\beta \lambda - \gamma^2 > 0. \tag{11}
\]
In Condition (10), the demand potential $\alpha$ needs to be sufficiently large to have the interior solutions and ensure the comparison of supply chain models. We also need Condition (11) to ensure the second-order sufficient condition (SOSC), the negative-definite property of Hessian determinants.

By applying $p^{Fr}$ and $q^{Fr}$ into Equations (1) and (4), we also obtain $D^{Fr}$ and $\Pi_{RMS}^{Fr}$ (and $\Pi^{Fr}$).

The solution of Case FI will be used as the benchmark for other cases. The solutions of all supply chain cases are summarized in Tables 1 and 2 in Appendix.

**Case RM: Integration of R&D and Manufacturing Processes**

In Case RM, either the R&D or the manufacturer integrates both R&D and manufacturing processes. We can also regard Case RM as a supply chain situation in which the manufacturer is under the monitoring and control of the R&D, such as in the OEM-CM (contract manufacturer) relationship between Apple Inc. and Foxconn Technology Group, or vice versa, such as in the relationship between Toyota Motor Co. and Denso Co., an automotive component R&D and supplier in Toyota Group. By integrating two processes, the player conducts the roles of both R&D and manufacturer (RM), and its profit $\Pi_{RM}$ is as follows, while the individual seller’s profit $\Pi_{S}^{RM}$ is in Equation (4).

$$\Pi_{RM} = \Pi_r + \Pi_m = T_{sm} - cD - \lambda q^2 = (w - c)D - \lambda q^2,$$

(12)

since $T_{sm} = wD$ in Equation (5). The superscript $RM$ denotes Case RM.

In this decentralized supply chain system, it is natural that each supply chain player shows the opportunistic behavior due to moral hazard, maximizing its own profit. The two-stage decision structure of Case RM can be defined based on the principal-agent paradigm as follows.

Maximize $\Pi_{RM}^{RM}(q, w)$
subject to $\Pi_{S}^{RM}(p | q, w) > 0$
Maximize $\Pi_{S}^{RM}(p | q, w)$.

(13)

(14)

(15)

Either the R&D or the manufacturer (RM) maximizes its own profit in the objective function (13), but it needs to satisfy constraints (14) and (15). Inequality (14) represents the seller’s individual rationality constraint. The seller participates in the contract guaranteeing the positive profit. Constraint (15) is the seller’s incentive compatibility constraint. The seller determines the sales price of the new item $p$ maximizing its own profit, given the decision on $q$ and $w$.

By the backward induction, we first obtain the response of the seller $p^{RM}$ given $q$ and $w$ from FONC of (13), which assures the concavity of $\Pi_{S}^{RM}$, i.e., $|H_1| = |\Pi_{S}^{RM}'| = -2\beta < 0$.

$$p^{RM}(q, w) = \frac{\alpha + \beta w + \gamma q}{2\beta}$$

(16)

After applying $p^{RM}(q, w)$ to (13) and by simultaneously solving FONCs of (13), we obtain the unique best response of the R&D (and manufacturer), which also ensuring the concavity of $\Pi_{RM}^{RM}$ by satisfying $|H_1| < 0$ and $|H_2| > 0$ by Condition (11).
The solution of Case RM is summarized in Tables 1 and 2 in Appendix.

Case MS-R: Integration of Manufacturing and Selling Processes with the R&D as the Stackelberg Leader

Case MS-R represents a supply chain situation in which the manufacturer directly sells the product by integrating the sales process, such as the direct sales of Dell Inc. Case MS-R can be regarded as a situation where the seller is under the perfect monitoring and control of the manufacturer. In Case MS-R, the R&D has the bargaining power over the manufacturer, and thus the contract term is controlled and offered by the R&D, such as Qualcomm Inc. which owns a huge number of essential technology patents in telecommunication and semiconductor industries. To characterize the transaction between the R&D and the manufacturer, we add the following assumption.

