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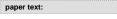
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Pricing Decision for Short Life-Cycle Products in a Closed-Loop Supply 4 Chain with

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that transforms a used product into "like-new" condition. It can extend the useful life of a product and help in reducing waste caused by a huge amount of short life-cycle products. Pricing decisions are an important aspect of successful remanufacturing and can secure the profitability of a firm. Remanufacturing for end-ofuse products needs to cope with high uncertainties

in terms of the quality and quantity of the acquired product 31

returns. Therefore, after inspection, only a fraction of returns can be recovered through remanufacturing operations. This uncertainty in recovery yield influences the decisions impacting acquisition, wholesale, and retail prices. We propose a pricing model that accommodates the

random yield effect of product returns on pricing decisions for short lifecycle products in a closed-loop supply chain.

The system

consists of a retailer, a manufacturer, and a collector of used-

products. We apply a sequential decision approach to 1 determine the optimum pricing decision to maximize supply chain profit, according to a pricing game that places the manufacturer as a Stackelberg leader. The results indicate that an increase in remanufacturing costs and manufacturer shortage penalties increases the remanufactured product's price and decreases remanufactured product quantity and



pricing decisions. Keywords: pricing, remanufacturing, short life-cycle product, yield of product return 1. INTRODUCTION Due to recent developments, product life cycle have been becoming

shorter and shorter, especially for technology-based products.

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Coupled with an increasing obsolescence in function and desirability, short life cycle products have created a huge amount of waste. Remanufacturing is a product recovery process that transforms used products into "like-new" condition. It can extend a product's useful life and help in reducing waste. There are three motives for remanufacturing that are often cited in the literature: ethical and moral responsibility, regulation, and profitability (Seitz, 2007). The first motive is relatively weak compared with the others, a fact that was originally noted by Ferrer & Guide (2002). The second motive relies on government regulation, which may not apply to some countries or states. The importance of profitability, however, is supported by Guide

et al. (2003), Guide et al. (2005), Atasu et al. (2008), and

Lund & Hauser (2010). There are three key activities

in the reverse supply chain, as 125

noted by Guide & Wassenhove (2009). They include the management of product return, issues in remanufacturing operations, and issues in remarketing the remanufactured product. Furthermore, these researchers find that the business perspective, including pricing, which is part of the market development activity, is an area that needs to be explored further. The pricing decision is an important aspect of a successful remanufacturing project and can secure the profitability of a firm. Atsu et al. (2010) find that cannibalization towards new products is not always occurred when remanufactured product is presented. Managers who understand the composition of their markets and use a proper pricing strategy should be able to create additional profit. In a similar manner, Souza (2013) notes that there are two implications when manufacturer offers remanufactured product alongside new product i.e.

a market expansion effect or a cannibalization effect; hence making the 93

pricing of the two products a critical issue. Therefore, pricing decision is very important in achieving economic advantages from remanufacturing practices. There are numerous studies on pricing remanufactured products for profit maximization. For instance, the studies by Ferrer & Swaminathan

(2006), Atasu et al. (2008), Ovchinnikov (2011), and Gan et al. (2015) search for the optimal price and

quantity under a deterministic setting. However, unlike the remanufacturing of consumer and business-tobusiness (B2B) returns, the remanufacturing of end-of-use products needs to cope with high uncertainties

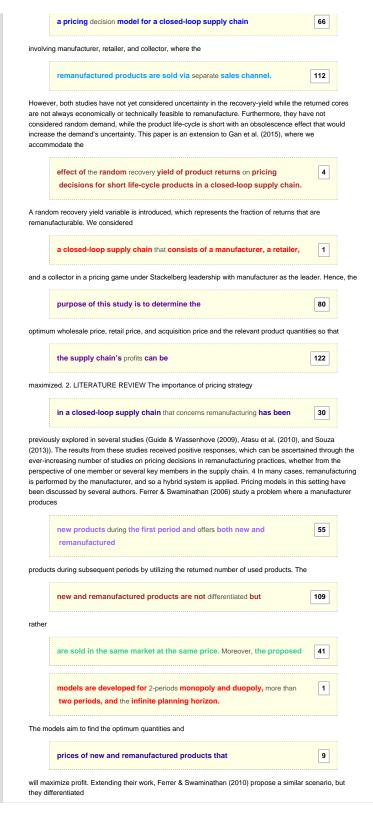
in terms of the quality, quantity, and timing of the acquired product returns. After the

