How the Reverse Channel Strategy is Affected by EPR Policies and Asymmetric Information

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Abstract

In the waste electrical and electronic equipment (WEEE) collection, the manufacturer can select reverse channel strategies between third-party-managed collection (Model 3P) and retailer-managed collection (Model R). However, he has to face up with collector's collection cost information asymmetry (IA), and the implementation of Extended Producer Responsibility (EPR) policies. We first derive, in closed forms, the optimal contracts for Model R and 3P, in joint consideration of EPR and IA. Meantime, we find complementary effect between IA and EPR. Our subsequent model comparison illustrates how to optimally select the mode of business, i.e. Retailer collection or collection by 3rd Party. The former is preferred if the manufacturer faces up with stricter EPR policies. If the magnitude of IA is higher, the latter would be a better option, because third party collection is less sensitive to IA but more sensitive to the EPR policies. Moreover, the presence of IA boosts the retail price and lower the demand due to the decrease of collection rate, while the EPR policies have just opposite effects on price and demand. Hence, the price, demand and collection rate all depend on the comparison between the magnitude of IA and EPR.

Keywords
reverse logistics; incentive contracts; EPR policies; reverse channel strategy

1. Introduction

Rapid development of information society and steadily growing consumption of electrical and electronic equipment (EEE) worldwide lead to increasing amounts of wasted electrical and electronic equipment (WEEE). Collection, recycling and remanufacturering for WEEE play a central role in sustain environmental-friendly industries. In different regions of the world, e.g., Europe, US, regulations, policies, and collection and recovery systems based on extended producer responsibility (EPR) have been implemented. In 2010, China's National Development and Reform Commission (CNDRC) announced that Chinese government will pay special attention to the development of remanufacturing industry [1]. Later, China has enacted similar legislations known as China WEEE and China RoHS to further direct WEEE collection and remanufacturing [2]. Recently, two types of EPR laws has been compared, collective producer responsibility (CPR) or individual producer responsibility (IPR) [3]. Li et.al. [4] make a comparison between the two from the perspective of whole supply chain governance.

In current practice, we find a variety of reverse channel strategies being deployed by manufacturers. A commonly seen scenario is that the majority of collecting operations are performed by others. As a representative case, Kodak receives single-use cameras returned from its retailers and recycles 76% of them in the manufacturing of new ones [5]. Meanwhile, it is also common industry practice to subcontract with a third-party in the operation of collection programs. For instance, in Europe, specialized firms are subcontracted by Dell Corporation to collect used computer equipment [6]. In China, Apple sponsors an independent recycling firm, named Li Tong Recycle, for collecting the used Apple branded electronic products and equipment [7]. The Kodak case could be referred as retailer-managed collection, while the practices of Dell and Apple can be termed as third-party managed collection. To make collection more accessible, traditional offline-recycling channel has been transformed into online recycling channel (refer to www.aihuishou.com) [8]. In practice, Changhong Green Group Company Limited has collected electronic wastes through both offline and online recycling channels [9]. Besides, there exists in many developing countries both informal and formal recycling sectors, of which the informal channel is usually more active and scatters in every corner of the country. Guiyu town, located in southern China and regarded as one of the largest informal recycling center in the world, has a population about 100,000 people engaging in daily informal recycling activities [10]. Widmer et al. [11] report that in India, the "Cyber City" of Bangalore is threatened by a rapidly increasing amount of e-waste where the informal sectors have caused serious harm to the health of the workers.

Thus, our goal in this study is to understand when a manufacturer would prefer Model 3P or R under both EPR policies and asymmetric information. Furthermore, it is more interesting to investigate the relationship between the EPR policies and information asymmetry.

2. Review of the Literature

The literature on reverse logistics and CLSC abounds. The present paper is particularly related to three streams of literature. First, the literature of reverse channel strategy is pertinent to our study. Savaskan et al. [12] study the strategies problems where three options of collection are analyzed and the retailer-managed collection is dominant over manufacturer-managed collection and 3P-managed collection. Optimal reverse channel strategy with single manufacturer competing retailers scenario is further extended in Savaskan and Van Wassenhove [5]. Unlike [12], the collection cost in our paper is treated as the private information of the collecting agent (either retailer or third party); in addition, we also study the EPR policies. Some other papers focus on the comparison of different channel design strategies. For instance, Hong and Yeh [13] suggest that retailer collection not always superior to non-retailer collection in the reverse supply chain. In the context of third-party remanufacturing mode selection, Zou et al. [14] find that OEM reaps higher profit through outsourcing than through authorization. Along this line, some research focus on particular factors that determine the mode selection. For example, Atasu et al. [15] discusses the impact of collection cost structure on the optimal reverse channel strategy under the framework of [12]. In their work, collection cost is composed of operational cost and investment cost. Note that, collection cost is also one of key issues in our study. However, we mainly focus on cost information asymmetry, rather than cost structure.