Assumption 4. When the R&D has bargaining power over the manufacturer, the R&D offers the contract for technology transfer based on a per unit royalty, while the manufacturer with bargaining power prefers the contract based on a fixed fee independent of demand.

In practice, there are three common payment modes for technology transfer, especially for patent licensing, such as a per unit royalty, a fixed fee independent of the quantity produced, and a combination of both. There have been various opinions about contract mode selection between per unit royalty and fixed fee from the viewpoint of the profit maximization of the outside R&D. Many studies have revealed that a fixed fee contract is preferred in a complete information framework (Shapiro, 1985; Kamien & Yair, 1986; Kamien et al, 1992), while we can also observe a different opinion that the outside R&D can be better off under the contract based on a per unit royalty (Wang, 1998, 2002; Poddar & Sinha, 2004; Sen, 2005). However, we need to note that most studies have focused on the patent licensing of cost-reducing technology differently from the present study, which deals with quality innovation directly affecting consumers’ buying intention. According to the patent licensing of quality innovation, Stamatopoulos and Tauman (2008) and Li and Wang (2010) have revealed that the per unit royalty licensing is superior to the fixed fee licensing from the perspective of the outside R&D. Similar to these studies, we also suppose that the R&D with bargaining power offers the contract based on a per unit royalty to the manufacturer in exchange for the technology transfer of quality innovation, since it in turn directly affects consumers’ demand requests of the product. On the contrary, the one-time fixed fee contract is preferred when the manufacturer has the bargaining power over the outside R&D.

Therefore, the total transfer payment from the manufacturer to the R&D in Case MS-R is defined as follows, where $r^R$ is the per unit royalty offered by the R&D.

$$T_{mR}^{MS-R} = r^R D.$$  \hspace{1cm} (19)

By the integration the manufacturer (and seller)’s (MS) profit $\Pi_{MS}^{MS-R}$ is defined as follows, while the R&D’s profit $\Pi_{R}^{MS-R} = \Pi_r$ in Equation (2).
\[ \Pi^{MS-R}_{MS} = \Pi_m + \Pi_s = (p - c)D - T_{mr} = (p - c - r^R)D. \]  

(20)

The problem of Case MS-R can be defined as follows.

Maximize \[ \Pi^{MS-R}_{MS}(r^R) \]  
subject to \[ \Pi^{MS-R}_{MS}(p | q, r^R) > 0 \]  
Maximize \[ \Pi^{MS-R}_{MS}(p | q, r^R). \]  

(21) \( (22) \) \( (23) \)

The R&D maximizes its own profit in (21), but it needs to satisfy the manufacturer’s individual rationality and incentive compatibility constraints in (22) and (23). By the backward induction similar to the solution approach to Case RM, we can obtain the best responses of the manufacturer and then the R&D. The results are summarized in Tables 1 and 2 in Appendix.

**Case MS-M: Integration of Manufacturing and Selling Processes with the Manufacturer as the Stackelberg Leader**

Case MS-M also considers the integration of manufacturing and sales processes like Case MS-R, but the bargaining power is of the manufacturer. Therefore, the manufacturer outsources R&D and offers the contract based on the fixed fee for the technology transfer as we defined in Assumption 4, which is independent of demand but proportional to the level of technology subsequently affecting product quality \( q \). Therefore, we define the fixed fee for the technology transfer from the manufacturer to the R&D in Case MS-M as:

\[ T^{MS-M}_{mr} = r^M q. \]  

(24)

where \( r^M \) is the marginal fixed fee of technology transfer offered by the manufacturer. Then, the manufacturer’s profit \( \Pi^{MS-M}_{MS} \) is defined as follows, while the R&D’s profit \( \Pi^{MS-R}_{MS} = \Pi_r \) in Equation (2).

\[ \Pi^{MS-M}_{MS} = \Pi_m + \Pi_s = (p - c)D - T_{mr} = (p - c)D - r^M q. \]  

(25)

The problem of Case MS-M can be defined as follows.