collected used products are inspected, only a fraction of the returns can be used in a remanufacturing operation. This uncertainty can influence pricing decisions. Moreover, neglecting recovery yields could hurt a firm, such as in Ford's attempt to enter the automotive recycling industry via Greenleaf LLC, which resulted in failure. A manager at Ford, James L. Richardson, stated that the value of the materials they bought was lower than the value for which they actually paid (Bakal & Akcali, 2006). Gan et al. (2015) focus on pricing

decisions in a closed-loop supply chain involving manufacturer, retailer and

collector of used products (cores). They consider a monopolist of a single item with no constraint on the quantity of remanufacturable cores throughout the selling 3 horizon. Demand functions are deterministic and linear in price; and they represent the short life-cycle patterns along the entire phases of product lifecycle. The

	objective of the proposed model is to find the optimal	104
	wholesale and retail prices for both new and remanufactured products; and the optimal acquisition	1
and tra	ansfer prices. Recently, Gan et al. (2017) propose	



between the prices of new and remanufactured products. Atasu et al. (2008)

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1

recognize three drivers from demand- related aspects which are competing with the Original Equipment Manufacturer (OEM) directly, having green segment as a the potential market from, and utilizing the speed of market growth. The results confirmed that these three factors have strong interactions and significant impacts on remanufacturing decisions. Furthermore, they manage to

show that remanufacturing can be an effective marketing strategy

and not merely a cost-saving strategy or an approach to achieving compliance with environmental regulations. In the competition with an OEM's strong brand image, the analysis shows that a remanufacturing strategy could draw more customers. Ovchinnikov (2011) proposes

a model for finding the optimal profit- maximizing prices and quantities of remanufactured products when both new and remanufactured

product are sold side by side. Customer switching behavior was also studied to understand their choices behind buying new or remanufactured products and to identify how large is the

	fraction of customers who switch from buying new products to remanufactured	2				
ones. S	ones. Shi et al. (2011) propose a model					
	to determine the price and quantities of new and remanufactured product, and the used products' acquisition price,	11				
which	would					
	maximize the total profit of the supply chain. In this model, the price of	51				
remani	afactured products is not 5 differentiated from					
	new products, and both are sold in the same market.	29				
Furthe	rmore,					
	demand and return are both stochastic and price-sensitive. The	73				
large n	analysis shows that for a small market size, the optimal strategy is pure remanufacturing. However, for a large market, the best strategy is mixed manufacturing/remanufacturing. The effect of demand uncertair significantly impacts the					
	production plan and the selling price of new products. Instead, the	26				
uncerta	ainty of return affects not only the					
	remanufacturing plan but also the manufacturing plan of new products.	26				
Chen & Chang (2013) develop a						
	dynamic pricing model for new and remanufactured products under a constrained supply of used	1				

products. The model is developed with a static environment as the benchmark and a two-period and multiperiod setting over the product life cycle, to determine the optimum prices for maximizing profit. Although the products are differentiated, they are partially substitutable. Another study by Xiong et al. (2014) takes into account the lost sales and uncertain quality of used products in developing a pricing model for core product acquisition for remanufacturing companies. In this model, the demand is stochastic and the objective of the

model is cost minimization over finite and infinite horizons. Several studies on pricing decisions from the remanufacturer's point-of-view are mainly focused on the

selling price of remanufactured products and the optimal acquisition price of used products	15
(Guide et al. (2003), Bakal & Akcali (2006), Liang et al. (2009), Li et al.	25

(2009)), in which the remanufacturer performs both collection and remanufacturing processes. Guide et al. (2003) claim that product recovery management is the primary driver determining the profitability of reuse activities.