Our paper is akin to the research on EPR policies. A growing body of literature studies the interface between operational decisions and the environment in the context of reverse channel. For instance, Atasu et al. [16] present a model under take-back legislation. The authors argue that the manufacturer is not able to see much incentive even though the WEEE legislation is aimed at creating incentives for environmentally friendly designs. Subramanian et al. [17] characterize the impact of various EPR levers on product design and supply chain coordination. They suggest that EPR policies require both the manufacturer and the consumer to bear environmental charges over the product's life cycle. Different types of EPR policies have also been discussed and contrasted in the literature. Atasu and Subramanian [3] compare the implications of collective and individual producer responsibility on manufacturers' design for product recovery mode and the resulting profits. Wang et al. [2] study responsibility sharing in WEEE collection between the collector and manufacturer, and identify a reward-penalty mechanism for the government to motivate industrial recycling endeavor. The EPR regulation is characterized in our paper, however, from the perspective of minimum collection rate.

Another area of research related to our study is the incentive contract design in the reverse channel. Wei et al. [18] investigate the optimal decision problem of a closed-loop supply chain with symmetric and asymmetric information structures using game theory. Wang et al. [19] study the incentive buyback contract under a reward-penalty mechanism (RPM). Comparing with the case where RPM is not implemented, Wang et al. [19] show that the RPM can lower both the wholesale price and retail price, while raising the buyback price and quantity. Li et al. [20] and Zhang et al. [21] propose similar contract design problems for a manufacturer who only has incomplete information on the collector's cost. Different from our paper, Li et al. [20] do not take the forward channel into consideration , while Zhang et al. [21]does not incorporate the EPR policies. Combining [20] with [21], our study compares two reverse channel strategies under both EPR policies and information asymmetry (IA).

Overall, this paper makes the following contributions to the literature. We explore how the Extended Producer Responsibility (EPR) and information asymmetry (IA) jointly affect the contract design and mode selection of the reverse supply chain. We also analyze the effect of EPR and IA on the collection rate, retail price, and market demand. We also show that the effects of EPR and IA are complementary to each other.

3. Model

To focus on the effect of both EPR policies and information asymmetry on the collection channel strategy choice, we use a similar model as in Savaskan et al. [12]. We formulate and analyze two reverse channel strategies: (i) Model R, retailer-managed collection, the reverse channel with the retailer collecting used products (Figure 1(a)); (ii) Model 3P, 3P-managed collection, in which the manufacturer (he) contracts the collection to the 3P (she) (Figure 1(b)). In Figure 1, the solid line represents the direction of forward logistics while the dotted line indicates the direction of reverse logistics. We compare the models with respect to wholesale price, retail price, market demand, collection rate, collector's information rent, and manufacturer's expected profit.

(**a**) (**b**)

Figure 1. Two reverse channel strategies: (a) Retailer-managed collection; (b) 3P-managed collection.

3.1. Assumptions

1) Retailer faces a demand which can be characterized by a function $D(p)=\phi-p$, where $\phi>c_m$ represents the market size.
2) Let c_m denotes the unit cost of manufacturing a new product directly from raw materials, and c_r denotes the unit cost of remanufacturing a returned product into a new one. First, consumer could not distinguish the remanufactured product between the new product because of the advanced remanufacturing technology; second, let $\Delta=c_m-c_r>0$.
3) $\tau(0<\tau<1)$ denotes the collection rate of used products, which could be also interpreted as the fraction of current generation products remanufactured from returned units. Correspondingly, the total collection cost is given by $A\tau^2$, where A, investment cost coefficient, is the collector's private information. The collector, both the retailer under retailer-managed collection and the 3P under 3P-managed collection, can be either an efficient one with parameter A_L or an inefficient one with parameter A_H, in which $\beta=A_H-A_L>0$. The manufacturer does not exactly know the collector's type but only has a belief of her probability: α for the one to be efficient and $(1-\alpha)$ to be inefficient. Additionally, our attention is mainly paid to cost information asymmetry, so the same cost structure is assumed, no matter who manages the collection.
4) We consider that an EPR policies can be exerted according to which the manufacturer is obliged to have a minimum collection rate, θ. Namely, θ denotes the lower bound of collection rate.
5) The manufacturer proposes the same menu of contract $\{(T_L,\tau_L),(T_H,\tau_H)\}$ to both the retailer under retailer-managed collection and the 3P under 3P-managed collection.
The following notations apply throughout our paper.

p Retail price
w Wholesale price
ϕ Market size
c_m Unit cost of manufacturing a new product directly from raw materials
c_r Unit cost of remanufacturing a returned product into a new one
Δ Unit cost savings from remanufacturing

A_i Investment cost coefficient with type i, where $i = L, H$

β Magnitude of asymmetric information, where $\beta = A_H - A_L > 0$

β_0 IA threshold, for which the manufacturer could profit equally between strategies

θ Prescribed minimum collection rate

θ_0 EPR threshold, for which the manufacturer could profit equally between strategies

$\pi_{\bar{R}}$ Retailer's reservation profit

π_i^j Profit of the collector with type i when party j manages collection, where $i = L, H,\ j = R, 3P$

τ_i^j Collection rate of the collector with type i when party j manages collection

3.2. Model R——Retailer-managed collection

In this model, the retailer also engages in the promotion and collection of used products in addition to distributing new products. The profit of manufacturer and retailer is

$$\max_{w,\{\tau,T\}} \pi_M^R = (\phi - p)(w - c_m + \Delta\tau) - T\,;$$
$$\max_{p,\tau} \pi_R^R = T + (\phi - p)(p - w) - A\tau^2$$

The sequence of events is: (i) the manufacturer first proposes a menu of contracts $<(\tau_L, T_L), (\tau_H, T_H)>$, (ii) the retailer chooses the contract, then the manufacturer sets price w, and (iii) the retailer sets price p. We adopt a backward approach to solve it.

