Decentralized Supply Chain Coordination with Revenue Sharing Mechanism: Transfer Pricing Heuristics and Revenue Share Rates

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Abstract. A revenue sharing contract is one of the mechanisms that coordinate decision makers in a decentralized supply chain toward the consensual goal. The transfer prices between different echelons in the supply chain influence the total supply chain profits. The study aims to explore various transfer pricing heuristics on the supply chain coordination in terms of the supply chain profits and their interactions with the revenue sharing rate. A model is proposed for formulating the collaborative production and distribution planning in a decentralized supply chain with the revenue sharing mechanism. Various transfer pricing heuristics are used for identifying the resulted supply chain profits. Computation results that set the transfer prices as the variable costs of the products obtain better supply chain profits than other heuristics. Additionally, the revenue sharing rate interacts with transfer pricing heuristics.

Keywords: supply chain, coordination, revenue sharing, transfer pricing heuristics.

1. INTRODUCTION

A decentralized supply chain (SC) consists of autonomous members in various echelons. No unbiased decision maker exists leading the supply chain. Each member identifies its most effective strategy without considering the impacts on other members in different echelons. In practice, a supply chain often operates in a decentralized form (Lee and Whang, 1999). The supply chain involves multiple organizations with different concerns, and it is impossible for a single organization to dominate the whole supply chain (Lee and Kumara, 2007). A good example of such a decentralized supply chain is the A-Team alliance which is initiated by bicycle companies Giant, Merida and other bike makers and part suppliers. The A-Team alliance has adopted the Toyota Production System for production (Tompkins, 2006).

The revenue sharing contract is one of the mechanisms for coordinating members in the decentralized supply chain. The supplier reduces transfer prices to retailers and the retailers share part of their revenue with the supplier under the revenue sharing contract. With the revenue sharing contract, the decentralized supply chain can achieve two main objectives: 1) increasing the total profits closer to those of centralized supply chain, and 2) sharing risks among members (Tsay et al., 1999). The revenue sharing contract coordinates decision makers in the decentralized supply chain toward the consensual goal.

Lots of works have been devoted to employing revenue sharing mechanism to coordinate a decentralized supply chain. Most of them focus on designing the revenue share schemes to improve the SC profits, such as Chauhan and Proth (2005) and Gupta and Weerawat (2006). However, it remains unclear on the effects of transfer pricing heuristics on the SC coordination and their interactions with the revenue sharing rates in a decentralized supply chain with multi-plants, multi-periods and finite capacity. The decentralized supply chain consists of manufacturer and distributor echelons. These two echelons interact with each other through the transfer prices and the product orders. The transfer price is a key variable in the coordination. The transfer prices influence the quantity of orders for the distributors and then affect the total SC profits. Yet, the revenue sharing rate can affect the manufacturer when determining the transfer prices. Understanding the effects of these pricing heuristics and their interactions with revenue sharing rate can help us design better revenue share schemes to put into practice.

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In this study, we have proposed a model to formulate the collaborative production and distribution planning in a decentralized supply chain with the revenue sharing mechanism. The model comprises two sub-models. The Production-distribution sub-model describes the production and distribution planning for the manufacturer echelon of multi-plant, multi-item, multi-period, and finite capacity. The Order Planning sub-model represents the ordering behavior for distributors under uncertain demands. Various pricing heuristics are employed to coordinate the production and distribution in the SC. Their performances have been evaluated in terms of the SC profits. Moreover, the study has explored how revenue share rates changes the profits for manufacturer echelon, distributor echelon and the supply chain under various transfer pricing heuristics. Experiment results reveal that the variable-cost pricing method leads to the best SC profits, compared to those of other pricing heuristics. Furthermore, the revenue sharing rate interacts with transfer pricing heuristics.

The remaining paper is organized as the following. Literature review is given in the next section. Section three presents the model for collaborative production and distribution planning in the decentralized supply chain with the revenue sharing mechanism. Various transfer pricing heuristics are compared in Section four. The last section is the conclusion.

2. LITERATURE REVIEW

In a revenue sharing contract, the buyer reimburses the seller some of its revenues for the discount on the wholesale prices (Smichi-Levi et al., 2008). For instance, Blockbuster shares approximately 30% to 40% of its rental revenues in exchange for reduced wholesale prices, as reported by Mortimer (Mortimer, 2007).

