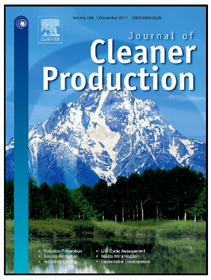

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A risk-averse marketing strategy and its effect on coordination activities in a remanufacturing supply chain under market fluctuation

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Research Highlights:

- A risk-averse marketing strategy is developed for a remanufacturing supply chain.
- The strategy considers coordination activities and two sources of uncertainties.
- Risk tolerance is used to define different risk attitude.
- The risk-averse strategy is insensitive to profit variations under heavier remanufacturing market fluctuation.

Abstract: The market fluctuation, usually caused by macro-economic shrinking/boom and ever-changing consumers' preferences/acceptance, brings a high managing challenge for remanufacturers and retailers' collection efforts and their coordination activities. Besides increasing profit, a market strategy also aims to reduce risk, i.e., profit variations. Thus, apart from the "maximum-profit" marketing strategy, this study tries to explore a risk-averse marketing strategy for a remanufacturer and a retailer in a remanufacturing supply chain. The proposed strategy satisfies the need of reducing risk of shortage/inventory under heavy remanufacturing market fluctuation. By adding the risk-averse factor into objective functions and using a concept of risk tolerance as a risk measurement, this paper investigates the effect of risk attitude for the remanufacturer and the retailer on remanufacturing quantity, expected profit and coordination activities. This paper finds that the proposed risk-averse marketing strategy brings more profit for both the remanufacturers and retailers than that for the "maximum-profit" marketing strategy in a heavier market fluctuation environment. Further, a coordination mechanism with risk attitude is designed and certain conditions are identified for inspiring the remanufacturer and the retailer to participate in supply chain contract coordination, which is of use for remanufacturing practitioners as well as academics. When the remanufacturer and the retailer develop their remanufacturing supply chain contracts in a heavier market fluctuation environment, the proposed strategy succeeds in balancing the expectation of benefits and the risk of market fluctuation. A truck engine remanufacturing case demonstrates that the risk-averse marketing strategy is relatively insensitive to market fluctuation.

Keywords: *Risk-averse marketing strategy; Remanufacturing supply chain; Coordination activity; Market fluctuation.*

1. Introduction

Remanufacturing is a desirable process for recovering resources from end-of-life products or components and extending their life cycles, and all enterprises in a remanufacturing supply chain intend to decrease negative environmental impacts (Bayindir et al., 2005; Wang et al., 2017). However, in the today's ever-changing business environment, the remanufacturing market fluctuation is evident, which brings a great challenge for enterprises in a remanufacturing supply chain to balance demand and supply. For example, due to the macroeconomic shrinking in 2015, sales of heavy trucks were sharply reduced by 26% in China. Demand fluctuation in the remanufacturing industry is substantially affected by consumers' preferences/acceptance towards remanufactured products and government incentives (Zhao et al., 2016). Given proper incentives by a remanufacturer, consumers would like to return products to supply the remanufacturing process and fulfil the demand in the high-degree fluctuating market.

Facing the high-degree fluctuating market, risk attitude of enterprises in a remanufacturing supply chain plays a significant role in their decisions for choices of a marketing strategy, especially under the market fluctuation environment. Remanufacturers develop different market strategies due to different risk attitudes. Under market fluctuation, both remanufacturers and retailers need to balance their expected profit and risk of shortage/inventory. Suppose risk attitude towards risk-averse rather than maximum-profit for both remanufacturers and retailers, following research questions need to be carefully examined:

1) How to measure their risk tolerance in a remanufacturing supply chain?

2) How to design or adjust their objectives rather than "maximum-profit" or "minimum-loss"?

3) Whether their coordination activities still work or not if their risk attitudes are changed?

4) How to design an appropriate coordination mechanism like a supply chain contract to

satisfy remanufacturing practitioners' need of risk consideration?

As a result, focusing on specific sources of market fluctuation, derived from the utility theory, many scholars have developed risk tolerance models to deal with this issue (Ge et al., 2016; Liu and Wang, 2015). Based on a definition of risk attitude by *Lau and Lau (1999)*, this study explores a risk-averse marketing strategy by adding the risk-averse factor into objective functions of remanufacturers and retailers.

Though more complicated risk-averse modeling papers exist, this paper has its unique research perspective and practical considerations. Compared to the existing literature regarding to end-of-life products acquisition and close-loop supply chain coordination, this paper, under the market fluctuation realistic consideration, focuses on the risk-averse contracting mechanisms issue (in the field of remanufacturing supply chain coordination) with multiple sources of uncertainties. Moreover, the proposed risk-averse marketing strategy and the further developed coordination mechanism cover multiple practical issues at the same time, including the remarketing issue regarding to shortage and lost sale consideration, the supply chain coordination issue between an end-of-life products collector (retailer) and a remanufacturer regarding to lack of contract regulation, and the uncertainties issue regarding to the fluctuating demand and the remanufacturability rate. Finally, based on the proposed risk-averse marketing strategy, the scientific value of this study lies in providing a feasible coordination mechanism under risk-averse consideration and identifying conditions for inspiring remanufacturers and retailers to participate in coordination of contract regulation, which helps to reduce the risk of remanufacturing shortage/inventory under heavy remanufacturing market fluctuation.

The rest of the paper is organized as follows. The next section presents a literature review. Section 3 first describes problems that remanufacturers and retailers face with respect to market fluctuation, and presents the risk-averse marketing strategy. Then at the end of Section 3 it derives model formulations related to the risk-averse marketing strategy. Section 4 analyzes the effect of the risk-averse marketing strategy on coordination activities with managerial implications. Section 5 provides a case about a remanufacturing truck engine supply chain. Section 6 concludes with future research directions.

2. Literature review

The supply chain players' risk consideration is of great necessity in practice, but it has been ignored in some of previous studies. For example, the well-known newsvendor problem allows manufacturers to quantify stocking and purchasing decisions, but this model is based on the assumption that the manufacturer is risk-neutral and hence optimizes its expected profit. However in practice, risk does matter, and procurement decisions (in particular the degree of flexibility to market fluctuation) has an impact on final profit. Considering two well-known risk criteria, which are Value-at-Risk and Conditional Value-at-Risk, Wu et al. (2013) study a newsvendor problem with capacity uncertainty, and find that the optimal order quantity is affected by the capacity uncertainty if the newsvendor is risk-averse. Using similar assumption of risk averse, this study extends to explore a remanufacturing supply chain on how to develop a contract mechanism between a remanufacturer and a collector.