Retailer's problem at stage (iii) is to set price p to maximize her profit $\pi_R = T + (\phi - p)(p - w) - A\tau^2$.

Lemma 1 Under the contract (τ_i, T_i), the retailer's optimal price is $p_i(w_i) = (\phi + w_i)/2$; the demand is $d_i = (\phi - w_i)/2$; and the profit of the manufacturer is $\pi_M^R = (w_i - c_m + \Delta\tau_i)(\phi - w_i)/2 - T_i$ while the retailer's is $\pi_R = T_i + (\phi - w_i)^2/4 - A\tau_i^2$.

Given (τ_i, T_i) has been chosen by the retailer, the manufacturer's problem at stage (ii) is to set wholesale price w to maximize his profit $\pi_M^R = (w_i - c_m + \Delta\tau_i)(\phi - w_i)/2 - T_i$.

Lemma 2 Under the contract (τ_i, T_i), $w_i = (\phi + c_m - \Delta\tau_i)/2$ is the manufacturer's optimal wholesale price, $\pi_M = (\phi - c_m + \Delta\tau_i)^2/8 - T_i$, $\pi_R = T_i - A\tau_i^2 + (\phi - c_m + \Delta\tau_i)^2/16$ are the profit of manufacturer and retailer, respectively.

Accordingly, the manufacturer's problem at stage (i) is to determine the menu of contracts $<(\tau_L, T_L), (\tau_H, T_H)>$ by solving

$$\begin{aligned}
&\max_{\{\tau_L, T_L, \tau_H, T_H\}} \pi_M = \alpha\left((\phi + \Delta\tau_H - c_m)^2/8 - T_H\right) + (1-\alpha)\left((\phi + \Delta\tau_L - c_m)^2/8 - T_L\right)\\
&s.t. \quad T_L - A_L\tau_L^2 + (\phi + \Delta\tau_L - c_m)^2/16 \ge T_H - A_L\tau_H^2 + (\phi + \Delta\tau_H - c_m)^2/16\\
&\quad T_H - A_H\tau_H^2 + (\phi + \Delta\tau_H - c_m)^2/16 \ge T_L - A_H\tau_L^2 + (\phi + \Delta\tau_L - c_m)^2/16\\
&\quad T_L - A_L\tau_L^2 + (\phi + \Delta\tau_L - c_m)^2/16 \ge \pi_{\bar{R}}\\
&\quad T_H - A_H\tau_H^2 + (\phi + \Delta\tau_H - c_m)^2/16 \ge \pi_{\bar{R}}\\
&\quad 1 \ge \tau_H \ge \theta\\
&\quad 1 \ge \tau_L \ge \theta
\end{aligned} \tag{1}$$

We let $a_L^R := \dfrac{3\Delta(\phi - c_m)}{16A_L - 3\Delta^2}$, $a_H^R := \dfrac{3\alpha\Delta(\phi - c_m)}{16\beta + \alpha(16A_L - 3\Delta^2)}$, $T_H^{R*} = A_H {a_H^R}^2 - (\phi - c_m + \Delta a_H^R)^2/16 + \pi_{\bar{R}}$, $T_L^{R*} = A_L {a_L^R}^2 - (\phi - c_m + \Delta a_L^R)^2/16 + \pi_{\bar{R}} + \beta {a_H^R}^2$, then we can obtain the following proposition.

Proposition 1 (i) The optimal contract $<(\tau_L, T_L), (\tau_H, T_H)>$ is given by

(a) If $\theta \le a_H^R$, $\tau_L^R = a_L^R, T_L^R = T_L^{R*}, \tau_H^R = a_H^R, T_H^R = T_H^{R*}$;

(b) If $a_H^R < \theta \le a_L^R$, $\begin{cases} \tau_L^R = a_L^R \\ T_L^R = A_L {\tau_L}^2 - (\phi + \Delta\tau_L - c_m)^2/16 + \pi_{\bar{R}} + \beta\theta^2 \end{cases}$ and $\begin{cases} \tau_H^R = \theta \\ T_H^R = A_H\theta^2 - (\phi - c_m + \Delta\theta)^2/16 + \pi_{\bar{R}} \end{cases}$;

(c) If $\theta > a_L^R$, $\tau_H^R = \tau_L^R = \theta$, $T_H^R = T_L^R = A_H\theta^2 - (\phi - c_m + \Delta\theta)^2/16 + \pi_{\bar{R}}$;

(ii) If $\theta > a_H^R$, the EPR policies and IA have complementary effect.

