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Reverse supply chain coordination by revenue sharing contract: A case for the personal computers industry

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ABSTRACT

Products that are not recycled at the end of their life increasingly damage the environment. In a collection – remanufacturing scheme, these end-of-life products can generate new profits. Designed on the personal computers industry, this study defines an analytical model used to explore the implications of recycling on the reverse supply chain from an efficiency perspective for all participants in the process. The cases considered for analysis are the two- and three-echelon supply chains, where we first look at the decentralized reverse setting followed by the coordinated setting through implementation of revenue sharing contract. We define customer willingness to return obsolete units as a function of the discount offered by the retailer in exchange for recycling devices with a remanufacturing value. The results show that performance measures and total supply chain profits improve through coordination with revenue sharing contracts on both two- and three-echelon reverse supply chains.

1. Introduction

Customers' attention to environmental issues, business' adaptation to the competitive market, and an increasingly controlled legislation all play a central role in the way businesses are created and managed in the global market. To meet these requirements, companies increasingly focus on developing sustainability practices and on creating reverse supply chains in order to recapture value and to provide methods of proper disposal. A series of mechanisms have been identified that coordinate the forward supply chain. To a great extent, many of these mechanisms – contracts, information technology, information sharing, and joint decision-making – can be applied to coordinate the reverse supply chain as well. Among these coordination mechanisms, contracts are tools designed to facilitate interaction between disparate members of the supply chain and to motivate participants to behave in the best interests of a supply network (maximization of total supply chain profit). By specifying parameters such as quality, deadlines, and other similar incentives, the introduction of contracts, as a coordination mechanism, provides protection to members against individual free riding (Cachon, 2003).

While many studies have analyzed the behavior of the forward supply chain under contractual terms, it is of interest to observe the applicability and implications of these contracts on the reverse supply chain, which has limited analysis at present. The main area in practical research is on the coordination of reverse supply chains represented by e-waste and electronics recycling. Practical examples in the industry are found in Toktay et al. (2000) with a focus on Kodak single use cameras and inventory control, Kumar et al. (2002) on Hewlett Packard printer division showing that product returns can be a profitable business, Guide et al. (2003) on the mobile phone industry that considers acquisition management's impact on realized profit, Nagurney and Toyasaki (2005) on the management of e-waste and recycling, and Bai (2009) with a focus on cartridge recycling and revenue sharing contract in two-echelon supply chains.

Looking at the global electronics market, there is one particular industry where reverse supply chains are being created and coordinated among businesses and where little attention has been addressed in literature, namely the personal computers (PC) industry. PCs are a commodity in the developed countries with a lifespan of 2–5 years. As a consequence, and for economic benefits, the industry receives increased consideration at all levels, from the government and PC manufacturers to individual PC users.

According to the industry and centered on the available reverse supply chains, the recycled products take various paths. Based on its functionality state, a PC can enter one of the four channels presented in Fig. 1.

Devices that are no longer useful for the owner can be offered for *resale* in the secondhand PC market or through internet auctions (eBay). There are some original equipment manufacturers (OEMs) such as Dell Computers and Apple Inc. who collect old

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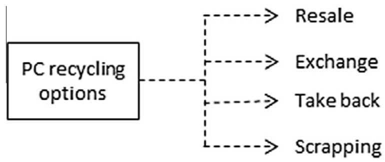

Fig. 1. Recycling channels for PCs.

products when a customer purchases a new product, thus providing the opportunity for *exchange*. Others (Hewlett–Packard) offer a coupon for further purchases or free services in exchange for a used PC: hence, *take back*. Finally, if the devices are of no further use, they are separated into component parts and recycled to enter new production systems: *scrapping*. According to the particular country's legislation, recycling channels can be under state control (California), under the manufacturer's responsibility (United States), or with diverse responsibility known as free market system (Europe).

Based on Fig. 1, it is relevant for the contracting literature to conduct an analysis of the supply chain under the situation where old products return to the OMG for recapturing value, refurbishing, and reselling on the market. Therefore, attention in this study is directed on the *take back* channel under the assumption that for each recycled PC with remanufacturing value, OMG offers the final customer a discount for a new purchase in the form of coupon to be used with its retailers.

As a new contribution to the existing literature, the intention of this article is to *propose an analytical model to observe the implications of coordination by contracts on the two-echelon and three-echelon reverse supply chain and on the profit of the supply chain members*. Correspondingly, the main objectives of the research are to:

– Identify appropriate coordination contracts to be analyzed given the situation described in Section 1.
– Define the PC recycling supply chain, to be the foundation for generating the analytical model.
– Design specific profit functions of the supply chain members (two-echelon and three-echelon reverse supply chains).
– Derive and find limitations for the decision variables considered for profit evaluation.
– Observe model behavior and profit implications by the applicability of a numerical example.

The study was solely conducted through desk research with the proposed analytical model being verified through applicability on a numerical example and by means of Excel computations.

The article is structured as follows: Section 2 looks at the literature review on coordination contracts applied on forward and reverse supply chains; Section 3 presents the analytical model; Section 4 defines a numerical example and a discussion based on results, and the general conclusions and model drawbacks, along with suggestions for further research, are presented in Section 5.

2. Related literature

Optimal supply chain performance can be achieved if participants in the cooperative game coordinate their efforts and use contractual incentives so that all participants' objectives are aligned with the objectives of the supply chain (Cachon, 2003). These incentives are imposed by the implementation of coordination contracts such as wholesale price, buy back, revenue sharing, quantity flexibility, sales rebate, and quantity discount. General approaches to these coordination contracts can be found in Malone and Crowston (1994) and Cachon (2003, 2004). Recent reviews of coordination contracts and contracting literature on the forward supply chain are available in Albrecht (2010) and Höhn (2010).

Regarding performance improvement brought to the supply chain by coordination contracts, some studies were conducted to analyze coordination contracts by comparison. Gerchak and Wang (2004) analyze revenue sharing contracts versus wholesale price contracts. Cachon and Lariviere (2005) and Wang et al. (2007) look at performance improvement brought by buy back and revenue sharing contracts, while Höhn (2010) studies the implementation of buy back and quantity flexibility contracts. With a focus on wholesale price, buyback, revenue sharing, and quantity flexibility settings, Arshinder et al. (2009) offers a performance measure evaluation with regard to a decentralized setting within two-level supply chains. Under the consideration of three-level supply chains, Arshinder et al. (2009a) presents an evaluation of wholesale price, buy back, and quantity flexibility in relation to the decentralized case and in terms of performance measures improvement. Kannan et al. (2012) investigates a series on contracts applied on the two-echelon supply chain and indicates that revenue-sharing contracts offer the highest profit margins for the manufacturer.

Based on these studies, it was observed that a revenue sharing contract performs very well in terms of profit improvement under coordination and brings the highest benefit to the manufacturer. For this reason, we direct our attention to the literature that addresses coordination by implementation of a revenue sharing contract.

There are numerous studies focusing on revenue sharing analysis on the forward two-echelon supply chains. Some recent studies that investigated the behavior of revenue sharing under specific settings are presented by Kunter (2012) with a focus on consumer demand simultaneously affected by price and non-price variables, Krishnan and Winter (2011) on a dynamic incentive model under competition, and Wang et al. (2008) on the implications of fuzzy variables, while Cachon and Lariviere (2005) look at contract strengths and limitations, and Giannoccaro and Pontrandolfo (2009) examine the negotiation approach.