For the purpose of describing the interaction of uncertainty and the extent of its related cost or benefit, the idea of risk consideration is being applied for lots of research areas. In fact, researchers have touched lots of areas, like *supply chain/dual-channel/channel coordination (Gan et al., 2004, 2005; Wang and Webster, 2007; Xu et al., 2014), reverse logistics (Han et al., 2016; Soleimani and Govindan, 2014), inventory management (Chen et al., 2007), newsvendor problem (Wu et al., 2013), pricing decisions (Li et al., 2014), channel bargaining (Ma et al., 2012), and Stackelberg game (Li et al., 2013a)*, etc.

Many supply chain players are willing to trade off lower possible losses at the expense of lower expected profit, that is to say, not all supply chain players are risk neutral. For example, in the area of supply chain/channel coordination, Gan et al. (2004) address the risk-averse agents' coordination issues in a supply chain by developing contracts under three cases. Gan et al. (2005) prove that the buy-back and revenue-sharing contract may not coordinate a supply chain that consists of a risk-neutral supplier and a risk-averse retailer. Taking the viewpoint of the behavioral principal agency theory, Wang and Webster (2007) investigate the role of a Gain/Loss-sharing provision for mitigating the loss-aversion effect in a supply chain which the manufacturer is risk neutral and the retailer is loss averse, and find that there exists a special class of distribution-free Gain/Loss-sharing-and-Buyback contracts that can coordinate the supply chain. Xu et al. (2014) study a dual-channel coordination when the supply chain agents are risk averse, and analyze that how the supply chain agents' risk attitude changes the parameters of the proposed contract. Assuming the dual-channel supply chain has one perishable product and the demand is price-dependent stochastic, Li et al. (2014) investigate pricing decisions in a dual-channel supply chain where only retailer is risk-averse. Xiao and Xu (2014) study the pricing and product line strategy of a risk-averse players in forward supply chain.

In the area of reverse logistics, Soleimani and Govindan (2014) consider a risk-averse two-stage stochastic optimization technique to design and plan a reverse logistics network with specifying the conditional value at risk (CVaR) as a risk evaluator. Considering the vulnerability due to operational and disruption risks, Han et al. (2016) compare direct and indirect reverse channels from the perspectives of profitability and robustness, and find that the indirect channel performs better when end-of-life products' collection cost arises. Chen et al. (2007) propose a general framework to incorporate risk aversion into multi-period inventory models.

In the area of channel-bargaining or games, Ma et al. (2012) study a channel-bargaining problem where one manufacturer and one retailer negotiate about wholesale price and order quantity, and show that there exists a Nash-bargaining equilibrium for the wholesale price and order quantity with equal and unequal bargaining power. Assuming suppliers are Stackelberg leaders, Li et al. (2013a) investigate the Stackelberg game equilibrium contract strategies of two competing supply chains, and further compare the outcomes obtained from different scenarios and study the impact of competition density and risk attitude on the suppliers' contract choices.

The literature on risk-averse supply chain players is quite extensive, and different objective dimensions of supply chain management need different measures. Researchers have already used many risk criteria. In the literature, researchers usually adopt Mean-Variance (MV) (Chiu and Choi, 2016), Standard Deviation (SD), Value-at-Risk (VaR) (Alexander and Baptista, 2004; Chi and Tan, 2011; Yiu et al., 2008) and Conditional-Value-at-Risk (CVaR) (Rockafellar and Uryasev, 2000; Uryasev, 2000; Xu et al., 2013) as risk measures (Heckmann et al., 2015; Qazi et al., 2017; Soleimani et al., 2014). A previous review paper (Heckmann et al., 2015) does detailed comparison and discussion on different risk criteria, researchers could refer to.

This research is an extension of contract coordination for risk-neutral remanufacturing supply chains, and introduces supply chain players' risk consideration as one objective to consider in bargaining effective supply chain contracts under heavier remanufacturing market fluctuation. The paper by Wu et al. (2013) is related to ours, but is different from the research hypothesizes and research objectives. Their study focuses on a forward supply chain and aims to find an optimal order quantity for a retailer, but in our study we focuses on a remanufacturing supply chain and aims to provide a contract for a remanufacturer and a collector. To our best knowledge, the research on risk-averse remanufacturing issues under market fluctuation is quite limited, and many of studies on decision making in a remanufacturing supply chain have assumed enterprises' marketing strategy are "maximum-profit" or "minimize-lost", i.e., risk neutral. This research aims to cover this gap to examine market fluctuation for remanufactured products to select a reasonable method to measure risks. We further explore contract mechanisms by developing a risk-averse marketing strategy for both a remanufacturer and a retailer in a remanufacturing supply chain.

3. Problem descriptions and settings

3.1 Notations

Notations used throughout paper are listed as follows:

D : the high-degree fluctuating demand in remanufacturing market.

$f(\cdot)$: the probability density function (PDF) of demand D.

$F(\cdot)$: the cumulative distribution function (CDF) of demand D.

ξ : the random remanufacturability rate of collected end-of-life products.

$g(\cdot)$: the probability density function (PDF) of the remanufacturability rate ξ.

$G(\cdot)$: the cumulative distribution function (CDF) of the remanufacturability rate ξ.

$E(\Pi)$: the expected profit. The superscripts D and RS denote the parameters corresponding to the non-coordination (decentralized) system and the coordination (revenue-sharing) system. The subscripts m , r and SC denote the remanufacturer, the retailer and the remanufacturing supply chain, respectively.

$Var(\Pi)$: the variance of the expected profit $E(\Pi)$.

k : the risk tolerance, and $k = 0$ means that one adopts "maximum-profit" marketing strategy.

Q : the quantity of collected end-of-life products.

P : the selling price of one remanufactured product.

p_r : unit collection price to consumers for end-of-life products acquisition.

w^d : the transfer payment charged by a retailer on a remanufacturer per end-of-life product.

q : the quantity of remanufactured products supplied by a remanufacturer.

c_{me} : the examination cost per end-of-life product, the remanufacturability would be examined after this process.

c_{ms} : the sorting cost per end-of-life product (including dismantling cost).

c_{mr} : the remanufacturing cost per end-of-life product (including testing cost).

c_{md} : the disposal cost per end-of-life product that cannot be remanufactured.

c_{mi} : the inventory cost per end-of-life product during holding at the remanufacturer

c_{mf} : the freight cost per remanfacturing product from the remanufacturer to the retailer

$S(q)$: the expected sales of remanufactured products, and $S(q) = q - \int_0^q F(y)dy$.

l : the leftover value per unsold remanufactured product.

s : the lost-sales cost per remanufactured product shortage.

c_{ri} : the inventory cost per end-of-life product in retailer's location.

c_{rf} : the freight cost per end-of-life product from a retailer to a remanufacturer

c_{rh} : the handing cost per remanufactured product in retailer's location.

ϕ : the percentage of revenue shared by the remanufacturer with the retailer.