Proposition 1(i) describes the impact of the EPR policies and IA on the incentive contracts. We can know $<(a_L^R, T_L^{R*}), (a_H^R, T_H^{R*})>$ is the optimal contract for the special case of $\theta = 0$, which simply indicates the effect of IA on the contract. Generally speaking, the type of contract depends on the prescribed minimum collection rate, θ. If θ is low, the situation is the same as that under no EPR policies, namely, the incentive contract is not influenced by the EPR policies; if θ is higher than the inefficient retailer's collection rate, the contract for inefficient one will be affected while the other won't. That is, the EPR policies will take effect until θ is high enough. Naturally, if θ is even higher than the efficient one's collection rate, the manufacturer will propose the same contract to both inefficient and efficient retailer, in which the collection rate is exactly the one prescribed by the EPR policies. To sum up, the impact of the EPR policies on the incentive contracts will increase in θ.

Proposition 1(ii) indicates the complementary effect between the EPR policies and IA when the EPR policies will have effect on the reverse channel. Accordingly, Corollary 1 shows the effect of asymmetry information and EPR policies on the reverse channel.

Corollary 1 We have $\tau_i^R = \max(a_i^R, \theta), i = L, H$ which is increasing in θ. Then

(i) Both $w_i^R(\tau_i^R)$ and $p_i^R(w_i^R)$ are decreasing in θ while $d_i^R(p_i^R)$ is increasing in θ;

(ii) If $\theta \ge a_L^R$, $\tau_H^R = \tau_L^R$, $w_H^R = w_L^R$, $p_H^R = p_L^R$, $d_H^R = d_L^R$;

(iii) Information rent $R^R = \beta(\max(a_H^R, \theta))^2$ is first invariant and then increasing in θ while the manufacturer's expected profit is first invariant and then decreasing in θ.

(iv) Information rent is first increasing and then decreasing with β while manufacturer's expected profit is decreasing with β;

Corollary 1(i) shows both the wholesale price and the retail price decrease in the prescribed minimum collection rate, θ, while the market demand is opposite. (ii) indicates if θ is high enough, the wholesale price for the efficient retailer will be in line with the inefficient one since both collection rate is the one prescribed by the EPR policies. The retail price set by the retailer and the market demand have the similar properties.

(iii) describes the impact of EPR policies. First, the retailer's information rent is first invariant since the lower prescribed minimum collection rate has no effect. More specifically, the rent will increase until θ is even higher than the inefficient retailer's collection rate. Second, manufacturer's profit will decrease in θ if θ is just higher than the inefficient retailer's collection rate. Since IA and EPR policies have complementary effect, the decrease of magnitude of IA will save manufacturer's profit. Thus, if the manufacturer has to bear a stricter EPR policy, he can choose a more familiar retailer due to lower magnitude of IA.

(iv) shows the impact of IA on the reverse channel. From the perspective of retailers, larger information uncertainty could not generate more information rent for the efficient retailer since collective rate of inefficient retailers is also decreasing in information uncertainty. However, from the manufacturer's perspective, IA is harmful to the manufacturer's profit. Similar to Corollary 1(iii), the manufacturer's profit could be saved by the decreased θ. Hence, if the manufacturer has to bear higher risk of information asymmetry, e.g. first cooperating with one retailer, he can select one region where the EPR policies are quite relax.

In summary, the complementary effect between IA and EPR has been specifically shown in (iii) and (iv) for just single reverse channel. Moreover, the complementary effect has also affected the comparison of reverse channel strategies, which will be argued in 3.4.

3.3. Model 3P——Third-party-managed collection

It is also not unusual to see the used-product collection activity contracted by the manufacturer to a third party, who is engaged only in the collection of the used products from the market.

The profit of the manufacturer, the retailer, the 3P is

$$\max_{w,\{\tau,T\}} \pi_M^{3P} = (\phi - p)(w - c_m + \Delta\tau) - T;$$

$$\max_{p} \pi_R^{3P} = (\phi - p)(p - w);$$

$$\max_{\tau} \pi_R^{3P} = T - A\tau^2$$

The sequence of events is: (i) the manufacturer first sets price w and proposes a menu of contracts $<(\tau_L, T_L), (\tau_H, T_H)>$ to the 3P, (ii) the 3P chooses the contract, and the retailer sets price p. We adopt a backward approach to solve it.

Retailer's problem at stage (ii) is to set price p to maximize her profit $\pi_R = (\phi - p)(p - w)$. Similar to Lemma 1, the retailer's optimal price is $p(w) = (\phi + w)/2$. Given (τ_i, T_i) has been chosen by the 3P, the manufacturer's problem at stage (i) is to set wholesale price w to maximize his profit $\pi_M^R = (w_i - c_m + \Delta\tau_i)(\phi - w_i)/2 - T_i$.

Lemma 3 Under the contract (τ_i, T_i), $w_i = (\phi + c_m - \Delta\tau_i)/2$ is the manufacturer's optimal wholesale price and the profit of manufacturer and 3P is $\pi_M = (\phi - c_m + \Delta\tau_i)^2/8 - T_i$, $\pi_{3P} = T_i - A\tau_i{}^2$, respectively.