In case study on the video rental industry, Dana and Spier (2001) conclude that the revenue sharing contract can be employed to coordinate the supply chain. Also, the contract induces the retailers to cut down their rental prices under competition. The Gerchak and Wang (2004) study uses the revenue sharing contract to coordinate a decentralized supply chain in which the decision on the component production quantity for a supplier interacts with that of other suppliers providing complementary components. Their study shows that revenue-plus-surplus-subsidy scheme can increase the profits for all parties involved.

The revenue sharing provides incentives for retailers to stock more. Cachon and Lariviere (2005) prove that revenue sharing contracts are equivalent to buy back contracts in the fixed-price newsvendor environment; and are equivalent to price discounts in the price-setting newsvendor. However, there are some cases in which revenue sharing contracts are not appropriate, as pointed out by Cachon and Lariviere. Firstly, while revenue sharing contracts coordinate retailers to compete on quantity, it does not coordinate retailers to compete both on price and quantity. Secondly, when the earnings from the revenue sharing contract do not cover the additional administrative expense incurred by such a contract, it is not appropriate to employ revenue sharing contracts to coordinate a supply chain. Thirdly, the revenue sharing contract may not be attractive if retailers can take action to influence demand.

The revenue sharing (RS) contract has been designed from many perspectives in the literature. Chauhan and Proth have studied the RS contract that is proportional to the risks undertaken by the involved parties (Chauhan and Proth, 2005). Gupta and Weerawat (2006) study three types of revenue sharing contracts for supplier-manufacturer coordination. The first kind of contract is that revenue sharing depends on the supply lead time. In the second kind of contract, the supplier guarantees a delivery lead time to the manufacturer and incurs an expedited shipping charge if the supplier can not meet the promised lead time. In the last kind of contract, the revenues shared to the supplier rely on the supplier’s inventory level. Geng and Mallik (2006) propose a reverse revenue sharing contract for a distribution system with competing channels. The scheme of such a contract relates to retail prices, switch rates from channels, and the uncertain demand faced by channels along with a fixed franchise fee and a penalty for an unfilled order.

In addition to schemes of the RS contracts, the relationship between the transfer prices and the RS contracts has deserves lots of attention. Giannoccaro and Pontrandolfo (2004) have built revenue sharing models for two- and three-stage supply chains. Their analytical solutions show that the transfer price for the distributor equals the revenue keep rate times the marginal cost in the two-stage supply chain. Nachiappan and Jawahar (2007) have developed a genetic algorithm to identify the optimal contract prices and the revenue sharing ratio between the vendor and the buyer.

3. PRODUCTION AND DISTRIBUTION
COORDINATION WITH REVENUE SHARING

3.1 Model Overview

The decentralized supply chain consists of manufacturer and distributor echelons. The two echelons interact with each other through the transfer prices and the product orders. The manufacturers are required to decide the transfer prices for distributors. Next, the distributors identify the orders for manufacturers. Then, the manufacturers produce and distribute products according to the order. The production and distribution planning model with revenue sharing (PDP/RS) consists of two sub-models, as shown in figure 1. The Production-Distribution Planning sub-model is for identifying the optimal production and distribution plan in terms of the
orders given by the distributors. The Ordering Planning sub-model is for determining the optimal order quantity, given the transfer prices from manufacturers. The objective of the model is to maximize the total profits of the supply chain.

Before presenting the mathematical formulation for the PDP/RS model, required notations are introduced in the following.

### 3.2 Notations

**Index/Sets**
- $i$: Index for an item.
- $m$: Index for a manufacturer.
- $s$: Index for a distributor.
- $t$: Index for a given period.

**Parameters**
- $\alpha$: Shortage penalty for a product.
- $\beta$: Penalty for a unit of idle capacity.
- $\lambda_{ist}$: Mean of the random demand for an item of a distributor during a given period.
- $\phi$: Revenue sharing rate.
- $BC_{is}$: Purchasing cost of an item for a distributor.
- $\tilde{D}_{ist}$: Demand of an item from a distributor during a given period. The demand is a random variable.
- $FC_{im}$: Fixed charge of an item for a manufacturer.
- $HC_{im}$: Holding cost of an item for a manufacturer.
- $HC_{is}$: Holding cost of an item for a distributor.
- $M$: A very large number.
- $MC_{im}$: Maximum capacity of a manufacturer during a given period.
- $PC_{im}$: Production cost of an item for a manufacturer.
- $SC_{im}$: Shipping cost of an item from a manufacturer to a distributor.
- $RP_{is}$: Retail price for an item in a distributor.
- $SV_{is}$: Salvage value of an item for a distributor.
- $UC_{im}$: Consumed capacity of an item in for manufacturer.