Referring to the multi-echelon setting, Van der Rhee et al. (2010) studies advantages that all pairs of adjacent entities have under revenue sharing and stochastic demand in a linear supply chain, Ji et al. (2007) analyzes a three-stage supply chain and cost structure implications on the total profit, and Giannoccaro and Pontrandolfo (2004) look at the contract parameters in a three-echelon supply chain under both decentralized and centralized settings. Chen (2006) looks at the free riding problem under the consideration of productive effort, risk aversion, and incentive intensity.

With respect to coordinating contracts with applicability on reverse supply chains, some studies were conducted to meet supply chain coordination objectives (cost and risk reduction and/or profit maximization) but they did not particularly focus on coordination contracts. Among the incentives used to coordinate the reverse supply chain, a deposit refund with impact on quality, quantity, and timing of the returns seem the most preferred approach among researchers. Some of the studies that focus on these considerations may be found in Palmer and Walls (1997), Guide and Jayaraman (2000), and Savaskan and Wassenhove (2006). Furthermore, Guide and Wassenhove (2001) developed a framework with the scope of analyzing returns brought by remanufacturing, Dobos and Richter (2004) investigate supply chain implications of buyback costs in a production-recycling system, and Mostard and Teunter (2006) analyze newsboy problem with resalable returns. Atasu and Subramaniyan (2012) looks at the implications of collective and individual producer responsibility on product recovery and profits and on consumer surplus in the presence of competition; Ferguson et al. (2006) looks at supply chain profit improve-

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ment as a consequence of reducing the number of false failure returns and using a target rebate contract approach.

A particular approach to coordination contracts is presented by Shi and Bian (2009); it analyzes the aspects of revenue sharing and quantity discount contracts in a two-echelon closed loop supply chain and reveals that by contract implementation and elimination of double marginalization, the closed loop supply chain achieves coordination. Another recent study conducted by Wang (2009) shows that coordination can be broken by various events. In this aspect, the author proposes an adjusted revenue sharing contract with anti-disruption ability as an optimal strategy for the closed loop supply chain. Other studies that analyze revenue sharing contracts on the two-echelon supply chain within the reverse logistics setting include Shi and Bian (2011) on closed loop with government subsidy and Xiao et al. (2011) on the remanufacturing problem under product quality.

Although some attempts were made on developing recycling models for coordinating the two-echelon supply chains – with contracts – within different industries, limited research was undertaken on studying these implications within the coordination of multi-echelon reverse supply chains, i.e., Cai (2011) and Yi and Wang (2011).

Based on (1) the revenue sharing contract offering the highest benefit to the manufacturer on the forward supply chain setting (Kannan et al., 2012), (2) the limited contracting literature on the reverse logistics, and (3) the increasing attention addressed to the PC industry, it is perceived as essential to conduct a study that addresses the take back return path of PCs with remanufacturing value under two- and three-echelon supply chains. In Section 3 we propose an analytical model to accommodate these criteria and to derive the corresponding profit functions for each of the participants among the reverse supply chain activities.

3. Analytical model

Obsolete PC devices that are not resold in the secondhand market, exchanged, or scrapped enter the take back path for remanufacturing purposes. In creating the model we assume that the recycling process takes place through a closed loop supply chain where the goods return to the manufacturer using the same distribution chain similar to the one used to sell goods, the forward supply chain, as visualized in Fig. 2.

Using a drop-off collection mode (Atasu and Souza, 2011), the retailer collects PC's from users and sends them down the supply chain. The distributor receives the PCs from the retailer and forwards them to the manufacturer who, in turn, refurbishes and sells them. The refurbished devices are to be sold through different supply chains via Internet pages or through a manufacturer's own retail stores.

3.1. Model description

The analytical model was designed using an event sequence scheme. To address the objectives of this paper, we introduce parameters taken into consideration along with their representative notations and model simplifying assumptions. Based on this, we generate the expressions for profit functions for the members of the two- and three-echelon reverse supply chains. In both cases we first look at the decentralized case followed by the coordinated case under a revenue sharing contract, as visualized in Fig. 3.

Under the decentralized case scenario, the retailer acts in his own interest so that his own profit is maximized, disregarding other members of the reverse supply chain. He collects PCs with remanufacturing value and, in return, offers the customer an optimal discount for further purchases. The devices are sold for a wholesale price, higher than the discount offered to the customer, down the supply chain. In the three-echelon supply chain, the distributor buys the devices from the retailer and sells them to the manufacturer.

Coordination by a revenue sharing contract implies that the retailer collects devices with remanufacturing value and offers an optimal discount to the customer so that the total supply chain profit is maximized. Contrary to the decentralized case, under coordination, the retailer is acting for the benefit of the entire supply chain and not for maximizing his own profit. Collected devices are shipped down the supply chain for a recycling fee lower than the wholesale price applied in the decentralized case.

Under both decentralized and coordinated cases, the PCs are subject to inspection with the retailer. At the manufacturers' site, the devices undergo a second inspection where the devices that do not meet remanufacturing standards are disposed of (Fig. 2). After a re-manufacturing process, the PCs are sold and returns are generated. With a revenue sharing contract the benefit is shared with other members of the supply chain.

After specifying the profit functions, the next sequence involves model testing, where a numerical example is applied to evaluate the implications on the profit functions under the decentralized case and under coordination by the revenue sharing contract.

The recycling system presented in Fig. 2 includes multiple participants at each level of the supply chain. To proceed with the analytical model, we propose two simplified supply chains consisting of one retailer and one PC manufacturer for the two-echelon reverse chain and of one retailer, one distributor, and one PC manufacturer for the three-echelon reverse chain, as visualized in Fig. 4. With regard to the two-echelon supply chain, the collected devices are transferred directly from retailer to manufacturer; there are no intermediaries. In the three-echelon supply chain, the distributor is an active member in the chain, adding margin in the decentralized case and taking a fraction of the revenue in the coordinated setting.

Following the analytical model and the proposed simplified supply chains, we first introduce simplifying notations and the decision variables considered in generating the profit functions and the assumptions behind the model, followed by the profit representations in the second part of Section 3.1.

3.1.1. Notations

The terms used to generate profit functions and their representative simplifying notations for all supply chain members are as follows:

The retailer (R):

- W: customers' willingness to return used PCs expressed as function of the discount value offered by the retailer (d_c): $W = f(d_c)$ where $0 < f(d_c) < 1$;
- E: the number of eligible units for return (the number of units that have the potential to enter the take back path – as fraction of total sales);
- w_r: the recycling fee received by the retailer from the distributor/manufacturer for each unit with remanufacturing value;
- c_{ri}: inspection cost at retailer;
- ϑ: acceptance rate at retailer (as fraction of E);
- c_{rh}: handling cost at the retailer (including storage cost);
- c_{rs}: shipping cost from retailer to distributor (three-echelon).

The distributor (D) – for three-echelon consideration only:

- w_d: recycling fee received by the distributor from the manufacturer for each unit with remanufacturing value;
- c_{dh}: handling cost at distributor;
- c_{ds}: shipping cost from distributor to manufacturer.