Maximize \[ \Pi^{MS-M}_{MS}(p, r^M) \]  
subject to \[ \Pi^{MS-R}_{MS}(q | p, r^M) > 0 \]  
Maximize \[ \Pi^{MS-R}_{MS}(q | p, r^M). \]  

We summarize the solution in Tables 1 and 2 in Appendix.

**Case PD-R: Pure Decentralization with the R&D as the Stackelberg Leader**

Case PD-R represents a supply chain situation where each player maximizes its own profit, while the R&D is the focal company of the supply chain. In this purely decentralized supply chain situation, all players concentrate on their own basic processes, i.e., \( \Pi^{PD-R}_{M} = \Pi_m \) in Equation (2), \( \Pi^{PD-R}_{R} = \Pi_r \) in Equation (3), and \( \Pi^{PD-R}_{S} = \Pi_s \) in Equation (4).

In Case PD-R, the R&D offers the per unit royalty contract as in Case MS-R, so \( T^{PD-R}_{mr} = T^{MS-R}_{mr} = r^R D \) in Equation (19), and then the manufacturer offers the wholesale contract to the seller. Therefore, the three-stage decision structure of Case PD-R is defined as follows.
Maximize $\Pi_{R}^{PD-R}(q, r^R)$ subject to $\Pi_{M}^{PD-R}(w \mid q, r^R) > 0$.

Maximize $\Pi_{M}^{PD-R}(w \mid q, r^R)$ subject to $\Pi_{S}^{PD-R}(p \mid q, r^R, w) > 0$.

Maximize $\Pi_{S}^{PD-R}(p \mid q, r^R, w)$.

By following the similar solution approach to Case MS-R or MS-M but conducting the backward induction twice, we obtain the best response of each player as summarized in Tables 1 and 2 in Appendix.

**Case PD-M: Pure Decentralization with the Manufacturer as the Stackelberg Leader**

Case PD-M considers the same purely decentralized supply chain structure of Case PD-R, but the bargaining power is of the manufacturer. Therefore, the manufacturer offers the R&D the fixed fee contract for the technology transfer, i.e., $T_{mr}^{PD-M} = T_{mr}^{MS-M} = r^M q$ in Equation (24), while also offering the wholesale price supply contract to the seller. Considering the dual role of the manufacturer as a control center, the two-stage optimization problem of Case PD-M with two agents (followers) can be defined as:

Maximize $\Pi_{M}^{PD-M}(r^M, w)$ subject to $\Pi_{R}^{PD-M}(q \mid r^M, w) > 0$.

Maximize $\Pi_{R}^{PD-M}(q \mid r^M, w)$ subject to $\Pi_{S}^{PD-M}(p \mid r, w) > 0$.

Maximize $\Pi_{S}^{PD-M}(p \mid r, w)$.

The solution of Case PD-M is also summarized in Tables 1 and 2 in Appendix.

**COMPARISON OF SUPPLY CHAIN STRUCTURES**

In this section, we reveal the unique characteristics of supply chain cases. We first compare the transactions between players in various supply chain structures.

**Proposition 1.** Comparing the transfer payments between players, they are related as follows:

1. $r^{MS-R} > r^{PD-R}$ and $r^{MS-M} > r^{PD-M}$.
2. $w^{PD-R} > w^{MS-M} > w^{PD-M}$.

The transfer payment for technology from the manufacturer to the R&D is always greater in the integrated supply chain structure (Case MS-R or MS-M) than in the decentralized system (Case PD-R or PD-M), regardless of the payment type, whether it is the royalty per unit sold (Cases MS-R and PD-R) or the fixed fee independent of demand (Cases MS-M and PD-M).