Accordingly, the optimal contract from the manufacturer at stage (i) is characterized by

$$\begin{aligned} \max_{\{\tau_L, T_L, \tau_H, T_H\}} \pi_M &= \alpha\left((\phi + \Delta\tau_H - c_m)^2/8 - T_H\right) + (1-\alpha)\left((\phi + \Delta\tau_L - c_m)^2/8 - T_L\right) \\ s.t.\quad & T_H - A_H\tau_H{}^2 \ge T_L - A_H\tau_L{}^2 \\ & T_L - A_L\tau_L{}^2 \ge T_H - A_L\tau_H{}^2 \\ & T_H - A_H\tau_H{}^2 \ge 0 \\ & T_L - A_L\tau_L{}^2 \ge 0 \\ & 1 \ge \tau_H \ge \theta \\ & 1 \ge \tau_L \ge \theta \end{aligned} \tag{2}$$

We let $a_L^{3P} := \dfrac{\Delta(\phi - c_m)}{8A_L - \Delta^2}$, $a_H^{3P} := \dfrac{\alpha\Delta(\phi - c_m)}{8\beta + \alpha(8A_L - \Delta^2)}$, $T_H^{3P*} = A_H a_H^{3P^2}$, $T_L^{3P*} = A_L a_L^{3P^2} + \beta a_H^{3P^2}$, then we can obtain the following proposition.

Proposition 2 (i) The optimal contract $<(\tau_L, T_L), (\tau_H, T_H)>$ is given by

(a) If $\theta \le a_H^{3P}$, $\tau_L^{3P} = a_L^{3P}, T_L^{3P} = T_L^{3P*}, \tau_H^{3P} = a_H^{3P}, T_H^{3P} = T_H^{3P*}$;

(b) If $a_H^{3P} < \theta \le a_L^{3P}$, $\tau_L^{3P} = a_L^{3P}, T_L^{3P} = A_L\tau_L^{3P^2} + \beta\theta^2$ and $\tau_H^{3P} = \theta, T_H^{3P} = A_H\theta^2$;

(c) If $\theta > a_L^{3P}$, $\tau_H^{3P} = \tau_L^{3P} = \theta$, $T_H^{3P} = T_L^{3P} = A_H\theta^2$.

(ii) If $\theta > a_H^{3P}$, the EPR policies and IA have complementary effect.

By Proposition 2, we could also draw some conclusion similar to Corollary 1.

3.4. Comparison of the models

In this section, two reverse channel strategies are compared to understand the effect of EPR policies and information asymmetry (IA). To begin with, we consider two baseline cases, that is, no EPR policies case ($\theta = 0$) under asymmetric information ($\beta > 0$), EPR policies case ($\theta > 0$) under symmetric information ($\beta = 0$).

3.4.1 Case 1: EPR policies case ($\theta > 0$) under symmetric information ($\beta = 0$)

Let $\pi_M^R(\theta) = 3(\phi - c_m + \Delta\theta)^2 / 16 - A\theta^2 - \pi_{\bar{R}}, \pi_M^{3P}(\theta) = (\phi - c_m + \Delta\theta)^2 / 8 - A\theta^2$, we can draw Corollary 2.

Corollary 2 Let θ_0 be the solution of $\pi_M^R(\theta) = \pi_M^{3P}(\theta)$. If $\theta \geq \theta_0$, $\pi_M^R(\theta) \geq \pi_M^{3P}(\theta)$; If $\theta < \theta_0$, $\pi_M^R(\theta) < \pi_M^{3P}(\theta)$.

Corollary 2 shows that there exists a threshold, θ_0 , for which the manufacturer could profit equally between Model R and Model 3P. If the prescribed minimum collection rate exceeds the threshold, the manufacturer would prefer retailer-managed collection; otherwise, 3P-managed collection is optimal.

3.4.2 Case 2: No EPR policies case ($\theta = 0$) under asymmetric information ($\beta > 0$)

Let $\pi_M^R(\beta) = \frac{1}{2}(\frac{3A(\phi - c_m)^2}{16A_L - 3\Delta^2} + \frac{3(A_L + 2\beta)(\phi - c_m)^2}{16(A_L + 2\beta) - 3\Delta^2}) - \pi_{\bar{R}}$, $\pi_M^{3P}(\beta) = \frac{1}{2}(\frac{A(\phi - c_m)^2}{8A_L - \Delta^2} + \frac{(A_L + 2\beta)(\phi - c_m)^2}{8(A_L + 2\beta) - \Delta^2})$, we can draw Corollary 3.

Corollary 3 (i) Let β_0 be the solution of $\pi_M^R(\beta) = \pi_M^{3P}(\beta)$. If $\beta \geq \beta_0$, $\pi_M^R(\beta) \leq \pi_M^{3P}(\beta)$; if $\beta < \beta_0$, $\pi_M^R(\beta) > \pi_M^{3P}(\beta)$; (ii) The gap between the information rent of two strategies will be first increasing and then decreasing in β ; (iii) If $\beta \geq A_L / 4$, $\tau_H^{3P} < \tau_H^R < \tau_L^{3P} < \tau_L^R$; If $\beta < A_L / 4$, $\tau_H^{3P} < \tau_L^{3P} < \tau_H^R < \tau_L^R$, namely, $\tau_i^R > \tau_i^{3P}, i = L, H$, then $w_i^R < w_i^{3P}$, $p_i^R < p_i^{3P}$, $d_i^R > d_i^{3P}$.