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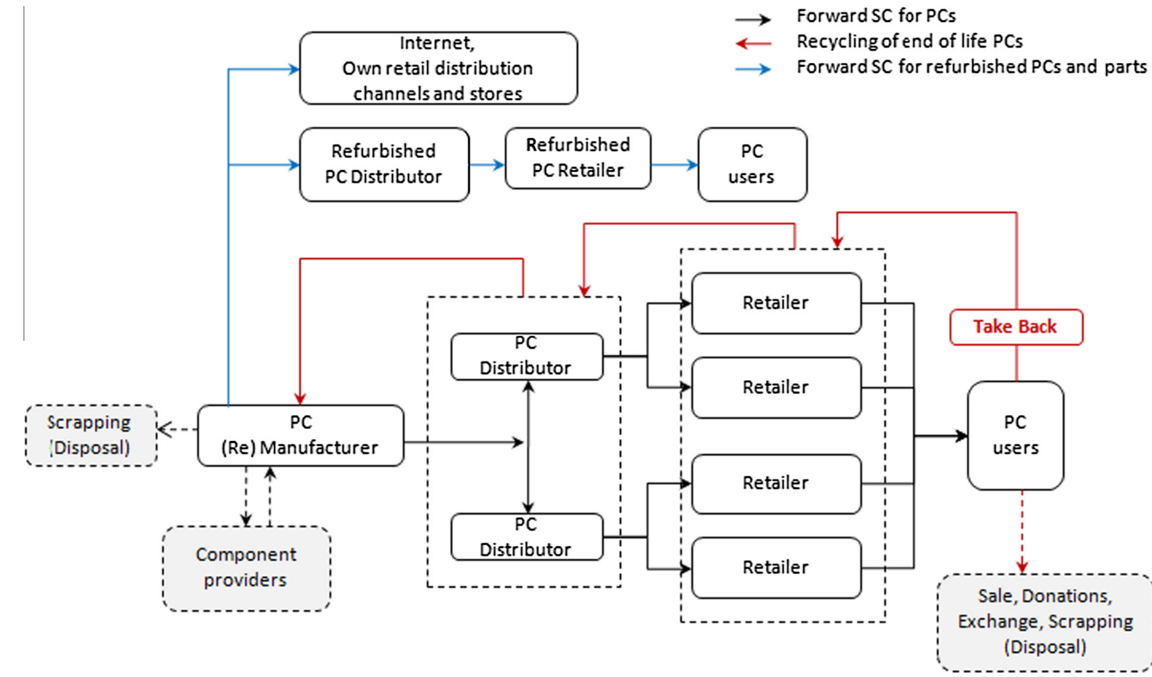

Fig. 2. PC recycling supply chain.

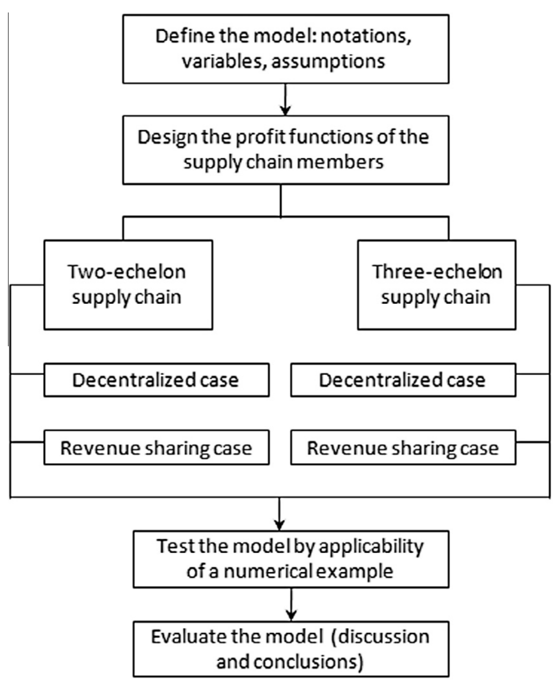

Fig. 3. Analytical model.

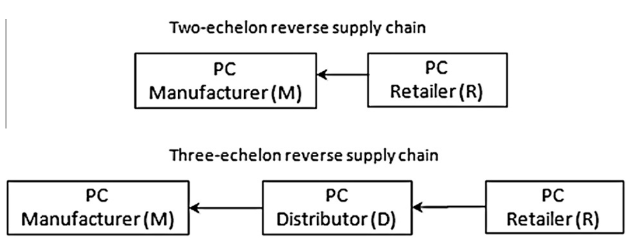

Fig. 4. Simplified reverse supply chain.

The manufacturer (M):

- Q: sales quantity of new devices realized by the retailer during one period (considered for computation of E);
- ω: recovery rate (the percentage of devices that can enter the remanufacturing process as part of ϑ);
- P: selling price of refurbished devices;
- c_{mf}: refurbishing/remanufacturing cost;
- c_{mi}: inspection/sorting cost;
- c_{md}: disposal cost for devices not selected for refurbishment;
- c_d: recycling fee to distributor (two-echelon only).

Decision variables for the decentralized case:

- d_c^r: optimal discount offered to the customer by the retailer in exchange for recycling units with remanufacturing value (non-coordination).

Decision variables for the revenue sharing case:

- d_c^C: optimal discount offered to the customer by the retailer for recycling devices with remanufacturing value (coordination);
- α : fraction of the total revenue allocated to the manufacturer;
- β: fraction of the total revenue allocated to the distributor (three-echelon only);
- γ: fraction of the total revenue allocated to the retailer (three-echelon only) and with $\alpha + \beta + \gamma = 1$;
- w_r': discounted recycling fee received by the retailer from the distributor/manufacturer and $w_r' \leqslant w_r$;
- w_d': discounted recycling fee received by the distributor from the manufacturer and $w_d' \leqslant w_d$ (three-echelon only).

3.1.2. Assumptions

In creating the model, we have defined and considered the following assumptions:

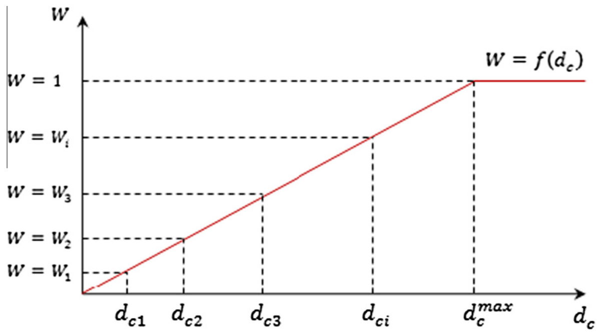

Fig. 5. Linear distribution of the willingness to return.

– The time frame considered is one planning horizon with only one return shipment made by each member.
– The quantity to be shipped is subject to inspection, and only units that qualify for reuse are accepted by the retailer; in return for recycling these units, the user is offered a discount for future purchases.
– The manufacturer has unlimited capacity to refurbish all recycled devices.
– All devices refurbished by the manufacturer are sold.
– Under revenue sharing consideration, the revenue generated at the manufacturers is shared by all members.

3.2. *Profit functions and decision variables*

Following the analytical model described in this section along with notations, decision variables, and simplifying assumptions, we design the profit formulas of the reverse supply chain members for two-echelon and three-echelon settings.