They develop a model to find the optimal selling prices of remanufactured	15
products and the acquisition prices	

for each quality class of returns, which together maximize the manufacturer's profit. Liang et al. (2009) address the problem of collecting used products when there is a random fluctuation in remanufactured products' prices, given the condition that the remanufacturer is required to offer a certain core price to motivate customers to return the used products. The remanufactured products price is 6 presumed to follow the Geometric Brownian Motion.



Moreover, they use option principles to further

determine the selling price of the remanufactures products.

Remanufactured products' prices vary according to market sentiment, thus exhibiting the nature of stocks; hence, the core price shows the characteristics of the options. Other studies, rather than focusing on the effect of acquisition price

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on the quantity and quality of product returns, focus on the effect of 28

random yield. For example, Bakal & Akcali (2006) develop a pricing

model to determine the acquisition and selling prices that maximize	75
profit	

when the



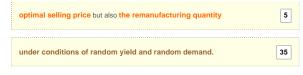
They also investigated the effect of random yield by setting different timings for price decisions. The recovery yield refers to the

fraction of parts that are remanufacturable, and it can be

influenced by used products' acquisition price. The first setting takes the selling price decision after the recovery yield is calculated, and the second setting takes the pricing decision prior to the determination of the recovery yield. Hence, this model simultaneously determines the acquisition and selling prices. Later, Li et al. (2009) not only consider the effect of random yield but also random demand. They proposed an optimization model using two-step stochastic dynamic programming. First, they found the optimal selling price to maximize expected revenue and then calculated the collection price that maximizes the utility of the firm. This study is further extended in Li et al. (2014), and they study two

sequential decision strategies i.e. First- Remanufacturing-Then-Pricing 5 (FRTP) and First-Pricing-Then-Remanufacturing (FPTR).

Therefore, these optimization models attempt to conclude not only the remanufactured product's



There are several approaches used in the literature that addresses random yield. Mukhopadhyay & Ma (2009) study the effect of random yield rates by comparing three cases: the

deterministic yield rate and the random yield rate with the

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order placed both before and 7 after the actual yield is observed. Ferguson et al. (2009) propose the use of a grading system to tackle uncertainty in return quantity and uncertainty in the demand for remanufactured products. They develop a model with capacitated remanufacturing facilities for remanufacturing when returns have various quality levels. In Roy et al. (2009), the material for remanufacturing process is fed by the defective units from the production system, The rate of defectiveness is uncertain, and is approximated by a constant or fuzzy parameter. Teunter &

Flapper (2011) consider multiple quality classes and multinomial quality distribution for acquired lots and

find that it is necessary to obtain additional used products as safety stock to avoid cost errors. Robotis

et al. (2012) consider the random quality of returns as the source of	61
uncertainty in	

remanufacturing costs and propose an inspection environment setting based on the firm's ability to perform a reliable inspection of used products. Wang et al. (2011)

study a hybrid manufacturing remanufacturing system for a short lifecycle product with stochastic demand and stochastic returned products

to get a minimum total cost for the hybrid system. Qiang et al. (2013) provide a finite dimensional variational inequality problem as the governing equilibrium condition in the existence of stochastic demand and a returns yield rate. Ahiska & Kurtul (2014)

study a stochastic hybrid manufacturing/ remanufacturing system with substitution using a

discrete-time Markov Decision process,

with stochastic demand and returns. A

product substitution strategy and its profitability are studied, and it can be shown that profitability is significantly affected by the remanufactured-product price to manufacturing cost ratio. The pricing models within a supply chain that involve several members of the supply chain were also discussed in several studies. Qiaolun et al. (2008)

consider a supply chain that consists of a manufacturer, a retailer, and a

collector. These companies are involved in selling new products, collecting used core products, remanufacturing, and reselling the recovered products. The

manufacturer is the Stackelberg leader, and he determines the	118
wholesale price, whereas the retailer and collector decide on the retail price and the acquisition price of the	3