$w_r(\phi)$: the transfer payment charged by a retailer on a remanufacturer per end-of-life product after given ϕ percentage revenue.

$N(\mu,\sigma^2)$: Normal distribution with the mean of μ and the standard deviation of σ .

$U(a,b)$: Uniform distribution with the minimum value of *a* and the maximum value of *b*.

3.2 The trade-off problem

This subsection elaborates the trade-off problem that remanufacturers and their retailers face. First, causes for remanufacturing market fluctuation are analyzed. Then, the necessity of coordination in a remanufacturing supply chain under risk consideration is explained. At last, a risk-averse marketing strategy for a remanufacturing supply chain is provided.

3.2.1 Market fluctuation for remanufactured products

Even though the remanufacturing industry is under the guidance of the government such as that in China, this industry is still in its infancy. Many issues can affect consumers' preference/acceptance. In some consumers' perception, the bias on remanufactured products still exists. The concept of remanufacturing is poorly understood by consumers, and for many consumers they are unwilling to consider remanufactured products even when they have a competitive lower price. The reputation of remanufactured products depends on its quality guarantee, price discrimination (Wei and Zhao, 2015) and after-sales service (Zhu et al., 2016). Besides, consumers' environmental consciousness varies (Zhao et al., 2016). As a result, the "green demand" manifests more uncertainty than that for new products.

Remanufacturing market is also affected by macro-economic cycle and the competition from manufacturers that produce new products (Majumder and Groenevelt, 2001; Mitra and Webster, 2008; Wu, 2013). Take the remanufactured truck engine in China as an example. The sales for new and remanufactured truck engines grew dramatically in 2009, after a "four-trillion CNY (Chinese Yuan, 1 CNY equals about USD 0.1459) bailout plan" led by the Chinese government. When the macro-economic shrank in 2015, the demand for infrastructure construction was far less than before, and the machinery volume in construction and transportation industry reduced fiercely. As a result, demand for remanufactured truck engines was decreased by 26%, from 744,211 in 2014 to 550,716 in 2015.

The remanufacturing market fluctuation can be increased due to effect of the uncertainties regarding "green consumers" size (do Paco and Raposo, 2010), government policy incentives (Ma et al., 2013; Mitra and Webster, 2008; Zhao and Zhu, 2015; Zhao et al., 2016), consumer valuations (Atasu and Souza, 2013), consumer perception (Li et al., 2015), competition with new products (Majumder and Groenevelt, 2001; Mitra and Webster, 2008; Wu, 2013) and the macro-economic shrinking/boom cycle. The remanufacturing market fluctuation brings an operational challenge for remanufacturing practices. Therefore, it is reasonable to suppose that both remanufacturers and their retailers are risk-averse. Since in our assumptions, a surplus of the expected gain is considered as risky as an equal-sized loss, the mean-variance measurement is applicable. The measure we adopt belongs to deviation-based measures (Heckmann et al., 2015), which are widely used as a measure of supply chain risk.

3.2.2 Coordination in a remanufacturing supply chain

Duo to the high-degree uncertainty in demand for remanufactured products, the *bullwhip effect* (Ouyang, 2006; Ozelkan and Lim, 2008; Zanoni et al., 2006) in a remanufacturing supply chain is more serious than that in a regular forward supply chain. The upstream of a remanufacturing supply chain is consumers that hold end-of-life products. As suppliers of suppliers (retailers) in the remanufacturing supply chain, those consumers are scattered. The supply of end-of-life products is not guaranteed and cannot always meet the order for end-of-life products. In fact, consumers' uncertain return of end-of-life products is related with many aspects, for example, 1) their environmental consciousness--if those consumers are green, they are more likely to return end-of-life products properly, 2) working conditions of end-of-life products — end-of-life products with satisfactory conditions may be reused and thus their return process would be delayed apparently, 3) convenience of reverse logistic--if reverse logistic is designed conveniently, consumers are more likely to return on time, 4) the incentives from the remanufacturing system—higher payment, from either remanufacturers or the government, for consumers results in more collection, 5) government regulations—The implementation of the *Extended Producer Responsibility* (EPR) would encourage producers to collect end-of-life products (Li et al., 2012) and embeds the idea of remanufacturing potential when designing the new products, and 6) government publicity—consumers' regular returns would be encouraged through promotion for greener and more sustainable life-style by governments.

The remanufacturing system could choose at least three reverse logistics structures for end-of-life collection, they are, collecting directly from consumers to remanufacturers, inducing retailers to collect, and getting through a third party for collection (Savaskan et al., 2004). However, an evidence shows that retailers always play the key role as efficient collectors in a remanufacturing system (Savaskan et al., 2004). Remanufacturers and the retailers are usually independent decision-makers, and they have conflicting interests without proper coordination. Therefore, under the market fluctuation analyzed before and uncertain supply in end-of-life products, the risk-averse remanufacturer and risk-averse retailer would suffer a profit loss caused due to a double marginalization effect (Dellarocas, 2012; Li et al., 2013b).

3.2.3 A risk-averse marketing strategy for a remanufacturing supply chain

Researchers studied how remanufacturing can be an effective marketing strategy to get profit for manufacturers under different cost, technologies, and logistics structures (Atasu et al., 2008), but their objective function focuses only on "maximum-profit" and the risk of market fluctuation is not considered. This subsection presents a risk-averse marketing strategy for a certain remanufacturing supply chain. The remanufacturing supply chain is characterized by one remanufacturer, one retailer and consumers with end-of-life products. The remanufacturer acquires a lot size of end-of-life products via the retailer and produces remanufactured products to satisfy a demand. We assume that the market is high-degree fluctuating, and the demand D

is a stochastic variable characterized by probability density function (PDF), $f(\cdot)$, and cumulative distribution function (CDF), $F(\cdot)$. Due to the quality uncertainty of collected end-of-life products, there is a random remanufacturability rate ξ with PDF $g(\cdot)$ and CDF $G(\cdot)$. The supply of remanufactured products is affected by retailer' acquisition activities and the remanufacturability rate. Meanwhile, the fluctuation demand for remanufactured products is affected by consumers' environmental consciousness and the related *Willingness-to-Pay* (Abbey et al., 2017; Zhao et al., 2016). Under the remanufacturing market fluctuation, any unsatisfied demand is considered as a loss and the remaining inventory has the salvaged value. Since the assumption of risk neutrality is not always applicable, both the remanufacturer and the retailer are risk-averse and self-interested, who aim to maximize their expected profit and reduce the risk of market fluctuation.

3.3 Model formulations and cost analysis

After given problem descriptions with respect to remanufacturing market fluctuation and coordination, this subsection formulates a model under a "risk-averse" marketing strategy.