3.2.1. *Two-echelon setting*

(a) Decentralized case
The profit functions of the manufacturer and the retailer are:

- Manufacturer's profit = Sales revenue – Recycling fee paid to the retailer – Remanufacturing cost – Disposal cost – Inspection/Sorting cost – Contribution cost to distributor

$$P_m^D = P\omega QW\vartheta - w_r QW\vartheta - c_{mf}\omega QW\vartheta - c_{md}(1-\omega)QW\vartheta - c_{mi}QW\vartheta - c_d QW\vartheta \quad (1)$$

- Retailer's profit = Recycling fee received from manufacturer – Discount offered to the customer – Inspection cost – Handling cost – Shipping cost to manufacturer

$$P_r^D = w_r QW\vartheta - d_c QW\vartheta - c_{ri}QW - c_{rh}QW\vartheta - c_{rs}QW\vartheta \quad (2)$$

Under the decentralized supply chain setting, the retailer tries to maximize his own profit and chooses the value of the discount to be offered to customers accordingly. To find this optimal discount value that maximizes retailer's profit, we assume that the customer's willingness to return takes a linear distribution as presented by Eq. (3)[2] and which is visualized in Fig. 5.

$$W = f(d_c) = \begin{cases} \frac{d_c}{d_c^{max}}, & 0 < d_c < d_c^{max} \\ 1, & d_c > d_c^{max} \end{cases} \quad (3)$$

By replacing the willingness to return with its equivalent linear function, making the derivative of retailer's profit according to d_c and equaling the equation to zero, the optimal discount to be offered to the customer can be expressed as presented below.

Retailer's profit based on linear willingness to return is:

$$P_r^D = w_r Q\frac{d_c}{d_c^{max}}\vartheta - Q\frac{d_c^2}{d_c^{max}}\vartheta - c_{ri}Q\frac{d_c}{d_c^{max}} - c_{rh}Q\frac{d_c}{d_c^{max}}\vartheta - c_{rs}Q \times \frac{d_c}{d_c^{max}}\vartheta \quad (4)$$

The derived optimal customer discount formula for the decentralized reverse supply chain is:

$$d_c^r = \frac{w_r - c_{rh} - c_{rs} - {}^{c_{ri}}/\vartheta}{2} \quad (5)$$

(b) Coordination by revenue sharing contract
In the coordinated case, the discount offered to the customer maximizes the entire supply chain profit (unlike the decentralized case where only the retailer's profit ix maximized). The optimal discount to be offered to the customer can be derived from total supply chain profit ($P_{SC}^C = P_m + P_r$) following the same procedure as in the decentralized case.

$$P_{SC}^C = P\omega Q\frac{d_c}{d_c^{max}}\vartheta - c_{mf}\omega Q\frac{d_c}{d_c^{max}}\vartheta - c_{md}(1-\omega)Q\frac{d_c}{d_c^{max}}\vartheta - c_{mi}Q \times \frac{d_c}{d_c^{max}}\vartheta - c_d Q\frac{d_c}{d_c^{max}}\vartheta - Q\frac{d_c^2}{d_c^{max}}\vartheta - c_{ri}Q\frac{d_c}{d_c^{max}} - c_{rh}Q\frac{d_c}{d_c^{max}}\vartheta - c_{rs}Q\frac{d_c}{d_c^{max}}\vartheta \quad (6)$$

The derived optimal customer discount equation for the coordinated reverse supply chain is:

$$d_c^C = \frac{P\omega - c_{mf}\omega - c_{md}(1-\omega) - c_{mi} - c_d - c_{rh} - c_{rs} - {}^{c_{ri}}/\vartheta}{2} \quad (7)$$

The profit functions of the manufacturer and the retailer under coordination by revenue sharing contract are:

- Manufacturer's profit = Share of sales revenue – Discounted recycling fee paid to the retailer – Remanufacturing cost – Disposal cost – Inspection/Sorting cost – Distributor fee
$$P_m^{RS} = \alpha(P\omega QW^C\vartheta) - w_r' QW^C\vartheta - c_{mf}\omega QW^C\vartheta - c_{md}(1-\omega)QW^C\vartheta - c_{mi}QW^C\vartheta - c_d QW^C\vartheta \quad (8)$$

- Retailer's profit = Share of sales revenue realized by manufacturer + Discounted recycling fee received from manufacturer – Discount offered to the customer – Inspection cost – Handling cost – Shipping cost to manufacturer
$$P_r^{RS} = (1-\alpha)(P\omega QW^C\vartheta) + w_r' QW^C\vartheta - d_c^C QW^C\vartheta - c_{ri}QW^C - c_{rh}QW^C\vartheta - c_{rs}QW^C\vartheta \quad (9)$$

From a coordination perspective, it makes sense for the retailer to accept a revenue sharing contract only if the profit generated through coordination is higher than the profit obtained in the decentralized case. From $P_r^{RS} \geqslant P_r^D$ we can obtain the value of α as a function of the recycling fee offered by manufacturer to the retailer:

$$\alpha \le \frac{W^C(P\omega + w_r' - d_c^C) - W(w_r - d_c^r) - (W^C - W)(c_{rh} + c_{rs} + c_{ri}/\vartheta)}{P\omega W^C} = \alpha^{max} \quad (10)$$

The supply chain profit realized through coordination is equal to the supply chain profit obtained in the decentralized case plus a surplus from coordination (S): $P_{SC}^{RS} = P_{SC}^D + S$. Under the consideration that

[2] Approach also considered by Bai (2009) in designing a two-level reverse supply chain.

the surplus is equally shared among supply chain members, we have: $P_r^{RS} = P_r^D + S/2$ and $P_m^{RS} = P_m^D + S/2$.

By extrapolation of the shared surplus, the optimal fraction of the revenue is:

$$\alpha = \alpha^{max} - \frac{S}{2\alpha^{max}(P\omega QW^C\vartheta)} \tag{11}$$

From Eq. (10) it can be observed that the fraction of the revenue α has a direct, linear relation with the discounted recycling fee charged by the retailer w'_r. The higher the recycling fee charged by the retailer, the higher the share retained by the manufacturer from the total revenue.

3.2.2. Three-echelon setting

(a) Decentralized case

The profit functions of the three-echelon reverse supply chain members in the decentralized case are:

- Manufacturer's profit = Sales revenue – Recycling fee paid to distributor – Remanufacturing cost – Disposal cost – Inspection/Sorting cost

$$P_m^D = P\omega QW\vartheta - w_dQW\vartheta - c_{mf}\omega QW\vartheta - c_{md}(1-\omega)QW\vartheta - c_{mi}QW\vartheta \tag{12}$$

- Distributor's profit = Recycling fee received from manufacturer – Recycling fee paid to the retailer – Handling cost – Shipping cost to manufacturer

$$P_d^D = w_dQW\vartheta - w_rQW\vartheta - c_{dh}QW\vartheta - c_{ds}QW\vartheta \tag{13}$$

- Retailer's profit = Recycling fee received from distributor – Discount offered to the customer – Inspection cost – Handling cost – Shipping cost to distributor

$$P_r^D = w_rQW\vartheta - d_cQW\vartheta - c_{ri}QW - c_{rh}QW\vartheta - c_{rs}QW\vartheta \tag{14}$$

Similar to the two-echelon setting, when the supply chain is not coordinated the retailer tries to maximize his own profit. From Eq. (14) we can derive the optimal discount to be offered by retailer to the customer. The discount takes the same optimal value as presented in Eq. (5): $d_c^r = \frac{w_r - c_{rh} - c_{rs} - c_{ri}/\vartheta}{2}$.

