Multi-level Green Supply Chain Coordination with Different Power Structures and Channel Structures Using Game-theoretic Approach

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***Abstract*—In this paper, we consider the problem of coordinating price, remanufacturing in a three-level green supply chain composed of a single supplier, a single manufacturer and a single retailer. Channel selection and power structure as two important roles in pricing and remanufacturing decisions have also been included. The paper deals with the decentralized, the semi-integrated, and the integrated channel structures. Leader-follower and independent power balance scenarios are both considered for the former two channels. We focus on pricing and remanufacturing problems in all three channels with different power scenarios and explore the effects of power structures, channel structures, as well as market parameter on equilibrium price, remanufacturing decisions and profits.**

***Index Terms*—green supply chain, pricing, remanufacturing, channel structure, power structure, Stackelberg game, Nash game**

I. Introduction

Nowadays, global resources consumption and ecological and environmental destruction has become serious. How to ensure economic growth, while reduce resource consumption and environmental pollution is a common concern of the world's governments and peoples (Roseland 2012). Firms engaging in green supply chain management have experienced both environmentally and financially benefits (Wilkerson 2005b). Wilkerson (2005a) shows that Taxas Instruments saved $8 million on annual basis, about 20% annual saving, through source reduction, recycling, and use of reusable packaging system for semi-conductor business. In the automotive after-sale market, remanufacturing generates USD 37 billion in sales, representing approximately two-thirds of the USD 65 billion per annum remanufacturing industry in the US (Business Week Online 2005). Any major greening efforts require cooperation of the entire supply chain, as reported by Wal-Mart (Plambeck 2007). We look at an importance research area on conflict and cooperation between green supply chain partners under different supply chain structures.

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Our study is based on the home appliance industry of the world. In China, it is estimated that the volume of scrapped home appliances has reached 50 million each year, growing at a rate of 20% annually (http://recycle.cheaa.com). It is an immediate problem faced by the enterprises to take positive steps towards greening their supply chain to deal with these scrapped products in a more scientific and innocuous way to reach a goal of continuous development. Our problem is primarily motivated by the greening initiatives of Gree Electric Incorporated Company, in Zhuhai, China, established in 1991, which has become the world largest professional air-conditioner enterprise, integrated R&D, manufacturing, marketing and service as one. Gree has made giant strides in greening its products and processes, especially in recycling discarded products, as declaimed by its Chairman Dong, Mingzhu. Gree has set up an a fully owned subsidiary "Hunan Green Renewable Resources Limited Company" in 2010, which handles discarded electrical, electronic products, and precious metals recycling, and explore resource recycling technology.

Any major greening effort requires cooperation of the entire supply chain, as discovered by Wal-Mart (Plambeck, 2007). Nowadays, more emphasis has been put on integrating suppliers, manufacturers, distributors and retailers efficiently. Gree also teams up with some large electrical retailers, such as Gome in China or its own retail stores to offer old-for-new service to reclaim used products. Gree's core brass tubing supplier - Jiangxi Copper Group Corporation, the largest brass products production base in China, also recycles valuable residual elements from wasted materials.

In this circumstance, the greening effort is not only the concern of a single enterprise, but the cooperation of the entire supply chain. The enterprise can choose to integrate with the suppliers or the retailers, or both of them, to make the greening initiatives. When such multi-level channels are considered, the channel selection decision is a problem faced by the manufacturer. That is to say, the centralization could be a part of the supply chain. This is different from the previous studies for traditional channels, in which the relationship between different tiers can only be centralized or decentralized. Besides, the power scenarios of supply chains are more complex, because multiple echelons are involved.

Based on the above observations, we aim to answer the following questions in our paper: (1) how will the supply chain members of different echelons make pricing and remanufacturing decisions under different power and channel structures? (2) Which power structure will be preferred by the supply chain members and the whole system under different channel structures? (3) Will the integration

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between the manufacturer and the retailer or the supplier always be feasible?

To address these questions, this paper considers a single product three-level price model consisting of one supplier, one manufacturer and one retailer. Three different channel structures are considered in this supply chain. The first is decentralized channel that the manufacturer uses the independent supplier and retailer, in which they optimize their own profit individually and non-cooperatively. The second is that the manufacturer integrates with the retailer and uses the independent supplier simultaneously. This channel is called by semi-integrated channel. Leader-follower and independent power structures are both considered for the two channel structures. The third one is the integrated channel structure. In this channel, the manufacturer, the supplier and the retailer operate in total cooperation in a vertically integrated system. This paper studies the effects of the above channel structures, different power structures and market parameter on the equilibrium prices and profits of individual channel members and the supply chain system.