3.3.1 The risk-averse marketing strategy for a remanufacturer

Under market fluctuation, a remanufacturer is likely to exhibit risk-averse behavior. The risk-averse marketing strategy for the remanufacturer is defined by the optimization program:

$$Max \quad E\left(\Pi_m^D\right) - k_m \cdot \sqrt{Var\left(\Pi_m^D\right)} \tag{1}$$

In which

$$E\left(\Pi_m^D\right) = \text{Sales revenue } - \text{ Operation cost} + \text{Leftover value } - \text{Shortage cost} \tag{2}$$

$$Var\left(\Pi_m^D\right) = E\left(\left(\Pi_m^D\right)^2\right) - E\left(\Pi_m^D\right)^2 \tag{3}$$

The coefficient k_m represents the remanufacturer's risk tolerance, and $k_m = 0$ means that the remanufacturer adopts "maximum-profit" marketing strategy.

Duo to market fluctuation, the expected sales are stochastic. The sales revenue is highly related to the quantity of collected end-of-life products Q, the remanufacturability rate ξ and the selling price P. Therefore, the sales revenue is characterized by the equation below,

$$Sales\ revenue\ = P \times \left(Q\xi - \int_0^{Q\xi} F(x)dx \right) \tag{4}$$

A generalized remanufacturing supply chain' major processes include acquisition of end-of-life products (Bulmus et al., 2014; Galbreth and Blackburn, 2006; Gaur et al., 2017; Guide and Van Wassenhove, 2001; Shaharudin et al., 2017; Yang et al., 2015), transportation(Gaur et al., 2017), dismantling, detection of raw components (Nenes et al., 2010), remanufacturing(Liu et al., 2017), assembling, performance testing, waste disposal (Hasanov et al., 2012) and remarketing (Alqahtani and Gupta, 2017; Choi, 2017; Zhou and Yu, 2011). Thus, the operation cost (including acquisition, examination, sorting, remanufacturing, disposal, inventory, freight process) is characterized by equation below,

$$Operation\ cost = \left(w^d + c_{me} + c_{ms} + c_{mr}\xi + c_{md}(1-\xi) + \frac{c_{mi}}{2} + c_{mf}\xi \right) Q \tag{5}$$

When the quantity that end-of-life products are remanufactured is more than the unknown demand in the market, the remanufacturer is faced with leftover inventory. The leftover value is the value for unsold remanufactured products.

$$Leftover\ value\ = l \int_0^{q} F(x)dx \tag{6}$$

When the remanufactured products could not meet the unknown demand in the market, the remanufacturer is faced with a supply shortage. The lost-sales is characterized by equation below,

$$Shortage\ cost\ = s\left(\int_{0}^{+\infty}(x-q)f(x)dx+\int_{0}^{q}F(x)dx\right) \tag{7}$$

3.3.2 The retailer's risk-averse marketing strategy

Similarly, the retailer's risk-averse marketing strategy is defined by the optimization program:

$$Max\ \ E\left(\Pi_r^D\right)-k_r\cdot\sqrt{Var\left(\Pi_r^D\right)} \tag{8}$$

In which $E\left(\Pi_r^D\right)$ represents the expected profit and $Var\left(\Pi_r^D\right)$ represents the variance of expected profit.

$$E\left(\Pi_r^D\right)=\text{Transfer payment}-\text{Operation cost} \tag{9}$$

$$Var\left(\Pi_r^D\right)=E\left(\left(\Pi_r^D\right)^2\right)-E\left(\Pi_r^D\right)^2 \tag{10}$$

The coefficient k_r represents the retailer's risk tolerance, and $k_r=0$ means that the retailer adopts "maximum-profit" marketing strategy.

For the retailer, the transfer payment is given by equation below.

$$Transfer\ payment = w^d Q \tag{11}$$

When the retailer collects Q end-of-life products from consumers at the price p_r, the remanufacturer pays w^d for each end-of-life product to the retailer.

The operation cost for retailer (including payment to consumers, inventory cost, freight cost, handing cost) is characterized by equation below,

$$Operation\ cost=\left(p_r+\frac{c_{ri}}{2}+c_{rf}+c_{rh}\xi\right)Q \tag{12}$$

4. Modeling and analysis

This section discusses the problem for coordinating the risk-averse remanufacturer and the risk-averse retailer under the remanufacturing market fluctuation.

4.1. The integrated benchmark model

To establish a performance benchmark for coordination mechanism, this subsection analyzes the risk-averse marketing strategy in an integrated remanufacturing supply chain. The integrated remanufacturing supply chain's risk-averse marketing strategy is defined by the optimization programs:

$$Max \quad E\left(\prod_m^D\right)+E\left(\prod_r^D\right)-k_{SC}\cdot\sqrt{Var\left(\prod_m^D+\prod_r^D\right)} \tag{13}$$

where k_{SC} is the integrated remanufacturing supply chain's risk tolerance, and $Var\left(\prod_m^D+\prod_r^D\right)=E\left(\left(\prod_m^D+\prod_r^D\right)^2\right)-E\left(\prod_m^D+\prod_r^D\right)^2$.

Consider $Q=q/\xi$, $p_r=q/a\cdot\xi$, we easily know that $Var\left(\prod_m^D+\prod_r^D\right)$ is a function of stochastic demand in market, which is $Var\left(\prod_m^D+\prod_r^D\right)=\chi\left(Var\left(D\right)\right)$. To simplify the discussion, let $s=0$. Taking the first derivatives with respect to q, $\partial\left(E\left(\prod_m^D+\prod_r^D\right)-k_{SC}\cdot\sqrt{Var\left(\prod_m^D+\prod_r^D\right)}\right)\Big/\partial q=0$, we can get:

$$\left(P-l\right)\left(1-F\left(q\right)\right)\left(1-\frac{k_{SC}\cdot\int_0^q F(x)dx}{\sqrt{\sigma^2-2\mu^2+q^2\left(1-F\left(q\right)\right)}}\right)=\left(\begin{array}{l}\frac{q}{a\cdot\xi^2}+\frac{c_{mi}}{2\xi}+\frac{c_{ri}}{2}+c_{rh}+c_{mr}+c_{mf}\\+\frac{c_{rf}+c_{me}+c_{ms}+c_{md}(1-\xi)}{\xi}-l\end{array}\right) \tag{14}$$

From the implicit function with respect to q, the following result can be obtained.