(b) Coordination by revenue-sharing contract

In the coordinated three-echelon setting, the discount offered to the customer maximizes the entire supply chain profit. The optimal discount formula can be derived from total supply chain profit by following the same procedure as that used for the two-echelon setting.

Total supply chain profit is $P_{SC}^C = P_m + P_d + P_r$ and, under linear distribution of the willingness to return, it takes the form:

$$P_{SC}^C = P\omega Q\frac{d_c}{d_c^{max}}\vartheta - c_{mf}\omega Q\frac{d_c}{d_c^{max}}\vartheta - c_{md}(1-\omega)Q\frac{d_c}{d_c^{max}}\vartheta - c_{mi}Q\frac{d_c}{d_c^{max}}\vartheta - c_{dh}Q\frac{d_c}{d_c^{max}}\vartheta - c_{ds}Q\frac{d_c}{d_c^{max}}\vartheta - Q\frac{d_c^2}{d_c^{max}}\vartheta - c_{ri}Q\frac{d_c}{d_c^{max}} - c_{rh}Q\frac{d_c}{d_c^{max}}\vartheta - c_{rs}Q\frac{d_c}{d_c^{max}}\vartheta \tag{15}$$

The derived optimal customer discount formula for the coordinated reverse supply chain is:

$$d_c^C = \frac{P\omega - c_{mf}\omega - c_{md}(1-\omega) - c_{mi} - c_{dh} - c_{ds} - c_{rh} - c_{rs} - c_{ri}/\vartheta}{2} \tag{16}$$

Under the revenue sharing contract, revenue generated by the manufacturer is to be shared among supply chain members. In this paper, revenue shares are allocated on a spanning approach (Van der Rhee et al., 2010) where each member of the chain takes a fraction of the revenue realized by the manufacturer (as opposed to a pair-wise approach where the distributor is allocated a fraction of the revenue generated by the manufacturer and shares it with the retailer).

The representative profit functions of the members are:

- Manufacturer's profit = Share of sales revenue – Discounted recycling fee paid to the retailer – Inspection/Sorting cost – Remanufacturing cost – Disposal cost – Distributor's fee

$$P_m^{RS} = \alpha(P\omega QW^C\vartheta) - w'_dQW^C\vartheta - c_{mf}\omega QW^C\vartheta - c_{md}(1-\omega)QW^C\vartheta - c_{mi}QW^C\vartheta \tag{17}$$

- Distributor's profit = Share of sales revenue realized by manufacturer + Discounted recycling fee received from the manufacturer – Discounted recycling fee paid to the retailer – Handling cost – Shipping cost to manufacturer

$$P_d^{RS} = \beta(P\omega QW^C\vartheta) + w'_dQW^C\vartheta - w'_rQW^C\vartheta - c_{dh}QW^C\vartheta - c_{ds}QW^C\vartheta \tag{18}$$

- Retailer's profit = Share of sales revenue realized by manufacturer + Recycling fee received from the manufacturer – Discount offered to the customer – Inspection cost – Handling cost – Shipping cost to distributor

$$P_r^{RS} = \gamma(P\omega QW^C\vartheta) + w'_rQW^C\vartheta - d_c^CQW^C\vartheta - c_{ri}QW^C - c_{rh}QW^C\vartheta - c_{rs}QW^C\vartheta \tag{19}$$

Under similar consideration of each member gaining more from cooperation and equal share of cooperative supply chain surplus, the optimum extrapolated revenue share fractions are:

$$\alpha = \alpha^{max} - \frac{2S}{3\alpha^{max}(P\omega QW^C\vartheta)} \tag{20}$$

$$\beta = \beta^{min} + \frac{S}{3\alpha^{max}(P\omega QW^C\vartheta)} \tag{21}$$

$$\gamma = \gamma^{min} + \frac{S}{3\alpha^{max}(P\omega QW^C\vartheta)} \tag{22}$$

where

– From

$$P_d^{RS} \geq P_d^D \rightarrow \beta \geq \frac{(W^C - W)(c_{dh} + c_{ds}) - W^C(w'_d - w'_r) + W(w_d - w_r)}{P\omega W^C} = \beta^{min} \tag{23}$$

.

– From

$$P_r^{RS} \geq P_r^D \rightarrow \gamma \geq \frac{(W^C - W)(c_{rh} + c_{rs} + c_{ri}/\vartheta - W^C(w'_r - d_c^C) - W(w_r - d_c)}{P\omega W^C} = \gamma^{min} \tag{24}$$

.

– And from $\alpha + \beta + \gamma = 1 \rightarrow \alpha^{max} = 1 - \beta^{min} - \gamma^{min}$.

Table 1
Input data.

Retailer	Distributor	Manufacturer
$E = 0.80Q$	$w_d = 0.35$	$Q = 4130$
$w_r = 0.30$	$c_{dh} = 0.01$	$w = 89\%$
$d_c^{max} = 0.16$	$c_{ds} = 0.03$	$P = 0.8$
$c_{ri} = 0.02$		$c_{mf} = 0.27$
$\vartheta = 70\%$		$c_{mi} = 0.22$
$c_{rh} = 0.03$		$c_{md} = 0.15$
$c_{rs} = 0.07$ (two-echelon)		$c_d = 0.06$
$c_{rs} = 0.02$ (three-echelon)		

From Eqs. (23) and (24) it is observed that there is a direct linear relation between the fractions of the revenue and the discounted recycling fees charged by the distributor and the retailer α, β, γ and w'_r, w'_d. The higher the recycling fee charged by the distributor and the retailer, the higher the share retained by the manufacturer from total revenue.

The behavior of the analytical model proposed in this section for the decentralized and for coordination by revenue sharing cases – for both two-echelon and three-echelon supply chains – is observed by applying a numerical example, presented in detail in Section 4.

4. Numerical example

For the numerical example we consider the case of Apple Inc. At present, Apple Inc. collects used devices from customers in return for a coupon to be used to purchase another Apple product directly from the Apple website or from Apple retail stores. In this section we extend and accommodate the current Apple Inc. procedure to fit the model proposed in Section 3.

Under the above considerations and based on the actual sales generated by Apple, in the first quarter of 2011, of 4.13 million Macs[3] and an average retail price per unit of 997 EUR (1408 USD),[4] the data used in this numerical example represents estimations of what real data might indicate. After the introduction of the input data, we proceed to present and to discuss the results.

4.1. Data and decision variables

The data used for validation of the analytical model in thousands units (TU) and in thousand monetary units (TMU) are presented in Table 1.

Regarding the decision variables, the values resulted from Excel computations for maximum supply chain profit and a fair benefit sharing are as presented in Table 2. The optimal discount values were obtained by applying Eqs. (5), (7), and (16) to the numerical data. In the same manner, Eqs. (11) and (20-22) were applied to obtain shares of the revenue for the manufacturer, distributor, and retailer, where it is observed that the manufacturer retains the highest fraction of the total supply chain profit under both two- and three-echelon settings. In our example, the discounted recycling fees received by the distributor and by the retailer under coordination are considered to be 33% of the given total recycling fee of 0.35 TU and respectively 0.30 TU. This percentage is generally agreed through negotiation between the partners.

4.2. Results and discussion

The analytical model developed in Section 3 was applied on the proposed numerical example taking into consideration decision variables calculated in Table 2. The results are presented in Table 3, for both two-echelon and three-echelon reverse supply chains.