**Variables**
- $I_{im}$: Inventory of an item for a manufacturer at the end of a given period.
- $O_{ist}$: Quantity of an item ordered by a distributor during a given period.
- $QP_{im}$: Production quantity of an item for a manufacturer during a given period.
- $QS_{sm}$: Shipping quantity of an item from a manufacturer to a distributor during a given period.
- $TP_{im}$: Transfer price of an item for a manufacturer.
- $X_{is}$: Promised capacity of a manufacturer to the supply chain during a given period.
- $Y_{im}$: Yes/No decision for producing an item by a manufacturer during a given period.

### 3.3 Sub-model of Order Planning

The ordering sub-model describes the ordering behavior of a distributor. Given the uncertain demand and the transfer prices from manufacturers, a distributor determines the optimal ordering quantity. The study formulates the distributor's ordering problem as a news-vendor problem (Erlebacher, 2000).

Assuming the demand fits the exponential distribution with rate $\lambda_{ist}$, the density function for demands is
\[
f_{ist}(x) = \lambda_{ist} \exp(-\lambda_{ist} x).
\]
When a distributor owns inventory $y$, the expected total profits for the distributor in a period is:
\[
E(y) = -BC_{is}y + (1 - \phi)RP_{is} \left(\int_0^y f_{ist}(x)dx + \int_y^{\infty} f_{ist}(x)dx\right) + SV_{is} \int_0^y f_{ist}(x)dx
\]
\[
= -BC_{is}y + (1 - \phi)RP_{is} \left(\frac{1}{\lambda_{ist}}(1 - \exp(-\lambda_{ist} y))\right) + SV_{is} \left(y + \frac{1}{\lambda_{ist}}(\exp(-\lambda_{ist} y) - 1)\right)
\]

Since more than one manufacturer can provide the same item to a distributor, we assume that the purchase cost is the average of the transfer prices for an item. That is,
\[
BC_{is} = \frac{\sum TP_{im}}{N_m}.
\]

The optimal inventory level that maximizes the total profits is
\[
y^* = \frac{1}{\lambda_{ist}} \ln \left(\frac{1 - (1 - \phi)RP_{is} - BC_{is}}{(1 - \phi)RP_{is} - SV_{is}}\right),
\]
given $RP_{is} - BC_{is} \geq 0$ and $RP_{is} - SV_{is} > 0$. 

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**Figure 1: Architecture for production and distribution model with revenue sharing.**
3.4 Sub-model of Production-Distribution Planning

3.4.1 Objective Function

The objective function of the PDP/RS model is to maximize the total profit of the manufacturer echelon. We define the revenue and the related costs for manufacturer as eq. (5) to (11).

\[ \text{Revenues for manufacturers} = \sum_{i,m,t} \left( TP_{im} \sum_{x} QS_{imxt} \right) \]  

\[ \text{Production Cost} = \sum_{i,m,t} (FC_{im} Y_{imt} + PC_{imx} P_{imt}) \]  

\[ \text{Transportation Cost} = \sum_{i,m,t} SC_{im} QS_{imxt} \]  

\[ \text{Inventory Cost} = HC_{im} I_{imt} \]  

\[ \text{Idle Capacity Penalty} = \beta \sum_{m,t} \left( X_{mt} - \sum_{i} UC_{imt} P_{imt} \right) \]  

\[ \text{Shortage Penalty} = \alpha \sum_{i,m,t} \left( QS_{imxt} - O_{imt} \right) \]  

\[ \text{Returns from distributors} = \phi \sum_{i,s,t} \left( RP_{is} \frac{1}{\lambda_{is}} \left( 1 - \exp \left( -\lambda_{is} \sum_{m} QS_{imxt} \right) \right) \right) \]  

where \( \frac{1}{\lambda_{is}} \left( 1 - \exp \left( -\lambda_{is} \sum_{m} QS_{imxt} \right) \right) \) is the expected selling quantity for a supplier in a period for a product. Therefore, the profits for manufacturers can be formulated as eq. (12).

\[ \text{Profits for manufacturer} = (5) + (11) - [ (6) + (7) + (8) + (9) + (10) ] \]

3.4.2 Constraints

**Capacity Constraint**
\[ \sum_{m} UC_{imt} QP_{imt} \leq X_{imt}, \forall m,t. \]  

\[ X_{imt} \leq MC_{imt}, \forall m,t. \]

**Inventory Balance**
\[ I_{imt} = I_{imt(-1)} + QP_{imt} - \sum_{x} QS_{imxt}, \forall i, m, t. \]

**Demand fulfillment**
\[ \sum_{x} QS_{imxt} \leq O_{imt}, \forall i, s, t. \]

**Availability for fulfilling demand**
\[ \sum_{x} QS_{imxt} \leq QP_{imt} + I_{imt}, \forall i, m, t. \]

**Production quantity**
\[ QP_{imt} \leq MY_{imt}, \forall i, m, t. \]

**Variable domain constraints**

All variables are nonnegative and all \( Y_{imt} \) are binary.