The wholesale price from the seller to the manufacturer is also determined differently depending on the supply chain structure as we observe in Proposition 1(2). It is the largest in the R&D-leading decentralized supply chain (Case PD-R) due to its innate three-stage decision structure and subsequent triple marginalization issues, while it is the smallest in the manufacturer-leading decentralized system (Case PD-M). It is since the manufacturer can mitigate the marginalization issues by centralized control, directly controlling the opportunistic behaviors of both the R&D and the seller as we see in the problem structure of Case PD-M.
These different interactions between players then induce the different decisions on product quality and sales price.

Proposition 2. Comparing the product quality and sales prices in six supply chain cases, we obtain the following properties:

1. $q_{FI}^* > q_{RM}^* = q_{MS-R}^* = q_{MS-M}^* > q_{PD-R}^* = q_{PD-M}^*$, and
2. $p_{PD-R}^* > p_{RM}^* = p_{MS-R}^* > p_{PD-M}^* > p_{FI}^* > p_{MS-M}^*$.

In Proposition 2(1), it is interesting to observe that the results of product quality are clearly differentiated by the level of process integration. Specifically, the highest level of product quality is expected in the fully coordinated system (Case FI), while the purely decentralized supply chain always yields the lowest level of product quality (Cases PD-R and PD-M). The results do not depend on power dynamics in a supply chain. Note that the R&D’s bargaining power does not affect the product quality, i.e., $q_{MS-R}^* = q_{MS-M}^*$, and $q_{PD-R}^* = q_{PD-M}^*$.

In practice, building a virtually integrated supply chain system is difficult since the players are separate economic entities with different interests and cultures. However, we need to remind that the level of process integration is one of critical factors affecting product quality as we see in Proposition 2(1). Therefore, a supply chain needs to alleviate the negative effect of marginalization issues by forming a tighter strategic alliance, so as to create a higher-class product which satisfies consumers more. It needs to be based on right partner selection, reasonable contract conditions, centralized control, and/or shareholdings.

On the other hand, the sales price of the product is higher when the R&D leads the contract between players (Cases PD-R, RM and MS-R) as shown in Proposition 2(2). This can be owing to either the resulting higher product quality (Cases RM and MS-R) as shown in Proposition 2(1) or the higher wholesale price due to triple marginalization (Case PD-R) as shown in Proposition 1(2). However, the sales price can be lowered if the manufacturer can directly coordinate or control the action of not only the seller but also the R&D (Cases MS-M and PD-M). In addition, note that the lowest sales price does not always mean the coordinate result. Interestingly, the sales price can be higher in the coordinated system even without the marginalization issues than in the decentralized system, i.e., $p_{FI}^* > p_{MS-M}^*$. This is due to the higher product quality in the coordinated system. Also note that higher product quality is not always translated into the higher sales price.

Proposition 3. Comparing the demand requests and supply chain’s overall profits, we find the following properties:

1. $D_{FI}^* > D_{MS-M}^* > D_{RM}^* = D_{MS-R}^* > D_{PD-M}^* > D_{PD-R}^*$, and
2. $\Pi_{FI}^* > \Pi_{MS-M}^* > \Pi_{RM}^* = \Pi_{MS-R}^* > \Pi_{PD-M}^* > \Pi_{PD-R}^*$.

We can expect the best performance in the ideal fully-coordinated system (Case FI) as in Propositions 2(1) and 2(2). Among practical decentralized systems, the largest demand and profit are expected when the manufacturer with bargaining power fully coordinates the seller’s action (or directly sells the product) (Case MS-M). Among the purely decentralized system, the manufacturer-leading supply chain (Case PD-M) also yields a better result. This is owing to the manufacturer’s centralized control on the other players’ actions, while located between players.

On the other hand, we can observe that it is difficult for the R&D to play a role of a control center like the manufacturer as we see in the decision structure of Case PD-R since it is located at the upstream end of the supply chain. The R&D-leading system (Case PD-R) innately accompanies
multiple marginalization problems, leading the overall system inefficient. These would worsen as the structure of a supply chain is more complicated in practice. Therefore, it is very important for the R&D to systematically understand the supply chain’s overall processes and interactions between players in order to find the way to coordinate or control the other players’ actions. It can be one good solution to focus on both R&D and marketing, two core processes at upstream and downstream ends in a supply chain, in order to effectively understand and control the whole supply chain, such as in Apple Inc. and Nike, Inc.