It is observed that in both settings, the willingness to return increases considerably from the decentralized case to coordination by the revenue sharing case. This increase occurs as a consequence of offering supply chain optimal discount to the customers at coordination (0.135 and 0.14) against the customer discount value offered in the decentralized case (0.086 and 0.111), where the retailer tries to maximize his own profit. This increase also generates higher profits for the supply chain members.

Under the two-echelon setting, implementation of revenue sharing contract generates a total supply chain performance improvement of 35.418 TMU (15.5%), with an increase in both manufacturers' and retailer's profits. In the revenue sharing case, by retaining only a fraction of the total benefit, the manufacturers' revenue decreases, but is compensated by the smaller recycling fee paid to the retailer. The discounted recycling fee in the retailer's case is covered by the share of the revenue received from the manufacturer. All the other costs (inspection, refurbishing, disposal, handling, and shipping) increase in value from non-coordination to coordination due to the increase in the customer's willingness to return products.

The improvement in supply chain performance under coordination by revenue sharing contract against the decentralized case within the three-echelon setting is 12.579 TMU (4.6%). However, while profits of the distributor and retailer improve at coordination, by sharing the realized revenue with the other supply chain members, the profit of the manufacturer comes down 0.753 TMU. This loss can be eliminated if the manufacturer retains a higher share of the total revenue.

The introduction of the distributor in the three-echelon reverse supply chain plays an important role. In the two-echelon setting, transactions take place directly between retailer and the manufacturer with no intermediaries. In the three-echelon supply chain, however, the distributor takes on the role of an intermediary between retailer and the manufacturer and brings a significant decrease to the shipping cost of the retailer.

Having the distributor as part of the recycling process generates a higher total performance improvement for the retailer and the manufacturer in the decentralized three-echelon setting than the decentralized two-echelon setting (255.603 versus 228.861) with a bigger portion of the profit going to the retailer (177.184 TMU).

Based on the numerical example and as shown by the graphic representation of the total supply chain profit distribution (Fig. 6), under the revenue sharing contract, the manufacturer prefers to deal directly with the retailer (two-echelon supply chain). The retailer and the distributor are better off if they participate in the three-echelon supply chain and coordination by revenue sharing contract.

4.2.1. Sensitivity analysis

Looking at the factors influencing the discount value to be offered to the customer and the total supply chain profit, it is observed that refurbishing cost plays a major role as it is the highest cost in the recycling process. To conduct the sensitivity of the recycling discount based on the variation of the refurbishing cost, we use a set of input combinations ranging from 0.15 to 0.35. The results for all four cases considered for analysis are presented in Table 4.

The results indicate that discount value decreases with increase of refurbishment cost under coordination by revenue sharing contract, while under the decentralized cases it remains constant. The factor influencing discount value is the retailer trying to maximize his own profit. The values in this case are obtained by considering only the profit function of the retailer, with no consideration of the

[3] Source: Apple First Quarter Results extracted from http://www.apple.com/pr/library/2011/01/18results.html.

[4] Source: http://news.cnet.com/8301-13579_3-10149060-37.html.

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Table 2
Decision variables.

		Optimal discount	Manufacturer's share of the revenue	Distributor's share of the revenue	Retailer's share of the revenue	Discounted recycling fee – distributor	Discounted recycling fee – retailer
Two-echelon	Decentralized case	0.086	–	–	–	–	–
	Coordination by revenue sharing $(\alpha, \alpha - 1)$	0.135	0.638	–	0.362	–	0.100
Three-echelon	Decentralized case	0.111	–	–	–	–	–
	Coordination by revenue sharing (α, β, γ)	0.140	0.619	0.054	0.327	0.117	0.100

Table 3
Overview of the results.

	Two-echelon		Three-echelon	
	Decentralized	RS	Decentralized	RS
Willingness to return	0.536	0.845	0.692	0.876
Returned units	1239.000	1954.523	1600.375	2026.798
Manufacturer				
Revenue realized	792.960	797.706	1024.240	802.583
Recycling fee	371.700	195.452	560.131	236.460
Inspection cost	27.258	42.999	35.208	44.590
Remanufacturing cost	267.624	422.177	345.681	437.788
Disposal cost	3.717	5.864	4.801	6.080
Distributor				
Share of the revenue	0	0	0	69.962
Recycling fee	0	0	80.019	33.780
Handling cost	0	0	16.004	20.268
Shipping cost	0	0	48.011	60.804
Retailer				
Share of the revenue	0	453.188	0	424.605
Recycling fee	371.700	195.452	480.113	202.680
Customer's discount	106.200	264.279	177.184	284.186
Inspection cost	35.400	55.844	45.725	57.909
Handling cost	37.170	58.636	48.011	60.804
Shipping cost	86.730	136.817	32.008	40.536
Manufacturer's PROFIT	122.661	131.214	78.418	77.665
Distributor's PROFIT	0	0	16.004	22.670
Retailer's PROFIT	106.200	133.065	177.184	183.851
Total SC PROFIT	228.861	264.279	271.607	284.186

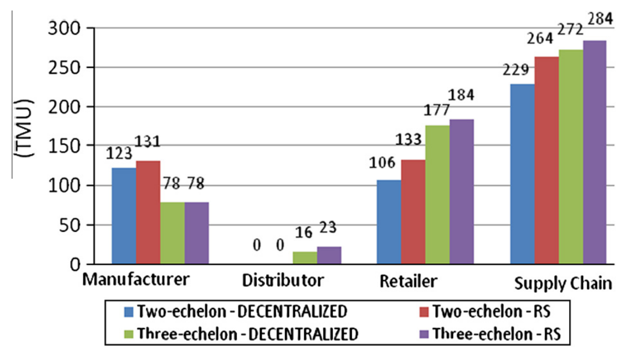

Fig. 6. Distribution of total supply chain profit.

Table 4
Optimal recycling discount under the variation of refurbishing cost.

c_{mf}	d_c			
	Two-echelon decentralized	Two-echelon coordinated	Three-echelon decentralized	Three-echelon coordinated
0.15	0.086	0.183	0.111	0.188
0.17	0.086	0.175	0.111	0.180
0.19	0.086	0.167	0.111	0.172
0.21	0.086	0.159	0.111	0.164
0.23	0.086	0.151	0.111	0.156
0.25	0.086	0.143	0.111	0.148
0.27	0.086	0.135	0.111	0.140
0.29	0.086	0.127	0.111	0.132
0.31	0.086	0.119	0.111	0.124
0.33	0.086	0.111	0.111	0.116
0.35	0.086	0.103	0.111	0.108

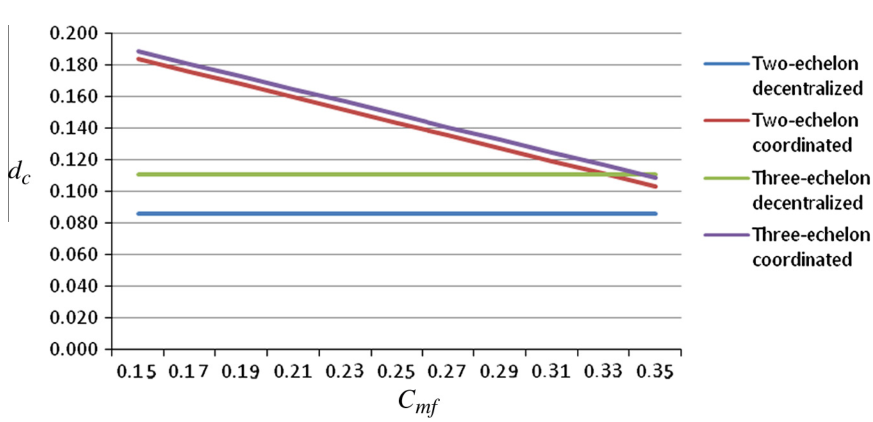

Fig. 7. Sensitivity of recycling discount due to refurbishment cost.