Our results show that show that in either decentralized or semi-integrated supply chain, the supply chain members invest most in remanufacturing when there is no channel leadership. Besides, the investment goes down as the market becomes more sensitive to the price. We also find that the supplier taking channel leadership will have different impact on retail price in different channel structures. Another finding is that the integration of the supply chain members would also enhance their investment in remanufacturing. Specially, as the market becomes more sensitive to the price, the supplier in the integrated channel or in the semi-integrated channel with the supplier taking the leadership, tends to invest more in remanufacturing to counter the impact of retail price lowering down. We also show that the integration for the manufacturer and the retailer cannot always improve their profits in a monopoly under a multi-level channel or in the situation that the supply chain members put in efforts for remanufacturing.

The remainder of this paper is organized as follows: Section 2 discusses the background literature for the paper. Section 3 gives the model assumptions and notations. The game models and the solutions of different power structures and channels structures are presented in Section 4. Section 5 provides the analytical analysis of the effects of different power structures, channel structures. Following the analytical results, Section 6 presents a representative numerical analysis. The last section summarizes major work and further research areas.

II. Literature review

In the marketing literature, coordination of different echelons of the channel is extensively studied (Martha and Lisa 1993). For instance, Jeuland and Shugan (1983) are among the early researchers to deal with channel coordination. They study the effect of cooperation between the manufacturer and the retailer comparing an independent channel structure with a vertically integrated channel and conclude that cooperation always results in higher profit. Choi (1991) investigates pricing problem for a channel structure consisting of two competing manufacturers and one common retailer who sells both manufacturers' products. He considers three non-cooperative games of different power structure between the two manufacturers and the retailer. Charles and Mark (1995) discuss the channel coordination with a manufacturer that sells an identical product to two competing retailers. Minakshi (1998) studies channel competition by analyzing three channel structures, the least constrained of which deals with two competing manufacturers and two retailers. In the above research, cooperative or non-cooperative pricing decisions have been made to coordinate the channel members. However, non-pricing strategies, like green supply chain initiatives, are not covered.

Green supply chain management means reducing the impact of business activities on the environment, which has been gradually concerned by researchers (O'Brien 1999, Sroufe 2003, Srivastave 2007, Swami and Shah 2013). Channel literatures related to green supply chain primarily concentrate on remanufacturing activities (Savaskan et al. 2004, Savaskan and Van Wassenhove 2006, Atasu et al. 2008, Ghosh and Shah 2012). Remanufacturing is an industrial process in which used products are repurposed for useful purposes (Lund 1996). Many researchers also study how products can be designed to facilitate the remanufacturing process. Shu and Flowers (1995) argue that, if a product (or its parts) is not intended to be reused, adapting a product for disassembly, cleaning, or reassembly is meaningless. Bras and Hammond (1996) develop a design for remanufacturing metrics and apply it to several product case studies. Shu and Flowers (1998) present a product part reliability model that can be used to estimate different recycling and remanufacturing costs for different product concepts. Using a production planning survey, Guide (2000) reports on managerial remanufacturing practices to control activities at the remanufacturing firms in the United States.

Further, the issue of green supply chain coordination using game theory has come up as a new research paradigm. Savaskan et al. (2004) investigate how an appropriate reverse channel structure is chosen for the collection of used products from customers. They model different collection options as decentralized decision-making systems with the manufacturer being the Stackelberg leader. Mitra and Wevster (2008) propose a two-period model in which a manufacturer sells a new product and a remanufacturer competes with the manufacturer in the second period. The authors study the effects of government subsidy on remanufacturing activities. Chen and Sheu (2009) propose a differential game model and demonstrate that a proper design of environmental-regulation pricing strategies can promote Extended Product Responsibility for green supply chain enterprises in a competitive market. Ghosh and Shah (2012) examine the influence of channel structures on greening levels, prices, and profits using game models, and propose a two-part tariff contract to coordinate the green channel. Swami and Shah (2013) coordinate a manufacturer and a retailer in a vertical supply chain in which both players put in efforts for "greening" their operations and the manufacturer acts as a Stackelberg leader. In the above research, price and level of green innovation / reverse channel performance are the major factors studied in the reverse channel or green supply chain. However, these studies only focus on the traditional channel structure, always composed of two echelons (buyer /manufacturer and seller/retailer) with different power structures.