Corollary 3 shows that retailer-managed collection would be dominated with the increase of magnitude of information uncertainty. From the perspective of the manufacturer, he could benefit more under 3P-managed collection when the magnitude of information uncertainty increases. On the other hand, (ii) shows the advantage of retailer-managed collection over 3P-managed collection on the information rent is decreasing with increase of magnitude of information uncertainty. Moreover, from the collection rate perspective, (iii) indicates collection rate of ineffective retailer will be dominated by that of effective 3P under 3P-managed collection with the increase of magnitude of IA. More specifically, the threshold of β is equal to $0.25A_L$.

3.4.3 Case 3: EPR policies case ($\theta > 0$) under asymmetric information ($\beta > 0$)

$$\text{Let } \pi_M^R(\theta, \beta) = \begin{cases} \frac{1}{2}(\frac{3A(\phi - c_m)^2}{16A_L - 3\Delta^2} + \frac{3(A_L + 2\beta)(\phi - c_m)^2}{16(A_L + 2\beta) - 3\Delta^2}) - \pi_{\bar{R}}, \theta \leq a_H^R; \\ \frac{1}{2}(\frac{3A(\phi - c_m)^2}{16A_L - 3\Delta^2} + \frac{3}{16}(\phi - c_m + \Delta\theta)^2 - (A_L + 2\beta)\theta^2) - \pi_{\bar{R}}, a_H^R < \theta < a_L^R; \\ 3(\phi - c_m + \Delta\theta)^2 / 16 - (A_L + 2\beta)\theta^2 - \pi_{\bar{R}}, \theta \geq a_L^R. \end{cases}$$

$$\pi_M^{3P}(\theta, \beta) = \begin{cases} \frac{1}{2}(\frac{A(\phi - c_m)^2}{8A_L - \Delta^2} + \frac{(A_L + 2\beta)(\phi - c_m)^2}{8(A_L + 2\beta) - \Delta^2}), \theta \leq a_H^{3P}; \\ \frac{1}{2}(\frac{A(\phi - c_m)^2}{8A_L - \Delta^2} + (\phi - c_m + \Delta\theta)^2 / 8 - (A_L + 2\beta)\theta^2), a_H^{3P} < \theta < a_L^{3P}; \\ (\phi - c_m + \Delta\theta)^2 / 8 - (A_L + 2\beta)\theta^2, \theta \geq a_L^{3P}. \end{cases}$$

Corollary 4 We have $\tau_i^j = \max(a_i^j, \theta), i = L, H, j = R, 3P$ which is increasing in θ . Then

(i) The gap between information rent of two strategies will be first invariant and then decreasing in θ . More specifically, the gap will be zero if $\theta > a_H^R$;

(ii)To a certain extent, θ_0 increases in β, and β_0 increases in θ.

Since both rents are related to collection rate of inefficient ones and prescribed minimum one, that is, $R^j = \beta(\max(a_H^j, \theta))^2, j = R, 3P$. Obviously, Corollary 4(i) shows both rents will be equal if θ exceeds the inefficient retailer's collection rate where both collection rate of inefficient collectors is the one prescribed by the EPR policies.

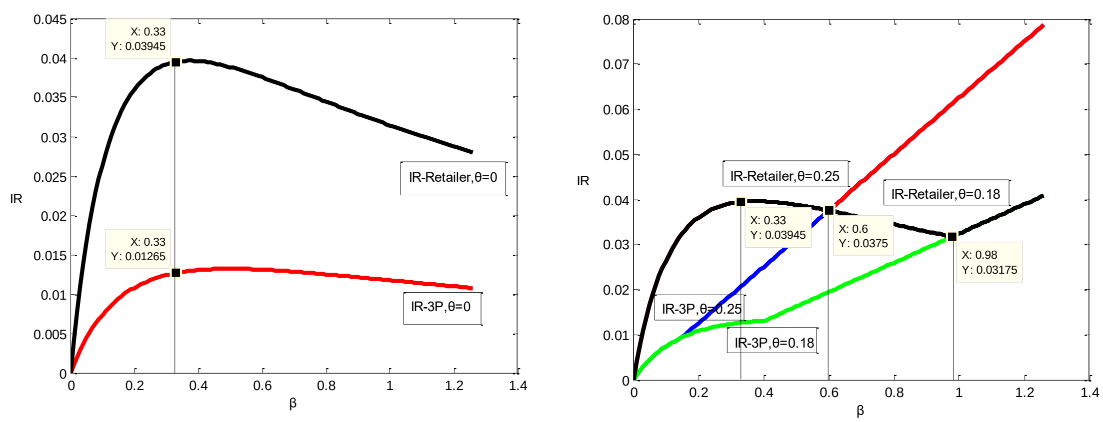
(ii) shows the complementary effect between IA and EPR on the reverse channel strategies selection. IA could enlarge EPR threshold, θ_0, meanwhile, EPR policies could also enlarge IA threshold, β_0. Since increasing β_0 is beneficial to retailer-managed collection, this indicates ERP policies are indirectly helpful to Model R.