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profit function of the manufacturer. The variation of recycling discount is visualized in Fig. 7. Furthermore, due to the nature of the recycling discount function (Eqs. (5), (7) and (16)), the same variation pattern can be obtained by fluctuating any of the terms adopted for calculations.

The sensitivity of the recycling discount due to the refurbishment cost has a further impact on the revenue sharing fractions, where the manufacturer will retain a higher percentage of the total revenue with the increase of the refurbishment cost, as shown in Table 5.

Following the variations generated by the proposed set of input values for the refurbishment cost on the recycling discount and on revenue sharing fractions, the total supply chain profit function diverges as represented in Fig. 8. Due to the constant recycling discount offered to the customers in the decentralized case, the profit function has a decreasing trend with an increasing refurbishment cost value. Under coordination, total supply chain profit increases with the increase of the recycling discount up to the value generated by the optimal recycling discounts. When it reaches the value resulting from computations based on optimal values, profit decreases as the recycling discount increases (due to negative impact on the retailer's profit).

Overall, the results from the numerical example show that the implementation of a revenue sharing contract can generate significant returns for the coordinated reverse supply chain in relation to the decentralized case in both two-echelon and three-echelon settings. The profits of the individual supply chain members keep improving under coordination, along with a higher discount offered by the retailer for returned devices and an increased willingness from the customer's side to return products.

Table 5
Revenue sharing fractions under the variation of refurbishment cost.

C_{mf}	Revenue sharing fraction			
	Two-echelon coordinated	Three-echelon coordinated		
	α (%)	α (%)	β (%)	γ (%)
0.15	60.50	60.50	3.80	35.60
0.17	61.00	60.70	4.20	35.10
0.19	61.50	60.80	4.60	34.60
0.21	62.00	61.00	4.80	34.10
0.23	64.30	61.30	5.10	33.60
0.25	63.10	61.50	5.27	33.20
0.27	63.70	61.90	5.40	32.70
0.29	64.40	62.20	5.46	32.29
0.31	65.10	62.70	5.44	31.90
0.33	65.90	63.20	5.30	31.50
0.35	64.50	63.70	5.10	31.10

5. Conclusions

This study is the first to direct attention towards the analysis of the supply chain performance measures under coordination by revenue sharing contract on the three-echelon reverse supply chain. The paper proposes an analytical model to support its objectives related to both centralized and decentralized cases in two respective three-echelon reverse supply chains. An examination of the PC industry's take back/drop-off collection mode, the two-stage (retailer–manufacturer) and three stage (retailer–distributor–manufacturer) reverse supply chains, where each member is constrained to perform the following activities was investigated: the retailer inspects the devices to be refurbished, collects and stores accepted devices for a predefined period of time, and ships them to the downstream supply chain; the distributor is responsible to retrieve the devices from the retailer and to send them to the manufacturer; the manufacturer inspects and sorts the devices for remanufacturing and, if necessary, for proper disposal. Further, the revenue generated at manufacturer from the sale of refurbished PCs is shared with the other members of the supply chain under the coordination by revenue sharing contract. Based on benefits and costs associated with each activity and on the simplifying assumptions, the profit functions and decision variables have been defined for both the decentralized and coordinated cases.

The proposed model has been tested by applicability on a numerical example. The results establish that supply chain coordination does improve performance measures of participants under the cooperative game and increases total supply chain profit. Further:

- Significant returns are realized for all supply chain members given the optimal discount offered to the customer and the retained fractions of the revenue.
- In both supply chain settings, performance improves from the decentralized case to coordination by the revenue sharing case. The introduction of the distributor into the setting affects the profit of the manufacturer such that, under the three-echelon setting, he shares the revenue with two participants, as opposed to sharing it with only one participant in the two-echelon setting. Yet, under current globalized markets the distributor is a key player in the supply chain as he takes on the role of collecting devices from multiple retailers and shipping them to the manufacturer.

The presented model performs well under current setting and offers a positive outcome. However, the model is limited by the assumptions made in designing the supply chain settings and profit formulas. The constraints imposed by the model can be relaxed to same degree, and seen from a theoretical standpoint, the model

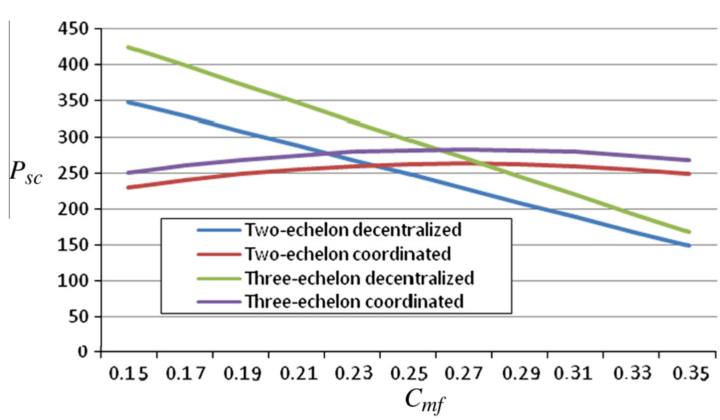

Fig. 8. Variation of the profit functions.

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is open for further research and development. In this respect, some of the suggestions to be considered are:

– As this research focuses on the reverse chain within a closed loop setting, possible extensions can be done by incorporating the forward supply chain into the analysis or by considering open loop supply chains and 3PRL.

– Consideration of the 'PC manufacturer – Component providers' link included in Fig. 2. Some of the topics to be covered here are: the impact on the bottom line of the component provider, the implications of having new parts incorporated in refurbished products or component provider's role in assisting in the refurbishing process.

– The revenue generated is shared based on a spinning approach. The results can be also computed to reflect the implications of a pairwise revenue sharing approach.
– As this research is solely based on desk research, more realistic results can be obtained by field research (i.e., a survey used to determine a user's willingness to return, based on different retailer discount ranges or on the use of a numerical example with input data collected from the industry).
– Consideration of the pick-up, collection mode or the approach of the stochastic collection mode.
– Consideration of the closed-loop supply chain for selling the refurbished devices. Would this cannibalize sales of new products?
– Some interesting questions to be tackled include: How does a zero value of the discount offered by retailer to customer affect a customer's willingness to return (linear/non-linear function) and what implication does this have on individual and total supply chain profits? How should the manufacturer increase the number of collected devices to generate profitable returns? Does the willingness to return increase because owning a PC has become a commodity?
– Related to contracting literature, the model can be further extended to incorporate different coordination contracts or models and parallel analysis in performance improvement terms between revenue sharing and other proposed models.
– In addition to the above mentioned practical, economical, and theoretical implications, the research also triggers attention on the social implications PC manufacturing and PC recycling have on the industry. For good functioning of the supply chain, better efforts must be made to establish well-grounded reverse logistics, to increase awareness, and to educate the final customer about PC recycling. in the long run, this approach would generate new challenges for the involved parties, new functional positions within the recovery operations area, and would ultimately reduce the environmental impact.