Our paper extends the above streams of research by specifically providing an analytical model to coordinate price and remanufacturing decisions in a multi-level green supply chain environment and comparison studies are conducted between different power structures and channel structures.

III. Model Assumptions and Notations

We consider the situation of one supplier, one manufacturer and one retailer of a product with price sensitive demand in a single period. 's', 'm', 'r' are used to mark the supplier, the manufacturer, the retailer respectively. The supplier provides the manufacturer with the sole raw material at a price of u, used to produce a single product sold to the retailer with a wholesale price w. Then the retailer sells the product to customers at a retail price p. Suppose that the supplier and the manufacturer both have incorporated a remanufacturing process for used products into their original production system, so that they can manufacture a new unit directly from raw material, or remanufacture part or whole of a returned unit into a new one. Since we only consider the new product market, the retailer cannot manufacture new product and thus, its recycle process will not be covered here. This simple monopoly structure allows us to focus on the competition and coordination between different echelons, without the distraction of multiple products, multiple suppliers, manufacturers and retailers. Similar assumptions can be seen from Alan and Medini (1992), Savaskan et al. (2004), Swami and Shah (2013), etc.

Let κ be the maximum amount of cost saving that the supplier can attain using a used product to produce a unit new raw material. According to Savaskan and van Wassenhove (2006), component innovation requires upfront investment in remanufacturing. In defining τ as the fraction of this maximum amount of cost saving resulted from the initial investment of the supplier, i.e. the return rate of unit used raw material from customers to the supplier, τ is assumed to be a single value for each unit of raw material returned. The upfront investment in remanufacturing provided by the supplier for the component, which is quadratic in nature, is $\varphi\tau^2$, where φ is the positive constant (Gilbert and Cvsa 2003). Thus, by investing $\varphi\tau^2$, the supplier can recover its unit cost by $\kappa\tau$ through recycling. This cost structure can be found in the literature (Gilbert and Cvsa 2003; Savaskan and van Wassenhove 2006). Thus, the higher τ, the larger amount of initial investment in remanufacturing and the more cost recovered. For the manufacturer, the remanufacturing cost structures are similar as the supplier.

The demand of the product generated at the retail end is assumed to be a downward slopping function of the retail price. We employ a downward sloping linear demand function for the analyses and results comparison.

$$D(p) = \theta - \alpha p, \tag{1}$$

where θ is a constant indicating the market scale and α is a price elasticity of demand.

The other parameters used in the model are summarized below:

c_s the procurement cost per unit raw material for the supplier
c_m the production cost per unit product for the manufacturer.
δ the usage of raw material per unit product
κ supplier's maximum amount of cost saving from remanufacturing one unit raw material
η manufacturer's maximum amount of cost saving from remanufacturing one unit product
φ positive constant to illustrate the investment in innovation provided by supplier for the product, i.e. $\varphi\tau^2$
ψ positive constant to illustrate the investment in innovation provided by manufacturer for the product, i.e. $\psi\rho^2$
m_m the manufacturer's marginal profit per unit product, $m_m = w - \delta u - c_m + \eta\rho$
m_r the retailer's marginal profit per unit product, $m_r = p - w$
m_{mr} the marginal profit of the integrated manufacturer and retailer per unit product, $m_{mr} = p - u\delta - c_m + \eta\rho$
τ return rate of unit used raw material from customers to the supplier
ρ return rate of unit used products from customers to the manufacturer
π_s manufacturer's profit
π_m manufacturer's profit
π_r retailer's profit
π_{mr} profit of the integrated manufacturer and retailer
π total profit in the integrated channel

IV. Game model

The supplier, manufacturer and retailer are assumed to be rational decision makers. The supplier and the manufacturer determine their pricing decision and return rate (i.e. remanufacturing decision) and the retailer makes decision on the retail price only. We wish to examine the effect of different power structures and channel structures on the optimal pricing and efforts decisions by the channel partners. The following profit functions are proposed.