It is also interesting to observe that the performances of Cases RM and MS-R are exactly the same in terms of quality, price, demand and also supply chain profit in spite of their different value chain structures. It indicates that the R&D with bargaining power can have a freedom to choose the supply chain structure while maintaining the same performance.

In the next section, we reveal additional properties by utilizing a numerical example.

**NUMERICAL EXAMPLE**

**Basic Numerical Setting**

We set the basic parameter settings for the numerical analysis as: $\alpha = 2000$, $\beta = 10$, $\gamma = 8$, $\lambda = 5$, $c = 50$. Table 3 summarizes the optimal solutions of six supply chain cases with different structures and power dynamics.

<table>
<thead>
<tr>
<th>Contract</th>
<th>Case FI</th>
<th>Case RM</th>
<th>Case MS-R</th>
<th>Case MS-M</th>
<th>Case PD-R</th>
<th>Case PD-M</th>
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<tbody>
<tr>
<td>$r^*$</td>
<td>N/A</td>
<td>N/A</td>
<td>89.29</td>
<td>357.14</td>
<td>81.52</td>
<td>163.04</td>
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<tr>
<td>$w^*$</td>
<td>N/A</td>
<td>139.29</td>
<td>N/A</td>
<td>N/A</td>
<td>172.28</td>
<td>131.52</td>
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<tr>
<th>Decision</th>
<th>Case FI</th>
<th>Case RM</th>
<th>Case MS-R</th>
<th>Case MS-M</th>
<th>Case PD-R</th>
<th>Case PD-M</th>
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<tbody>
<tr>
<td>$p^*$</td>
<td>160.29</td>
<td>183.93</td>
<td>183.93</td>
<td>139.29</td>
<td>192.66</td>
<td>172.28</td>
</tr>
<tr>
<td>$q^*$</td>
<td>88.24</td>
<td>35.71</td>
<td>35.71</td>
<td>35.71</td>
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<th>Demand</th>
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<th>Case MS-R</th>
<th>Case MS-M</th>
<th>Case PD-R</th>
<th>Case PD-M</th>
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<tr>
<td>$D^*$</td>
<td>1102.94</td>
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<td>446.43</td>
<td>892.86</td>
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<th>Case MS-R</th>
<th>Case MS-M</th>
<th>Case PD-R</th>
<th>Case PD-M</th>
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<tbody>
<tr>
<td>$\Pi_1^*$</td>
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<td>53,412</td>
<td>53,412</td>
<td>73,342</td>
<td>27,746</td>
<td>48,514</td>
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<tr>
<td>$\Pi_R^*$</td>
<td>82,721</td>
<td>33,482</td>
<td>33,482</td>
<td>63,78</td>
<td>15,285</td>
<td>1,329</td>
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<tr>
<td>$\Pi_M^*$</td>
<td>19,930</td>
<td>19,930</td>
<td>66,964</td>
<td>8,307</td>
<td>30,571</td>
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<tr>
<td>$\Pi_S^*$</td>
<td></td>
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<td>4,154</td>
<td>16,614</td>
</tr>
</tbody>
</table>

Table 3 exemplifies the properties characterized in Propositions 1 through 3. We can observe that all relationships shown in Propositions 1 through 3 hold in Table 3.

Overall, the results in Table 3 and also Propositions 1 through 3 represent a typical result also shown in the previous studies, in which an integrated system outperforms a decentralized supply chain. Moreover, the results in Table 3 also verify once again that a manufacturer-leading supply chain can yield a superior performance due to its centralized control on a supply chain.

**CONCLUSION**
In this study, we introduced six supply chain models in a three-stage supply chain by considering possible combination of supply chain processes. By comparing supply chain structures with three players, a R&D, a manufacturer and a seller, we investigated their distinct characteristics and revealed which supply chain structure can outperform others in terms of R&D and market performances. We simply summarize the results of this study as follows.