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References

Albrecht, M., 2010. Supply Chain Coordination Mechanisms: New Approaches for Collaborative Planning, Lecture Notes in Economics and Mathematical Systems, vol. 628. Springer-Verlag, Berlin, Heidelberg.
Arshinder, Kanda, A., Deshmukh, S.G., 2009. A framework for evaluation of coordination by contracts: a case of two-level supply chains. Computers & Industrial Engineering 56, 1177–1191.
Arshinder, Kanda, A., Deshmukh, S.G., 2009a. A coordination theoretic model for the three level supply chains using contracts. Sadhana 34 (5), 767–798.
Atasu, A., Souza, G.C. 2011. How does Product Recovery Affect Quality Choice? Production and Operations Management, forthcoming.
Atasu, A., Subramanian, R. 2012. Extended Producer Responsibility for E-Waste: Individual or Collective Producer Responsibility?. Production and Operations Management, 21 (6), 1042–1059.
Bai, H., 2009. Reverse Supply Chain Coordination and Design for Profitable Returns – An Example of Ink Cartridge. Unpublished Master Thesis. Worcester Polytechnic Institute.
Cachon, G.P., 2003. Supply chain coordination with contracts. In: Graves, S.C., de Kok, A.G. (Eds.), Handbooks in Operations Research and Management Science: Supply Chain Management: Design, Coordination and Operation, vol. 11. North-Holland, Amsterdam, pp. 227–339.
Cachon, G.P., 2004. The allocation of inventory risk in a supply chain: push, pull and advance-purchase discount contracts. Management Science 50 (2), 222–238.
Cachon, G.P., Lariviere, M., 2005. Supply chain coordination with revenue sharing contracts: strengths and limitations. Management Science 51 (1), 30–44.
Cai, C., 2011. Quantity discounts contract coordination model of three-stage closed-loop supply chain under retailer price competition. In: Proceedings of the IEEE International Conference on Transportation, Mechanical, and Electrical Engineering, December 16–18, Changchun, China, pp. 195–199.
Chen, J., 2006. Study of revenue sharing contract in virtual enterprises. Journal of Systems Science and Systems Engineering 15 (1), 95–113.
Dobos, I., Richter, K., 2004. An extended production/recycling model with stationary demand and return rates. International Journal of Production Economics 90 (3), 311–323.
Ferguson, M., Guide, V.D., Souza, G.C., 2006. Supply chain coordination for false failure returns. Manufacturing and Service Operations Management 8 (4), 376–393.
Gerchak, Y., Wang, Y., 2004. Revenue-sharing versus wholesale-price contracts in assembly systems with random demand. Production and operations Management 13 (1), 23–33.
Giannoccaro, I., Pontrandolfo, P., 2004. Supply chain coordination by revenue sharing contracts. International Journal of Production Economics 89, 131–139.
Giannoccaro, I., Pontrandolfo, P., 2009. Negotiation of the revenue sharing contract: an agent-based systems approach. International Journal of Production Economics 122 (2), 558–566.
Guide Jr., V.D.R., Jayaraman, V., 2000. Product acquisition management: a framework and current industry practice. International Journal of Production Research 38, 3779–3801.
Guide Jr., V.D.R., Wassenhove, L.N.V., 2001. Managing product returns for remanufacturing. Production and Operations Management 10 (2), 142–155.
Guide Jr., V.D.R., Jayaraman, V., Linton, J.D., 2003. Building contingency planning for closed-loop supply chains with product recovery. Journal of Operations Management 21, 259–279.
Höhn, M.I., 2010. Relational Supply Contracts, Lecture Notes in Economics and Mathematical Systems, vol. 629. Springer-Verlag, Berlin Heidelberg.
Ji, S.F., Liu, M.J., Han, L.J., 2007. The three-stage supply chain coordination by revenue-sharing contracts. In: Proceedings of the IEEE International Conference on Grey Systems and Intelligent Services, November 18–20, 2007, Nanjing, China, pp. 1216–1220.
Kannan, G., Diabat, A., Popiuc, M.N., 2012. Contract analysis: a performance measures and profit evaluation within two-echelon supply chains. Computers and Industrial Engineering 63 (1), 58–74.
Krishnan, H., Winter, R.A., 2011. On the role of revenue-sharing contracts in supply chains. Operations Research Letters 39 (1), 28–31.
Kumar, N., Guide Jr., V.D.R., Wassenhove, L.N.V., 2002. Managing Product Returns at Hewlett Packard, Teaching Case 05/2002-4940. INSEAD.
Kunter, M., 2012. Coordination via cost and revenue sharing in manufacturer–retailer channels. European Journal of Operational Research 216 (2), 477–486.
Malone, T.W., Crowston, K., 1994. The interdisciplinary study of coordination. ACM Computing Surveys 26 (1), 87–119.
Mostard, J., Teunter, R., 2006. The newsboy problem with resalable returns: a single period model and case study. European Journal of Operational Research 169 (1), 81–96.
Nagurney, A., Toyasaki, F., 2005. Electronic waste management and recycling: a multitiered network equilibrium framework for e-cycling. Transportation Research 41, 1–28.
Palmer, K., Walls, M., 1997. Optimal policies for solid waste disposal: taxes, subsidies, and standards. Journal of Public Economics 65 (3), 193–205.
Savaskan, R.C., Wassenhove, L.N.V., 2006. Reverse channel design: the case of competing retailers. Proceedings of Management Science 2006, 1–14.
Shi, C., Bian, D., 2009. Closed-loop supply chain coordination by revenue sharing contract and quantity discount contract. In: 2009 International Conference on Information Management, Innovation Management and Industrial Engineering, December 26–27, 2009, Xian, China, vol. 2. ICIII, pp.581–584
Shi. C., Bian, D., 2011. Closed-loop supply chain coordination by contracts under government subsidy. In: Proceedings of the IEEE International Conference on Control and Decision, May 23–25, 2011, Mianyang, China, pp. 2747–2750.
Toktay, B., Wein, L., Stefanos, Z., 2000. Inventory management of remanufacturable products. Management Science 46, 1412–1426.
Van der Rhee, B., Van der Veen, J., Venugopal, V., Vijayender, R.N., 2010. A new revenue sharing mechanism for coordinating multi-echelon supply chains. Operations Research Letters 38, 296–301.

Wang, Y., 2009. Closed-loop supply chain coordination under disruptions with revenue-sharing contract. Chinese Journal of Management Science 17 (6), 78–83.

Wang, Z., Yao, D.Q., Huang, P., 2007. A new location inventory policy with reverse logistics applied to B2C e-markets of China. International Journal of Production Economics 107 (2), 350–363.

Wang, J., Zhao, R., Tang, W., 2008. Supply chain coordination by revenue sharing contract with fuzzy demand. Journal of Intelligent & Fuzzy Systems 19 (6), 409–420.

Xiao, T., Yang, D., Shen, H., 2011. Coordinating a supply chain with a quality assurance policy via a revenue-sharing contract. International Journal of Production Research 49 (1), 99–120.

Yi, J., Wang, S., 2011. Optimal contract design of reverse supply chain considering uncertain recycle price. In: Proceedings of the IEEE International Conference on E-Business and E-Government, May 6–8, 2011, Shanghai, China, pp. 1–4.

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