The profit function of retailer *r* is given as:

$$\pi_r = D \cdot (p - w). \tag{2}$$

The profit function of manufacturer *m* is given as:

$$\pi_m = D \cdot (w - \delta u - c_m + \eta\rho) - \psi\rho^2. \tag{3}$$

And the profit function of supplier *s* is given as:

$$\pi_s = \delta D \cdot (u - c_s + \kappa\tau) - \varphi\tau^2. \tag{4}$$

A. Decentralized Channel

In this subsection, we consider the decentralized channel structure, in which the manufacturer uses the independent supplier and retailer. We consider three power balance scenarios under this channel structure. For the first scenario, the manufacturer is the leader, while the supplier and the retailer are the followers. For the second one, the supplier is the leader, while the manufacturer and the retailer are the followers. We also consider the scenario that the supplier, the manufacturer and the retailer are of independent equal status and no one dominates over others. We use Stackelberg game structure to model the first two scenarios and Nash game structure for the third one.

1) Manufacturer Stackelberg

We use Stackelberg game to model the power scenario that the manufacturer is the leader while the supplier and the retailer are the followers. For convenience, we name this game model as Manufacture Stackelberg (marked as *ms*). In fact, it is a sequential non-cooperative game, composed of two Stackelberg games. The first one is between the manufacturer and the supplier. In this game, the manufacturer chooses his marginal profit and remanufacturing decision using the reaction function of the supplier. The supplier sets his raw material price and remanufacturing decision, conditional on the manufacturer's decisions. The second Stackelberg game is between the manufacturer and the retailer, in which the manufacturer chooses his marginal profit and remanufacturing decision using the retailer's reaction function and then the retailer determines his retail price given the manufacturer's decisions.

2) Supplier Stackelberg

Stackelberg game is also employed to model the power scenario that the supplier is the leader while the manufacturer and the retailer are the followers. For convenience, we call this game model Supplier Stackelberg (marked as *ss*). It is a sequential non-cooperative game, composed of two Stackelberg games. The first Stackelberg game is between the supplier and the manufacturer. The supplier chooses his raw material price and remanufacturing decision using the reaction function of the manufacturer. The manufacturer sets his wholesale price and remanufacturing decision, conditional on the supplier's decisions. The second one is similarly played between the manufacturer and the retailer.

3) Vertical Nash

In the third power scenario, all supply chain members are of equal status and compete to make their own optimal decisions. This scenario is formulated as a Nash game. In this game, the supplier, the manufacturer and the retailer make pricing decisions simultaneously and non-cooperatively. Again for convenience, we call this game as Vertical Nash (marked as *vn*). In this game, the supplier chooses his raw material price and remanufacturing decision conditional on the manufacturer's marginal profit and remanufacturing decision as well as the retailer's marginal profit to maximize his profit. The manufacturer chooses his marginal profit and remanufacturing decision conditional on the other two players' decisions. The retailer sets his marginal profit so as to maximize his profit conditional on the supplier's and the manufacturer's pricing and remanufacturing decisions.

B. Semi-integrated Channel

In many industries, the manufacturer would like to work together with his downstream retailer in determining pricing, advertising, recycling etc., to cut down the cost, lower the retail price (Fisher, 2003). For example, P&G (Procter & Gamble) cooperates with Wal-Mart through JIT delivery, information sharing, and demand monitoring, etc. (Coyle et al., 1996, Foley and Mahmood, 1996). In the semi-integrated channel, the manufacturer chooses to integrate with the retailer and then work with the supplier. In effect, the supply chain with this channel structure is a two-level system where the manufacturer integrates with another echelon to be a single decision maker.

Three power balance scenarios are considered for this channel. The first one is the two integrated members (i.e. the manufacturer and the retailer) act as the leader, while the independent supplier acts as the follower. The second one is the independent supplier acts as the leader and the two integrated members act as the follower. The third one is that the two integrated members and the independent supplier are of equal status. We formulate Stackelberg for the first two scenarios and Nash games for the third one. Since the manufacturer and the retailer integrate together, we assume that there in no transfer price between them. Hence, there is no need to specify the manufacturer's price in the modeling process.

The profit function for the integrated manufacturer and retailer is:

$$\pi_{mr} = \left(p - u\delta - c_m + \eta\rho \right) \cdot D(p) . \tag{5}$$

1) MR-Stackelberg

We first consider the power scenario that the manufacturer and the retailer integrate and act as the leader of the supply chain, while the supplier acts as the follower. We formulate Stackelberg game between the integrated manufacturer and retailer and the independent supplier. We call this game model as MR-Stackelberg (marked as *mrs*). The manufacturer and the retailer agree to make their own marginal profit decision taking the supplier's reaction function into account. The supplier conditions its raw material price and remanufacturing decision on the marginal profit and remanufacturing decision given by the manufacturer and the retailer.