First, the level of process integration and different power dynamics between players in a supply chain induce overall performance results totally different. Therefore, a practicing manager need to carefully consider which type of supply chain structure can enhance the overall supply chain performances in practice.

Second, if the manufacturer can act as a control center in a multi-tiered supply chain, located between the R&D and the seller as in this study, the marginalization issues can be reduced, and we can expect better R&D and market performances.

Finally, the R&D-leading supply chain can innately accompany multiple-marginalization issues since it is located at the upstream end in a supply chain. It can lead the whole supply chain system inefficient, and subsequently induce a poor market performance. Therefore, it is important for the R&D to try to systematically understand the supply chain’s overall interactions between players in order to effectively control the other players’ actions. Focusing on both R&D and marketing, two core processes at upstream and downstream ends in a supply chain, can help reduce inefficiency.

**APPENDIX. SOLUTION SUMMARY**

<table>
<thead>
<tr>
<th>Case</th>
<th>Contract</th>
<th>Decision</th>
<th>Consumer response</th>
</tr>
</thead>
<tbody>
<tr>
<td>FI</td>
<td>N/A</td>
<td>$r^*$</td>
<td>$w^*$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$p^*$</td>
<td>$q^*$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$D^*$</td>
<td></td>
</tr>
<tr>
<td>RM</td>
<td>N/A</td>
<td>$4\lambda(a - \beta c)/8\beta_3 - \gamma_2^2 + c$</td>
<td>$2\lambda(a - \beta c)/4\beta_3 - \gamma_2^2 + c$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$6\lambda(a - \beta c)/8\beta_3 - \gamma_2^2 + c$</td>
<td>$\gamma(a - \beta c)/8\beta_3 - \gamma_2^2$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$6\lambda(a - \beta c)/8\beta_3 - \gamma_2^2 + c$</td>
<td>$\gamma(a - \beta c)/8\beta_3 - \gamma_2^2$</td>
</tr>
<tr>
<td>MS-R</td>
<td>$4\lambda(a - \beta c)/8\beta_3 - \gamma_2^2$</td>
<td>N/A</td>
<td>$6\lambda(a - \beta c)/8\beta_3 - \gamma_2^2 + c$</td>
</tr>
<tr>
<td>MS-M</td>
<td>$2\gamma_3(a - \beta c)/8\beta_3 - \gamma_2^2$</td>
<td>N/A</td>
<td>$4\lambda(a - \beta c)/8\beta_3 - \gamma_2^2 + c$</td>
</tr>
<tr>
<td>PD-R</td>
<td>$8\lambda(a - \beta c)/16\beta_3 - \gamma_2^2$</td>
<td>$12\lambda(a - \beta c)/16\beta_3 - \gamma_2^2 + c$</td>
<td>$14\lambda(a - \beta c)/16\beta_3 - \gamma_2^2 + c$</td>
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<tr>
<td>PD-M</td>
<td>$2\gamma_3(a - \beta c)/16\beta_3 - \gamma_2^2$</td>
<td>$8\lambda(a - \beta c)/16\beta_3 - \gamma_2^2 + c$</td>
<td>$12\lambda(a - \beta c)/16\beta_3 - \gamma_2^2 + c$</td>
</tr>
</tbody>
</table>
Table 2: Solution summary: Profits