Proposition 1. *For an integrated remanufacturing supply chain with risk tolerance* k_{SC}, *under remanufacturing market fluctuation* $Var\left(D\right)$,

a) *the optimal supply of remanufactured products* q^* *is uniquely determined by*

$$\left(P-l\right)\left(1-F\left(q^*\right)\right)\left(1-\frac{k_{SC}\cdot\int_0^{q^*}F(x)dx}{\sqrt{\sigma^2-2\mu^2+q^{*2}\left(1-F\left(q^*\right)\right)}}\right)=\left(\begin{array}{l}\frac{q^*}{a\cdot\xi^2}+\frac{c_{mi}}{2\xi}+\frac{c_{ri}}{2}+c_{rh}+c_{mr}+c_{mf}\\+\frac{c_{rf}+c_{me}+c_{ms}+c_{md}(1-\xi)}{\xi}-l\end{array}\right) \quad (15)$$

b) *The optimal payment to consumers for unit end-of-life product is* $q^*/a\cdot E\left(\xi\right)$*, and optimal quantity of end-of-life products collected is* $q^*/E\left(\xi\right)$.

c) *the optimal supply of remanufactured products is decreasing with respect to* k_{SC}. *When* $k_{SC}=0$*, i.e., the "maximum-profit" marketing strategy, the integrated remanufacturing supply chain provides the most remanufactured products.*

d) *the optimal supply of remanufactured products* q^* *is decreasing with respect to the remanufacturing market fluctuation* $Var\left(D\right)$.

Proof of Proposition 1: **a)** according to the previous analysis.

b) according to a), apparently.

c) Assume $\Theta\left(k_{SC}\right)=1-\frac{k_{SC}\cdot\int_0^{q}F(x)dx}{\sqrt{\sigma^2-2\mu^2+q^2\left(1-F\left(q\right)\right)}}$. It is easy to know $\frac{\partial\Theta\left(k_{SC}\right)}{k_{SC}}\le 0$.

According to a), we get $q=a\cdot\xi^2\left(P-l\right)\left(1-F\left(q\right)\right)\Theta\left(k_{SC},q\right)-\rho$, where

$$\rho=a\cdot\xi^2\left(\begin{array}{l}\frac{c_{mi}}{2\xi}+\frac{c_{ri}}{2}+c_{rh}+c_{mr}+c_{mf}\\+\frac{c_{rf}+c_{me}+c_{ms}+c_{md}(1-\xi)}{\xi}-l\end{array}\right)$$

is constant with q and k_{SC}. When k_{SC} is decreasing, q is increasing. When $k_{SC}=0$, we get $\Theta\left(k_{SC}\right)=1$, $q=a\cdot\xi^2\left(P-l\right)\left(1-F\left(q\right)\right)-\rho$. q reaches its maximum value for any $k_{SC}\ge 0$.

d) Assume $\Phi(\sigma) \equiv 1 - \frac{k_{SC} \cdot \int_0^q F(x)dx}{\sqrt{\sigma^2 - 2\mu^2 + q^2(1-F(q))}}$. Apparently, $\frac{\partial \Phi(\sigma)}{\sigma} \geq 0$ According to a),

we get $q = a \cdot \xi^2 (P-l)(1-F(q))\Phi(\sigma, q) - \rho$, where $\rho = a \cdot \xi^2 \begin{pmatrix} \frac{c_{mi}}{2\xi} + \frac{c_{ri}}{2} + c_{rh} + c_{mr} + c_{mf} \\ + \frac{c_{rf} + c_{me} + c_{ms} + c_{md}(1-\xi)}{\xi} - l \end{pmatrix}$

is constant with q and σ. When $\sigma = \sqrt{Var(D)}$ is increasing, the q is increasing.

End of proof.

With risk tolerance k_{SC}, Proposition 1 gives the optimal supply of remanufactured products $q*$ to meet the fluctuating demand D, and it shows that the "maximum-profit" marketing strategy, i.e., $k_{SC} = 0$ provides the most remanufactured products.

4.2 Decentralized decision making by a remanufacturer and a retailer under market fluctuation

In practice, the remanufacturer and retailer are independent decision makers. In order to inspire their coordination activities, an analysis on their negotiation process is needed.

For risk-averse retailer, we can get:

$$\begin{aligned} Var\left(\prod_r^D\right) &= Var\left(-p_r Q - \frac{c_{ri} Q}{2} - c_{rf} Q - c_{rh} Q\xi + w^d Q\right) \\ &= (c_{rh} Q)^2 \cdot Var(\xi) \end{aligned} \tag{16}$$

Substituting $Var\left(\prod_r^D\right)$ and $p_r = Q/a$ in its objective function, the objective function can be rewritten as

$$Max\left\{a\left[-p_r - \frac{c_{ri}}{2} - c_{rf} - c_{rh}\xi + w^d - k_r \cdot c_{rh}\sqrt{Var(\xi)}\right] \cdot p_r\right\} \tag{17}$$

Solve the maximum problem with respect to p_r,

$$p_r = \frac{1}{2}\left(w^d - \frac{c_{ri}}{2} - c_{rf} - c_{rh}\xi - k_r \cdot c_{rh}\sqrt{Var\left(\xi\right)} \right) \quad (18)$$

Or

$$w^d\left(p_r\right) = 2p_r + \frac{c_{ri}}{2} + c_{rf} + c_{rh}\xi + k_r \cdot c_{rh}\sqrt{Var\left(\xi\right)} \quad (19)$$

After the negotiation process on w^d, Proposition 2 shows comparison for two marketing strategies under remanufacturing market fluctuation.

Proposition 2. *If both the remanufacturer and the retailer adopt a risk-averse marketing strategy, compared to the "maximum profit" marketing strategy,*

a) the optimal supply of remanufactured products is

$$\frac{a\,E(\xi)}{2} \cdot \left(w^d - \frac{c_{ri}}{2} - c_{rf} - c_{rh}\xi - k_r \cdot c_{rh}\sqrt{Var\left(\xi\right)} \right) \quad (20)$$

b) the more remanufacturability uncertainty in the collected end-of-life products (shown with a higher variance of remanufacturability rate in the end-of-life products, $Var\left(\xi\right)$), the less end-of-life products are remanufactured in a risk-averse marketing strategy. However, in a "maximum profit" marketing strategy case $k_r = 0$, the optimal collected end-of-life products is not relevant with the market fluctuation, in other words, when the remanufacturing market fluctuates dramatically, the end-of-life products acquisition quantity remains unchanged.

c) the transfer payment between the remanufacturer and the retailer in a risk-averse marketing strategy is higher than that in a "maximum profit" marketing strategy. And the difference is $k_r \cdot c_{rh}\sqrt{Var\left(\xi\right)}$ per end-of-life product.

d) In both strategies, after the bargaining process, the more bargain power a retailer has (shown with higher transfer payment, w^d), the more end-of-life products would be collected.

e) the remanufacturing quantity in a risk-averse marketing strategy is less than that in a "maximum profit" marketing strategy. And the difference is $k_r \cdot \frac{a E(\xi)}{2} \cdot c_{rh}\sqrt{Var(\xi)}$.

f) the less the retailer's risk tolerance k_r *is, the less the end-of-life products are remanufactured.*

□

Proposition 2 proves the risk-averse marketing strategy is superior to the "maximum profit" marketing strategy when the remanufacturing market fluctuates dramatically.