2) IS-Stackelberg

We then consider the power scenario that the supplier acts the leader, while the manufacturer and the retailer integrated act as the follower. We also formulate Stackelberg game between the independent supplier and the integrated members. To distinguish from *ss* case, we call this game model as IS-Stackelberg (marked as *iss*). The supplier makes their own marginal profit and remanufacturing decision taking the reaction functions of the integrated manufacturer and retailer into consideration. The manufacturer and the retailer conditions its retail price and remanufacturing decisions given by the decisions of the supplier.

3) MR-Nash

The power scenario here features that the integrated manufacturer and retailer are of equal power with the supplier. We formulate Nash game between them. We call this game MR-Nash (marked as *mrn*). The supplier chooses his raw material price and remanufacturing decision conditional on the marginal profit and remanufacturing decision given by integrated the manufacturer and the retailer to maximize his profit. The manufacturer and the retailer integrate to choose his marginal profit and remanufacturing decision conditional on the supplier's raw material price and remanufacturing decision to maximize their total profit.

C. Integrated Channel

In this section, we focus on the integrated channel (marked as *I*). In this channel, the supplier, the manufacturer and the retailer integrate together to take decisions to maximize the total system profit. The integration of supply chain wide prevents the manufacturer from dealing with the conflicting incentives that an independent supplier or retailer would have. We assume there is no transfer price between the supplier, the manufacturer and the retailer, and thus only a single price p to be determined.

V. Discussion

This section presents several implications that are observed from the results. We particularly focus on the effects of power structures and channel structures. We now compare various analytical results of the decentralized, semi-integrated and integrated channels. These are presented in the form of various propositions. The results of the three channels are shown in Table 1 and Table 2.

A. Feasibility conditions

We first develop the condition of feasibility of parameters used in the paper. From the results of Table 1 and Table 2, we can see that the following feasibility condition should be satisfied across decentralized channel and integrated channel:

$$4\varphi\psi - \alpha\eta^2\varphi - \alpha\delta^2\kappa^2\psi > 0, \tag{6}$$

and

$$\theta - \alpha c_m - \alpha\delta c_s \geq 0. \tag{7}$$

Moreover, when studying the results of *vn* case, from equations (25)-(26), since return rate τ should be non-negative, we have

$$2\varphi - \alpha\delta^2\kappa^2 \geq 0, \tag{8}$$

and

$$2\psi - \alpha\eta^2 \geq 0. \tag{9}$$

Throughout the paper, the four conditions are assumed to hold for feasibility.

B. Effects of power structure

We first compare various analytical results of different power structures of the decentralized and semi-integrated channels. These are presented in the form of various propositions.

Proposition 1. The following relation holds between the decisions of decentralized channels:

a) $\tau^{vn} \geq \tau^{ms} \geq \tau^{ss}$, $\rho^{vn} \geq \rho^{ms} \geq \rho^{ss}$, $p^{ss} \geq p^{ms} \geq p^{vn}$, $w^{ss} \geq w^{ms} \geq w^{vn}$, $u^{ss} \geq u^{vn} \geq u^{ms}$;

b) $D^{vn} \geq D^{ms} \geq D^{ss}$. Furthermore, $\dfrac{D^{vn}}{D^{ss}} \geq 2$.

Proposition 1 indicates that when the upstream supplier takes the channel leadership, the return rate of used material / product or the investment in remanufacturing will be the least for both supplier and manufacturer, while the raw material price, wholesale price and retail price will be the highest between the three cases. When there is no channel leadership, the manufacturer and the supplier would invest most in remanufacturing and the return rates are the largest. Meanwhile, in this case, the wholesale price and retail price are the lowest, but the raw material price is higher than the case the manufacturer taking the channel leadership.

Proposition 2. *The following relation holds between the profits of the decentralized channels:* $\pi_r^{vn} \geq \pi_r^{ms} \geq \pi_r^{ss}$; $\pi_m^{ms} \geq \pi_m^{ss}$, $\pi_m^{vn} \geq \pi_m^{ss}$; $\pi_s^{vn} \geq \pi_s^{ms}$, $\pi_s^{ss} \geq \pi_s^{ms}$; $\pi^{vn} \geq \pi^{ms} \geq \pi^{ss}$.