4. Numerical investigation

In this section, to obtain more managerial insights about the impact of information asymmetry (IA) and EPR policies on the manufacturer's reverse channel strategy, numerical investigation would be presented. The parameters in common are as follows: $A_L = 1.5, c_m = 4.2, c_r = 2, \Delta = 2, \ \alpha = 0.5, \ \phi = 5.5, \ \pi_{\bar{R}} = 0.27, \beta \in [0,1.4]$.

4.1. Effect of IA and EPR on the information rent (IR)

Figure 2 shows the comparison of information rent under EPR policies. Corollary 1(ii), IR is first increasing and then decreasing with information uncertainty β, is shown in 2(a), and the retailer's IR under Model R is always higher than the one of 3P under Model 3P. 2(b) characterizes the effect of EPR on the IR. First, IR increases in the prescribed minimum collection rate, θ, and the increased proportion is also increasing with θ. We can conclude that a stricter EPR policy is beneficial to both collectors since they overtake the heavy task delegated by the manufacturer. Second, the 3P's IR is more sensitive to θ than the retailer's since the collection rate of inefficient collector under Model 3P is lower than Model R. Hence, the EPR policies are more beneficial to the 3P than the retailer so that the EPR policies can diminish the gap between the 3P's IR and the retailer's. And the gap is easier to be zero with the increase of θ.

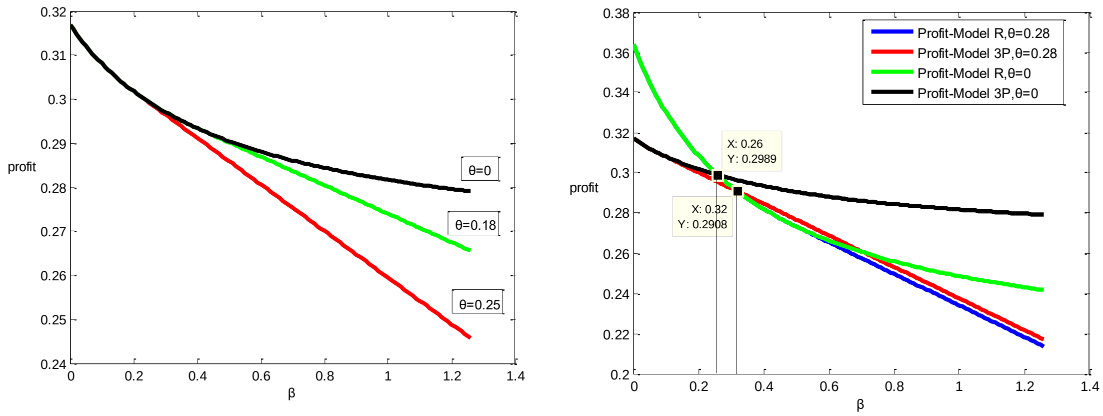


(a) **(b)**

Figure 2. Comparison of information rent under no EPR policies (a) and EPR policies (b).

4.2. Effect of IA and EPR on the manufacturer's expected profit

Figure 3 shows the comparison of manufacturer's expected profit under EPR and IA. 3(a) characterizes the effect of EPR and IA on the expected profit. Expected profit decreases in β, and the EPR policies boost the trend. The strong complementary effect has been shown. In addition, expected profit decreases in θ, and the decreased proportion is also increasing with θ. Clearly, both larger IA and stricter EPR policies is harmful to the manufacturer's profit. 3(b) numerically examines how the prescribed minimum collection rate, θ, and the information uncertainty, β, jointly affect the manufacturer's performance. First, the profit under both models decreases in β while the decrease under Model 3P is less than the one under Model R. Second, Model 3P is more sensitive to θ than Model R. Thus the EPR policies could diminish the gap of expected profit between models.

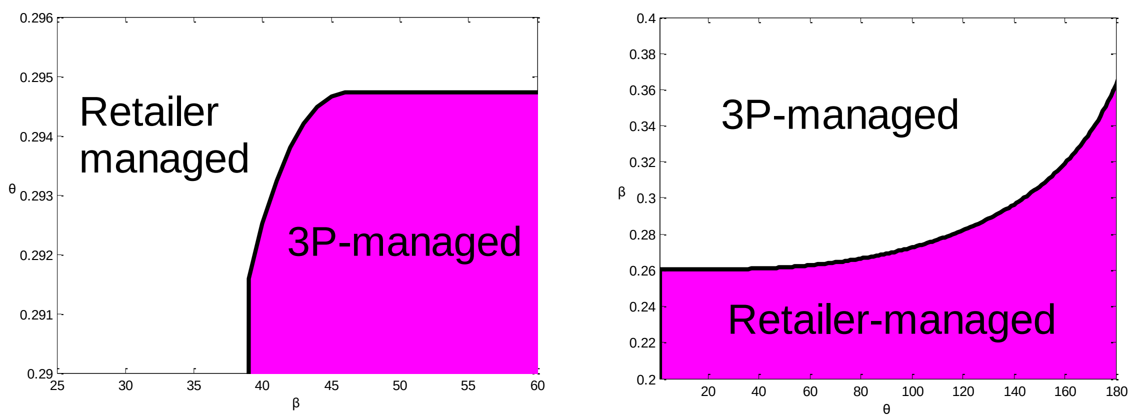


(a) **(b)**

Figure 3. Comparison of manufacturer's profit under EPR and IA. (a) Manufacturer's profit under Model 3P; and (b) Comparison of manufacturer's profit under EPR and IA.