Further, based on Proposition 2, let's find the optimal p_r after the transfer payment w^d is given.

Substituting $w^d(p_r)$ and $p_r = Q/a$ in the remanufacturer's objective function, the objective function can be rewritten as

$$Max \;\; E\left(\Pi_m^D\right) - k_m \cdot \sqrt{Var\left(\Pi_m^D\right)}$$

$$E\left(\Pi_m^D\right) = a \cdot p_r \begin{pmatrix} -c_{me} - c_{ms} - c_{mr}\xi - c_{md}(1-\xi) - \frac{c_{mi}}{2} - c_{mf}\xi \\ -\left(2p_r + \frac{c_{ri}}{2} + c_{rf} + c_{rh}\xi + k_r \cdot c_{rh}\sqrt{Var(\xi)}\right) \end{pmatrix}$$
$$+P\left(ap_r\xi - \int_0^{ap_r\xi} F(x)dx\right) + l\int_0^{ap_r\xi} F(x)dx - s\left(\int_0^{+\infty}(x - ap_r\xi)f(x)dx + \int_0^{ap_r\xi} F(x)dx\right) \tag{21}$$

$$Var\left(\Pi_m^D\right) = E\left(\left(\Pi_m^D\right)^2\right) - E\left(\Pi_m^D\right)^2$$

It is easily to know that $Var\left(\Pi_m^D\right)$ is a function of demand, $Var\left(\Pi_m^D\right) = \Psi\left(Var(D)\right)$, considering $Var\left(S(q)\right) = \sigma^2 - 2\mu^2 + q^2\left(1 - F(q)\right)$, $d\left[E(D)\right]/dq = 1 - F(q)$, $d\left[\mathrm{var}(D)\right]/dq = 2\left[1 - F(q)\right]\left[q - E(D)\right]$ and $s = 0$, take first derivatives with respect to $\partial\left(E\left(\Pi_m^D\right) - k_m \cdot \sqrt{Var\left(\Pi_m^D\right)}\right)/\partial q = 0$, one gets

$$(P-l)\left(1-F(q)\right)\left(1-\frac{k_m\cdot\int_0^q F(x)dx}{\sqrt{\sigma^2-2\mu^2+q^2\left(1-F(q)\right)}}\right)=\left(\frac{c_{me}+c_{ms}+c_{md}\left(1-\xi\right)+\frac{c_{mi}}{2}+w^d}{\xi}+c_{mr}+c_{mf}-l\right) \quad (22)$$

From the equation above, it is found that the optimal supply of remanufactured products q^* is decreasing with respect to k_m, and the optimal supply of remanufactured products q^* is decreasing with respect to the remanufacturing market fluctuation $Var(D)$.

4.3 Remanufacturing supply chain coordination under market fluctuation

This subsection studies the effect of risk consideration on coordination activities between the remanufacturer and the retailer. Facing the fluctuation in a remanufacturing market, coordination activities by a remanufacturer and a retailer can be expressed as a revenue sharing contract (Mafakheri and Nasiri, 2013). With a revenue-sharing contract, the retailer charges w_r per one end-of-life product plus the remanufacturer gives the retailer a percentage of revenue. In the revenue sharing contract, the transfer payment from the remanufacturer to the retailer is

$$T(q,w_r,\phi,\xi,D)=w_rQ+(1-\phi)P\cdot S(q)+(1-\phi)l\cdot(q-S(q)) \quad (23)$$

$T(q,w_r,\phi,\xi,D)$ reflects the coordination activities between the remanufacturer and the retailer in the remanufacturing supply chain. Then the risk-averse marketing strategy by the remanufacturer is changed below:

$$
\begin{aligned}
&Max \quad E\left(\prod_m^{RS}\right) - k_m \cdot \sqrt{Var\left(\prod_m^{RS}\right)} \\
&in\ which \\
&E\left(\prod_m^{RS}\right) = -c_{me}Q - c_{ms}Q - c_{mr}Q\xi - c_{md}Q(1-\xi) - \frac{c_{mi}Q}{2} - c_{mf}Q\xi \\
&\qquad - s\left(\int_0^{+\infty}(x-q)f(x)dx + \int_0^q F(x)dx\right) \\
&\qquad + \left(-w_r Q + \phi \cdot PS(q) + \phi \cdot l(q - S(q))\right) \\
&Var\left(\prod_m^{RS}\right) = E\left(\left(\prod_m^{RS}\right)^2\right) - E\left(\prod_m^{RS}\right)^2
\end{aligned}
\tag{24}
$$

It is easily to know that $Var\left(\prod_m^{RS}\right)$ is a function of stochastic demand in market, which is $Var\left(\prod_m^{RS}\right) = \Upsilon\left(Var\left(D\right)\right)$. Considering $Var\left(S\left(q\right)\right) = \sigma^2 - 2\mu^2 + q^2\left(1 - F\left(q\right)\right)$, $d\left[E\left(D\right)\right]/dq = 1 - F\left(q\right)$ and, $d\left[\mathrm{var}\left(D\right)\right]/dq = 2\left[1 - F\left(q\right)\right]\left[q - E\left(D\right)\right]$, let $\partial\left(E\left(\prod_m^{RS}\right) - k_m \cdot \sqrt{Var\left(\prod_m^{RS}\right)}\right)/\partial q = 0$, we get:

$$
(P-l)\left(1-F\left(q\right)\right)\left(1 - \frac{k_m \cdot \int_0^q F(x)dx}{\sqrt{\sigma^2 - 2\mu^2 + q^2\left(1 - F\left(q\right)\right)}}\right) = \frac{c_{me} + c_{ms} + c_{mr}\xi + c_{md}(1-\xi) + \frac{c_{mi}}{2} + c_{mf}\xi + w_r - \xi\phi l}{\xi\phi} \tag{25}
$$

If the acquisition quantity of end-of-life products Q^{RS} is the optimal value of the remanufacturing supply chain, then the remanufacturers' objective function would be an affine function of the remanufacturing supply chain. Consequently, we have Proposition 3 below.