Proposition 2 implies that, in the absence of channel leadership, the retailer's profit is the highest as well as the profit of the whole supply chain. When the supplier takes the channel leadership, the retailer's and the manufacturer's profits and the profit of the entire supply chain are the lowest. As to the manufacturer's profits between *ms* case and *vn* case and the supplier's profits between *ss* case and *vn* case, their relation depends. We will further study the relationship in the following numerical study. Together, Proposition 1-2 suggest that, when the environmental issues are emphasized, the power structure without channel leadership is preferred, which is also welcomed by the customers and the retailer as well as the entire supply chain for the lowest retail price and larger profits.

Proposition 3. The following relation holds between the decisions of semi-integrated channels:

a) If $\psi\delta^2\kappa^2 - \varphi\eta^2 \geq 0$ holds, we have $\tau^{mrn} \geq \tau^{mrs} \geq \tau^{iss}$, $\rho^{mrn} \geq \rho^{mrs} \geq \rho^{iss}$, $p^{iss} \geq p^{mrs} \geq p^{mrn}$; otherwise, $\tau^{mrn} \geq \tau^{iss} \geq \tau^{mrs}$, $\rho^{mrn} \geq \rho^{iss} \geq \rho^{iss}$, $p^{mrs} \geq p^{iss} \geq p^{mrn}$;

b) $u^{iss} \geq u^{mrn} \geq u^{mrs}$;

c) If $\psi\delta^2\kappa^2 - \varphi\eta^2 \geq 0$, $D^{mrn} \geq D^{mrs} \geq D^{iss}$; otherwise, $D^{mrn} \geq D^{iss} \geq D^{mrs}$.

As stated in the above proposition, the return rate of the used material / product or the remanufacturing investments of all supply chain members are the highest without channel leadership, which is the same as Proposition 1 shows. Meanwhile, under this situation, this channel also enjoys the lowest retail price as well as largest market demand, although the raw material price might not be the lowest. However, the relations between the *mrs* and *iss* cases in the remanufacturing decisions, retail prices and demands depend on the condition that whether $\psi\delta^2\kappa^2 - \varphi\eta^2$ is no less than zero or not.

C. Effects of channel structure

We investigate the effects of different channel structures on equilibrium price and profits in this section.

Proposition 4. The following relation holds between the decisions of decentralized, semi-integrated and integrated channels:

a) $\tau^I \geq \tau^{mrn}$, $\tau^{mrs}\left(\text{or } \tau^{iss}\right) \geq \tau^{vn}$, $\rho^I \geq \rho^{mrn}$, $\rho^{mrs}\left(\text{or } \rho^{iss}\right) \geq \rho^{vn}$, $p^{vn} \geq p^{mrs}\left(\text{or } p^{iss}\right)$, $p^{mrn} \geq p^I$, $u^{ss} \geq u^{iss} \geq u^{mrn} \geq u^{mrs} \geq u^{vn} \geq u^{ms}$;

b) $D^I \geq D^{mrn}$, $D^{mrs}\left(\text{or } D^{iss}\right) \geq D^{vn}$.

Proposition 4 implies that, the maximum remanufacturing investment in decentralized channels is still less than the lowest one in the semi-integrated channels. Further, the integrated channel has the largest investment in remanufacturing for both the supplier and the manufacturer. That is to say the integration will increase investment in remanufacturing for the supply chain members. The same result goes for the market demand of the three types of channels.

VI. CONCLUSION

Most previous studies have focused on price and remanufacturing coordination in green supply chain with two echelons (manufacturer and retailer, or manufacturer and supplier). In nowadays real market, coordination for the total supply chain wide is inevitable and necessary. This paper extends the growing literature of channel studies by analyzing competitive pricing and remanufacturing strategies for a three-level green supply chain consisting of supplier, manufacturer and retailer. Three different channel structures are considered for the price models. They are the decentralized channel, the semi-integrated channel and the integrated channel. Two non-cooperative games are used to model different power structures for each channel structures, i.e., Stackelberg and Nash games. We also investigate the effects of power structures, channel structures on the pricing, remanufacturing decisions and profits for channel members.

Although this study adds to the growing literature of competition and cooperation for a multi-level green supply chain, this paper suffers several limitations. The models in this paper only consider supply chains with one member in each echelon. A more general model with multiple suppliers, manufacturers, and retailers could be developed. The competition at each echelon is also an interesting and useful topic. Besides, involving inventory, marketing factors in supply chain is also not covered. Carrying inventories is essential to enhance customer service and reduce distribution costs. These limitations should be addressed in the future research.

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