In summary, without the EPR policies, if information uncertainty is low, the manufacturer prefers retailer-managed collection; otherwise, 3P-managed collection outperforms. Clearly, higher information uncertainty is beneficial to 3P-managed collection while the EPR policies will diminish the advantage of 3P-managed collection. So from the manufacturer perspective, a stricter EPR policy is beneficial to retailer-managed collection. This conclusion is just in line with above viewpoint by 4.1.

4.3. Effect of IA and EPR on the reverse channel strategies selection



(a) **(b)**

Figure 4. Comparison of reverse channel strategy: (a) Effect of IA on the EPR threshold; (b) Effect of EPR on the IA threshold.

Figure 4 shows the comparison of reverse channel strategy under EPR and IA. By 4(a) and 4(b), we can know if the prescribed minimum collection rate, θ, is high, Retailer-managed collection is preferred; if information uncertainty, β, is high, 3P-managed collection outperforms. By 4.1 and 4.2, it could be concluded which strategy the manufacturer would prefer depends on its sensitivity of IA or EPR. Namely, weak sensitivity implies low risk. More specifically, since the inefficient 3P's collection rate is lower than the inefficient retailer's, 3P-managed collection is more sensitive to θ. And a higher θ amplifies the property, then retailer-managed collection, less sensitive to θ, is preferred. β is similar.

In addition, IA and EPR have the strong complementary effect. Actually, there exist the threshold of both IA and EPR to be referred when the manufacturer chooses the reverse channel strategy. For instance, the line in Figure 4(a) is the EPR threshold which divides the figure into two parts. Above the line, retailer-managed collection is dominant; otherwise, 3P-managed collection is preferred. Figure 4(a) shows the effect of IA on the EPR threshold. In some range, EPR threshold, θ_0, increases in β. It implies that retailer-managed collection could be preferred under the stricter EPR policies with the increase of information uncertainty. This indirectly indicates higher information uncertainty is beneficial to 3P-managed collection. Likewise, as is shown in Figure 4(b), IA threshold, β_0, also increases in θ.

5. Conclusions

To investigate how to collect the used products in the reverse channel, this paper studies mode selection problems between 3P-managed collection (Model 3P) and retailer-managed collection (Model R) under both extended producer responsibility (EPR) policies and information asymmetry (IA). The main drivers for mode selection include: (i) EPR policies, which sets a minimum collection rate for the used product, and (ii) IA regarding the collection cost, in which the precise collection cost is not known by the manufacturer. More specifically, our model yields the following conclusions.

First, information asymmetry would boost the retail price and lower the demand due to the decrease of collection rate, while the EPR policies have exactly inverse effects on price and demand with increasing collection rate. Hence, the price, demand and collection rate all depend on the comparison between the magnitude of IA and EPR. Specifically, if IA exceeds some critical level, retailer-managed collection is no longer preferred from the aspect of collection rate.

Second, both IA and EPR help collectors cumulate higher information rent. Note that retailer's information rent is always higher than that of 3P without the EPR policies. Meanwhile, both information rent can be identical under EPR policies. As such, the presence of EPR policies adds advantage to Model 3P.

Third, on the contrary, from the manufacturer's standpoint, if he faces up with stricter EPR policies, Model R is preferred; on the other hand, if he has to bear higher risk due to asymmetric information, 3P-managed collection should be a better option. This stems from the fact that 3P-managed collection is less sensitive to IA while being more sensitive to the EPR policies. Compared to Model 3P, Model R, when selected by the manufacturer, lowers the retail price and raises the demand.

Finally, EPR policies and IA have complementary effect. Consequently, if the manufacturer faces up with a stricter EPR policy, he has to pick a more familiar collector, since lower magnitude of IA could save his more profit. Similarly, if the manufacturer is obliged to bear higher risk of information asymmetry, he has to seek for environments with weaker EPR policy for his business. Second, When IA scales up, it requires more EPR regulation for a manufacturer to switch to retailer-managed collection mode. When the EPR policy becomes tougher, the critical level of IA that shifts the business mode from retailer-managed to 3P-managed collection becomes increased

Three extensions to our research are worth investigation. First, the manufacturer can utilize the newly emerged collective producer responsibility (CPR) to support its collectors. Second, another extension could consider different cost settings (for example, 3P-managed collection has a cost advantage to retailer collection), or different proximity to the consumer (for example, retailer has more knowledge of the end market). At last, apart from the profits of supply chain entities (information rent and manufacturer's profit), the environmental impact (e.g. measured by carbon emission) caused by the two business modes (namely, retailer collection and 3rd party collection) can also be studied in contrast.

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