Proposition 3. *If both the remanufacturer and the retailer adopt a risk-averse marketing strategy, then the parameters of a revenue-sharing contract which represents their coordination activities would be changed as below,*

$$
w_r = \Delta_1\phi - \Delta_2
$$

In which

$$\Delta_1 = \begin{bmatrix} E(\xi)(P-l)(1-F(q))\left(1-\dfrac{(k_{SC}-k_m)\cdot\int_0^q F(x)dx}{\sqrt{\sigma^2-2\mu^2+q^2(1-F(q))}}\right) \\ +\begin{pmatrix} \dfrac{c_{ri}+c_{mi}}{2}+E(\xi)(c_{rh}+c_{mr}+c_{mf}) \\ +p_r+c_{rf}+c_{me}+c_{ms}+c_{md}(1-E(\xi)) \end{pmatrix} \end{bmatrix}$$

And

$$\Delta_2 = \left(c_{me}+c_{ms}+(c_{mr}+c_{mf})E(\xi)+c_{md}(1-E(\xi))+\frac{c_{mi}}{2}\right)$$

k_m *represents the remanufacturer's risk tolerance and* k_{SC} *represents the remanufacturing supply chain's risk tolerance.*

□

It is easy to see that $E(\prod_m^{RS}) = \lambda \cdot E(\prod_{SC}^{RS})$ and $E(\prod_r^{RS}) = (1-\lambda)\cdot E(\prod_{SC}^{RS}), (0 \le \lambda \le 1)$. The remanufacturing supply chain achieves the Pareto optimal status and the inefficient "double marginalization" effect is vanished. Proposition 3 could be used for exploring parameters of a revenue-sharing contract after adding the risk-averse factor into remanufacturing practitioners' considerations. With the help of this proposition, a feasible coordination could be achieved among risk-averse remanufacturing practitioners.

4.4 Managerial implications

From the perspective of the realistic consideration on remanufacturing market fluctuation, the proposed risk-averse marketing strategy with the further exploration on the risk-averse contracting mechanism issues provides significant insights for remanufacturers and their retailers (often acted as end-of-life products collectors in practice) seeking a proper strategy to trade off the expected profit and the risk of remanufacturing shortage/inventory.

Two major managerial implications can be explored. First, remanufacturers and their retailers usually focus on assessing the profitability of remanufacturing. However, remanufacturing practitioners encounter difficulties in identifying the risk of shortage/inventory because factors such as stochastic quality/quantity of end-of-life products, ever-changing consumers' preferences/acceptance on remanufactured products, and even macro-economic shrinking/boom make the decision more complex. This study is the first attempt to combine risk tolerance and expected profit as one goal under the environment of two uncertainty sources. The proposed risk-averse marketing strategy allows remanufacturers as well as retailers to make decisions based on reality. Therefore, the first managerial implication of this study is to show that a hybrid objective marketing strategy concerning profit variations as well as economic gain would be appropriate for remanufacturing practitioners.

Second, besides offering a hybrid objective marketing strategy, this study also provides guidelines for risk-averse and self-interested remanufacturing practitioners to select a proper contract to avoid the profit loss caused due to a lack of contract regulation, often known as double marginalization effect. In fact, the self-interested remanufacturing practitioners in the remanufacturing supply chain often struggle to achieve a feasible coordination mechanism in their operations, the proposed revenue sharing contract with a risk-averse marketing strategy satisfies the need. In practice, considering contract bargaining of these contract parameters (for example, transfer payment and revenue sharing percentage) enables remanufacturing practitioners to utilize their resources efficiently and effectively in meeting their needs of risk consideration. By designing an appropriate coordination mechanism, this study identifies conditions for inspiring remanufacturers and retailers to participate in coordination of contract regulation. Therefore, in order to satisfy the hybrid expectations of risk-averse and self-interested remanufacturing practitioners, the second managerial implication of this study is to prove the needs of contract regulation as well as offer the contract's conditions for remanufacturing practitioners.

5. Case analysis

As an example for analysis, this section presents a case of remanufactured truck engines. Sinotruk Jinan Fuqiang Power Co., Ltd., abbreviated to JFP, collects end-of-life truck engines from truck drivers in return for a discount for purchasing a remanufactured truck engine. JFP, which belongs to the China national heavy duty truck group Co., Ltd. Founded in 1994, is the first professional automotive engine remanufacturing enterprise in China.

The data used for analyzing the risk-averse marketing strategy are introduced in Table 1.

<Insert Table 1 about here>

Figure 1 shows the expected profit of the risk-averse marketing strategy and the maximum profit marketing strategy under the different market fluctuation $Var(D)$. Under the heavier remanufacturing market fluctuation environment, Figure 1 shows that the proposed risk-averse marketing strategy is relatively more insensitive. When the market fluctuation $Var(D)$ increases, the expected profit decrease in both strategies. It is shown that when the market fluctuates slightly, the maximum profit marketing strategy gains more expected profit than that for the risk-averse marketing strategy. However, with the increasing of market fluctuation $Var(D)$, the risk-averse marketing strategy is relatively more insensitive to market fluctuation than that for the maximum profit marketing strategy.

<Insert Figure 1 about here>

Figure 2 shows the effect of standard variance of the remanufacturability rate on the collected end-of-life products in two strategies. The remanufacturing quantity in a risk-averse marketing strategy is less than that in a "maximum profit" marketing strategy. When the standard variance increases, the collected end-of-life products decreases as the remanufacturer and the retailer worry about the uncertainty of their quality. However, the quantity in the "maximum profit" marketing strategy remains unchanged since it only depends on the expectation of the remanufacturability rate, not the standard variance of the remanufacturability rate. The comparison shows that when the uncertainty in quality of end-of-life products is high, the risk-averse remanufacturer and risk-averse retailer prefer to collect the fewer quantity of end-of-life products to reduce the remanufacturing risk of shortage/inventory under heavy remanufacturing market fluctuation.

6. Conclusions

Using Mean-Variance as a risk measure, a risk-averse marketing strategy is proposed under the market fluctuation environment. As risk attitude would affect decision-making by a remanufacturer and a retailer while their risk attitudes can also be different, it is necessary to explore the parameters of the proposed revenue-sharing contract after adding the risk-averse factor into objective functions for the remanufacturer and the retailer. This research discusses the effect of risk attitude of the remanufacturer and the retailer on the quantity of end-of-life products to be recovered, expected profit as well as the determination of the range of contract parameters. This research can be used to develop mechanisms on how to motivate risk-averse remanufacturers and retailers to participate in the supply chain contract coordination. Results from a case study indicate that in a risk-averse marketing strategy case, remanufacturers and retailers may get lower expected profit than that in the "maximum profit" marketing strategy case if market fluctuation is low. However, the risk-averse marketing strategy is superior to the "maximum profit" marketing strategy for profit gains and risks alleviation when the remanufacturing market fluctuates heavily.

The results provide guidance on how to better manage remanufacturers and retailers in a remanufacturing supply chain under market fluctuation with both demand and supply uncertainties. There are several research directions that are worth further studies. First, it would be interesting to investigate on how multiple remanufacturers and multiple retailers affect their coordination activities. Another direction for future research is to study other risk measurement for risk-averse remanufacturers or end-of-life products collectors.