4. Transfer Prices and Revenue Sharing Rates

In this section, we evaluate various transfer pricing methods on SC coordination and explore their relationships with the revenue sharing rate.

4.1 Transfer Pricing Methods

There are two common transfer pricing methods in practice (Horngren1982). The variable cost method uses the variable cost of an item as the transfer price. Total cost method use the sum of the fixed and variable costs of an item as the transfer price. Hence, based on the concepts of these methods, we employ the following heuristics for determining the transfer price:

- **Zero cost (ZC):** The item's transfer price is set to zero.
- **Variable cost (VC):** The item's transfer price is its variable cost. The variable cost is the sum of unit holding cost, unit production cost, and the average shipping cost of a unit.
- **Total cost (TC):** The item's transfer price is the sum of the variable cost and the fixed cost for the item. The fixed cost of an item in for manufacturers is estimated by equation (19).
- **Minimum retail price for products (Min):** The item's transfer price is set to the minimum retail price in the distributor echelon.
- **Medium retail price for products (Med):** Use the medium of the minimum and the maximum retail prices as the transfer price.
- **Maximum retail price for products (Max):** Transfer price is the maximum of the retail prices in the distributor echelon.

The transfer prices generated by the previous six heuristics have the following relationships:

\[ \text{Zero cost} \leq \text{Variable cost} \leq \text{Total cost} \leq \text{Minimum retail price} \leq \text{Medium retail price} \leq \text{Maximum retail price.} \]

4.2 Experiment Settings

We simulate a supply chain composed of two manufacturers and one distributor. Four items are produced and distributed in the supply chain. The planning horizon is four periods. The experiments run with revenue sharing rates at 10, 50, and 90 percents. Table 1 summarizes other experiment settings.
Table 1: Experiment Settings

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand Rate in a period</td>
<td>0.02 ~ 0.05</td>
</tr>
<tr>
<td>Retail price</td>
<td>200 ~ 250</td>
</tr>
<tr>
<td>Salvage value</td>
<td>10 ~ 20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>In manufacturer echelon:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity usage rate</td>
<td>1 ~ 5</td>
</tr>
<tr>
<td>Holding cost</td>
<td>5 ~ 15</td>
</tr>
<tr>
<td>Production cost</td>
<td>30 ~ 40</td>
</tr>
<tr>
<td>Shipping cost</td>
<td>5 ~ 10</td>
</tr>
<tr>
<td>Maximum capacity for a period</td>
<td>1500 ~ 2000</td>
</tr>
</tbody>
</table>

Table 2: Average Profits for manufacturers, distributors, and supply chain at revenue sharing rate 0.1.

<table>
<thead>
<tr>
<th>Transfer Pricing Method</th>
<th>Manufacturer Profits</th>
<th>Distributor Profits</th>
<th>SC Profits</th>
<th>Service Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZR</td>
<td>-1.6E11</td>
<td>0</td>
<td>-1.6E11 1</td>
<td>1.083</td>
</tr>
<tr>
<td>VC</td>
<td>16622.772</td>
<td>44411.487</td>
<td>61034.259</td>
<td>0.806</td>
</tr>
<tr>
<td>TC</td>
<td>16691.247</td>
<td>44314.326</td>
<td>61065.573</td>
<td>0.805</td>
</tr>
<tr>
<td>Min</td>
<td>1175.211</td>
<td>55.50518</td>
<td>1230.717</td>
<td>0.016</td>
</tr>
<tr>
<td>Med</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Max</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

1 Negative big value.

Table 3: Average Profits for manufacturers, distributors, and supply chain at revenue sharing rate 0.5.