<table>
<thead>
<tr>
<th>Case</th>
<th>R&amp;D $\Pi_R$</th>
<th>Manufacturer $\Pi_M^{\ast}$</th>
<th>Seller $\Pi_S^{\ast}$</th>
<th>Supply chain $\Pi^{\ast}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>FI</td>
<td>$\Pi_R^{FI*} = \frac{\lambda (\alpha - \beta c)^2}{4 \beta \lambda - \gamma^2}$</td>
<td>$\Pi_M^{FI*} = \frac{\lambda (\alpha - \beta c)^2}{8 \beta \lambda - \gamma^2}$</td>
<td>$\Pi_S^{FI*} = \frac{4 \beta \lambda^2 (\alpha - \beta c)^2}{(8 \beta \lambda - \gamma^2)^2}$</td>
<td>$\Pi^{FI*} = \frac{\lambda (12 \beta \lambda - \gamma^2)(\alpha - \beta c)^2}{(8 \beta \lambda - \gamma^2)^2}$</td>
</tr>
<tr>
<td>RM</td>
<td>$\Pi_R^{RM*} = \frac{\lambda (\alpha - \beta c)^2}{8 \beta \lambda - \gamma^2}$</td>
<td>$\Pi_M^{RM*} = \frac{4 \beta \lambda^2 (\alpha - \beta c)^2}{(8 \beta \lambda - \gamma^2)^2}$</td>
<td>$\Pi_S^{RM*} = \frac{\lambda (12 \beta \lambda - \gamma^2)(\alpha - \beta c)^2}{(8 \beta \lambda - \gamma^2)^2}$</td>
<td></td>
</tr>
<tr>
<td>MS-R</td>
<td>$\Pi_R^{MS*} = \frac{\lambda (\alpha - \beta c)^2}{8 \beta \lambda - \gamma^2}$</td>
<td>$\Pi_M^{MS*} = \frac{2 \lambda (\alpha - \beta c)^2}{8 \beta \lambda - \gamma^2}$</td>
<td>$\Pi_S^{MS*} = \frac{\lambda (16 \beta \lambda - \gamma^2)(\alpha - \beta c)^2}{(8 \beta \lambda - \gamma^2)^2}$</td>
<td></td>
</tr>
<tr>
<td>MS-M</td>
<td>$\Pi_R^{MS-M} = \frac{\lambda (\alpha - \beta c)^2}{16 \beta \lambda - \gamma^2}$</td>
<td>$\Pi_M^{MS-M} = \frac{8 \beta \lambda^2 (\alpha - \beta c)^2}{(16 \beta \lambda - \gamma^2)^2}$</td>
<td>$\Pi_S^{MS-M} = \frac{4 \beta \lambda^2 (\alpha - \beta c)^2}{(16 \beta \lambda - \gamma^2)^2}$</td>
<td>$\Pi^{MS-M} = \frac{\lambda (28 \beta \lambda - \gamma^2)(\alpha - \beta c)^2}{(16 \beta \lambda - \gamma^2)^2}$</td>
</tr>
<tr>
<td>PD-R</td>
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<td>$\Pi_M^{PD*} = \frac{2 \lambda (\alpha - \beta c)^2}{16 \beta \lambda - \gamma^2}$</td>
<td>$\Pi_S^{PD*} = \frac{16 \beta \lambda^2 (\alpha - \beta c)^2}{(16 \beta \lambda - \gamma^2)^2}$</td>
<td>$\Pi^{PD*} = \frac{\lambda (48 \beta \lambda - \gamma^2)(\alpha - \beta c)^2}{(16 \beta \lambda - \gamma^2)^2}$</td>
</tr>
<tr>
<td>PD-M</td>
<td>$\Pi_R^{PD-M} = \frac{\lambda (\alpha - \beta c)^2}{16 \beta \lambda - \gamma^2}$</td>
<td>$\Pi_S^{PD-M} = \frac{2 \lambda (\alpha - \beta c)^2}{16 \beta \lambda - \gamma^2}$</td>
<td>$\Pi^{PD-M} = \frac{16 \beta \lambda^2 (\alpha - \beta c)^2}{(16 \beta \lambda - \gamma^2)^2}$</td>
<td>$\Pi^{PD-M} = \frac{\lambda (48 \beta \lambda - \gamma^2)(\alpha - \beta c)^2}{(16 \beta \lambda - \gamma^2)^2}$</td>
</tr>
</tbody>
</table>

REFERENCES