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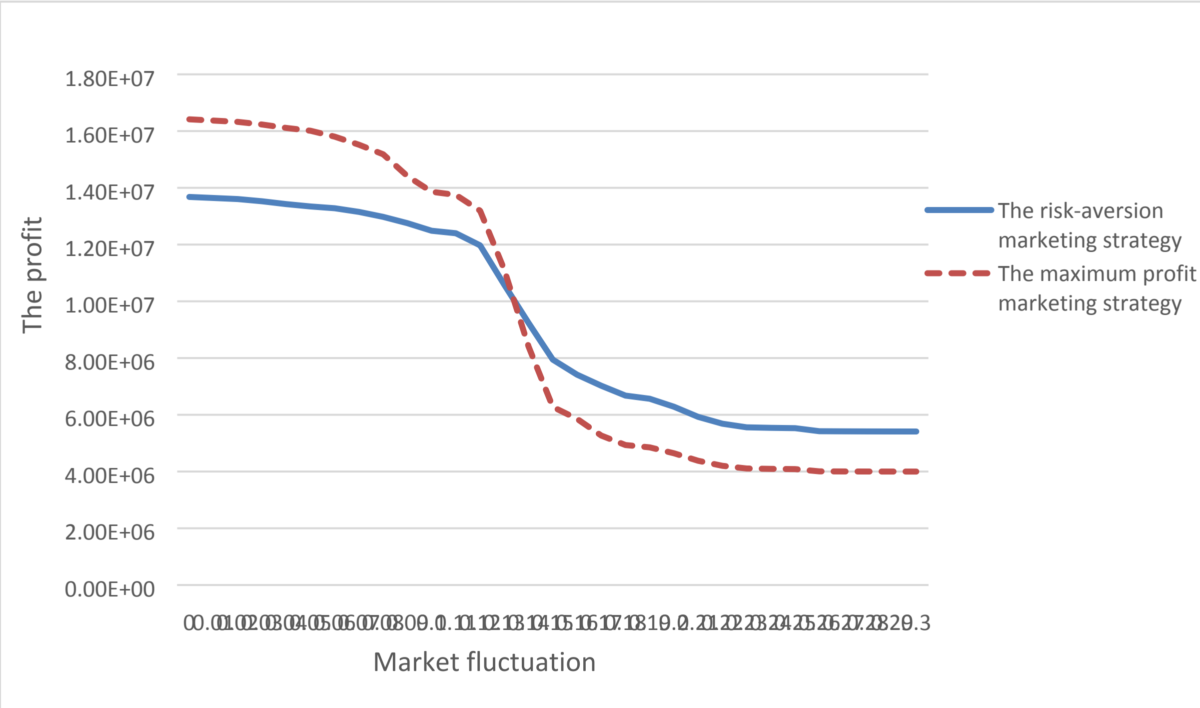

Figure 1. The comparison of two marketing strategies under different market fluctuation

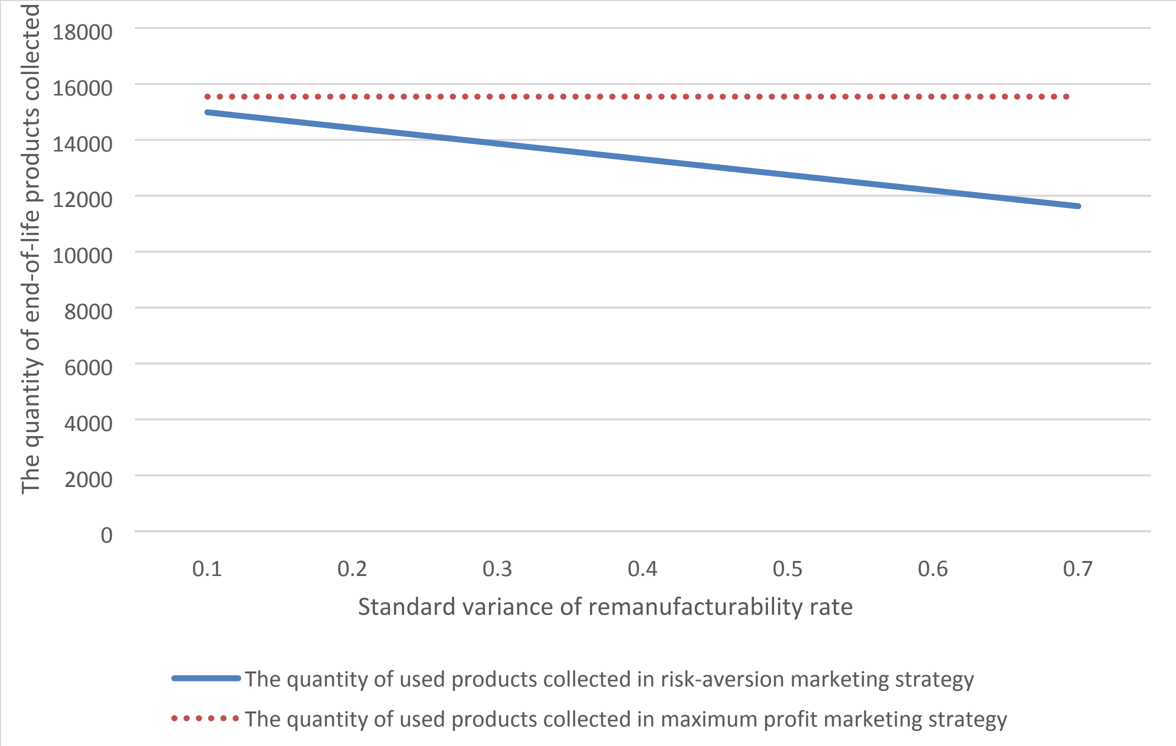

Figure 2. The quantity of collected end-of-life products with different standard variance of the remanufacturability rate

Table 1 Data related to one type of remanufactured truck engine

Remanufacturer	Retailer	Market
$P = 44000$CNY	k_r =0.5	k_{SC} =0.7
k_m =0.5	p_r =12500CNY	$\xi = N(0.8, 0.3^2)$ (Normal distribution with mean 0.8 and standard deviation 0.3)
w^d =14500CNY	$Q = 8/5 \times p_r$	$D = U(15000, 25000)$ (Uniform distribution with support defined by a minimum value 15000 and maximum value 25000)
s =10000CNY	c_{rf} =500CNY	
l =12500CNY	c_{ri} =100CNY	
c_{me} =120CNY	c_{rh} =100CNY	
c_{ms} =711CNY	$q = Q/\xi$	
c_{mr} =12500CNY		
c_{md} = -1600CNY		
c_{mi} =17CNY		