<table>
<thead>
<tr>
<th>Transfer Pricing Method</th>
<th>Manufacturer Profits</th>
<th>Distributor Profits</th>
<th>SC Profits</th>
<th>Service Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZR</td>
<td>-15999090.000.000</td>
<td>44275.298</td>
<td>-15999090.000.000</td>
<td>1.161</td>
</tr>
<tr>
<td>VC</td>
<td>38417.363</td>
<td>12330.595</td>
<td>56748.357</td>
<td>0.626</td>
</tr>
<tr>
<td>TC</td>
<td>38391.289</td>
<td>12272.225</td>
<td>56653.514</td>
<td>0.625</td>
</tr>
<tr>
<td>Min</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Med</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Max</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 4: Average Profits for manufacturers, distributors, and supply chain at revenue sharing rate 0.9.

<table>
<thead>
<tr>
<th>Transfer Pricing Method</th>
<th>Manufacturer Profits</th>
<th>Distributor Profits</th>
<th>SC Profits</th>
<th>Service Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZR</td>
<td>-1.6E+10</td>
<td>16639.279</td>
<td>-1.6E+10</td>
<td>4.043</td>
</tr>
<tr>
<td>VC</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>TC</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Min</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Med</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Max</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
4.3 Computation Results

Ten cases are randomly generated. The average profits for manufacturers, distributors, and the supply chain are shown in tables 2 to 4 at revenue sharing rates 0.1, 0.5, and 0.9, respectively. The service level for each transfer pricing method is shown in the last column for each table.

The service level is calculated by

\[
\text{Service Level} = \frac{(1 - \phi) R P_{\alpha} - BC_{\alpha}}{(1 - \phi) R P_{\alpha} - SV_{\alpha}},
\]

where \( BC_{\alpha} \) is the average transfer price. Transfer price zero causes the service level to exceed one. However, when the transfer price rising to the maximum of the retail price, the service level become less than zero.

The best SC profit occurs at the VC transfer pricing method when the revenue sharing rate is 0.1. On the contrary, the worst SC profits, which is a negative big value, happens at the ZR transfer pricing method. The same patterns can be observed at revenue sharing rate 0.5 and 0.9 respectively.

4.4 Discussions

The computation results have provided us with several findings. Firstly, the VC pricing method leads to the maximum SC profit, compared with other pricing methods, as shown in figure 2. The SC profit drops dramatically when using Minimum, Medium, and Maximum retail prices. In this study, the ZR pricing method results in large negative SC profits. The distributors order as many as they can so the order exceeds the capacity of the manufacturer echelon. As a result, the supply chain suffers the huge shortage penalty in the manufacturer echelon (Eq. (10)). Although finding the optimal transfer prices is required for maximizing the SC profits, the VC pricing method provides a good heuristic for determining the transfer prices between the manufacturer and distributor echelons.

Secondly, the optimal transfer price may occur in the neighborhood of the price generated from the VC pricing method. The SC profits declines as the transfer price increasing. The results provides us with clues for searching the optimal transfer price. The optimal transfer price may exist between the prices generated by the VC and ZR pricing methods. More efforts are required for finding the optimal transfer price.

Lastly, increasing the revenue sharing rate decreases the SC profits, as shown in figure 2. Moreover, changing the revenue sharing rate significantly alter the profits for the manufacturer and distributor echelons, as shown in figure 3 and 4. Increasing revenue sharing rate impacts the system in two ways, no matter what pricing methods are empolyed. One is decreasing the order quantity from the distributor echelon according to equation (4). The other is shifting the revenue from distributor echelon to manufacturer echelon.
5. Conclusion

The study investigates various transfer pricing heuristics for coordinating the decentralized SC with the revenue sharing mechanism. Specifically, the study has explored how the revenue sharing mechanism alters the profits for the manufacturer echelon, the distributor echelon and the supply chain under various transfer pricing heuristics. For examining their relationships, a model is established for formulating the collaborative production and distribution planning in a decentralized supply chain with the revenue sharing mechanism. Next, six transfer pricing heuristics are employed to identify the resulted SC profits. The six pricing heuristics are: zero-cost price, variable-cost price, total-cost price, the minimum retail price, the medium retail price, and the maximum retail price. Computation results show that the variable-cost pricing heuristic leads to the best SC profits. And, raising the revenue share rate decrease the SC profits for each pricing heuristic.

We further examined the interactions between the revenue sharing rate and the variable- and total-cost pricing heuristics. Changing the revenue sharing rate significantly alter the profits for the manufacturer and distributor echelons. Profits for distributor echelon are shifted to manufacturer echelon. In the future, the study will devote to developing procedures for identifying the optimal transfer price and other better transfer price methods for the problem.

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