used 8 products. The return rate is influenced by

	end-customer's willingness, and willingness is affected by the collecting price.	57
Wei &	Zhao (2011) consider fuzziness in customer demands, remanufacturing costs,	
	and collecting costs in a closed-loop supply chain and	64
use		
	fuzzy theory and game theory to find the	111
	optimal retail price, wholesale price, and remanufacturing rate. There are	3
two sc theory	enarios considered, namely, centralized and decentralized decision scenarios. Wu (20	012) uses g
	to investigate the OEM's product design strategy and the remanufacturer's pricing strategy.	36
The O	EM has	
	to consider the level of interchangeability in its product design and needs to	67
find the	e optimal level because	
	increasing the level of interchangeability would decrease the OEM's manufacturing cost and the remanufacturer's cost in	1
the att	empt to cannibalize the	
	OEM's product. The remanufacturer evaluates its pricing strategy and decides on either low or high pricing.	1
	In this model, the demands for new and remanufactured products	87
	th linear and sensitive to price. Wu (2013), similar to Wu (2012), applies game theory rium decisions when determining the prices of	to compute
	new and remanufactured products and the degree of the disassemblability of the	18
	OEM's product design. The OEM risks price competition with the	113
reman	ufacturer because when the degree of disassemblability is high, it not only reduces th	e
	OEM's production cost but also reduces the remanufacturer's recovery cost.	23
The m	odel is constructed for two-period and multi-period problems. Moreover, the demands	for
	new and remanufactured products are both linear and price-sensitive. However, the	9
above	studies consider only deterministic or fuzzy demand and do not consider randomness	s in the dem

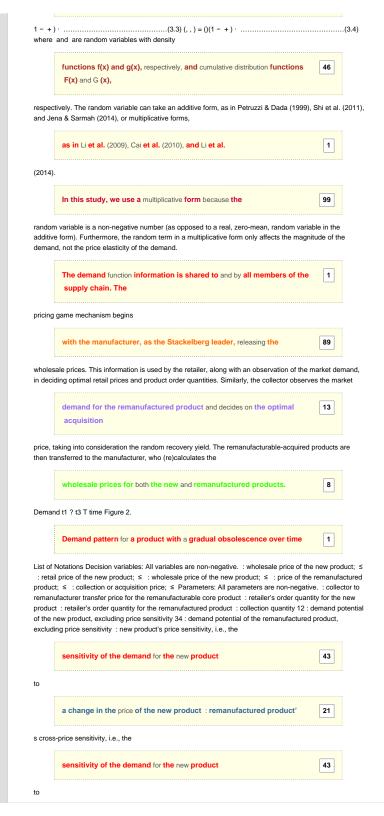
function. Jena &

	Sarmah (2014) study optimal acquisition price management in a remanufacturing system, considering three schemes of	48		
collection: direct, indirect, and coordinated. The model involves				
	a remanufacturer and a retailer and aims to determine the optimum core price	81		
that ma	aximizes profit within a single period. This study considers random demand, but only			
	for the remanufactured product. It is our goal to study	119		
pricing	decisions with random demand for both			
	new and remanufactured products within a closed-loop supply chain.	1		
	study focuses on the random recovery yield and random demands, and we consider a ars of the	all of the F		
	closed-loop supply chain: the manufacturer, the retailer, and the	56		
collect	or. Therefore, we consider			
	both new and remanufactured products and the pricing decisions	28		
	by the above-mentioned members. A sequential decision approach is used in this studi imal prices. The	dy to calc		
	rest of this paper is organized as follows. In section 3, we provide a description of the	14		
problem, which includes the process flow, the variables involved, the demand pattern, the definitions multiple functions, and the decision flows. The development of optimization models for each of the th members				
	in the closed-loop supply chain	3		
	is discussed in section 4. In section 5, we provide numerical	65		
	les and discuss several important factors in the pricing decisions. Finally, our conclus ted in section 6. 3. PROBLEM DESCRIPTION As depicted in Figure 1, we considered			
	a closed-loop supply chain that consists of three members: a manufacturer, a retailer, and a collector. The closed-loop system is	1		
initiated by the production of new product, which is				
	sold at a wholesale price to the retailer according to the	90		
quantity ordered. The new product is then released on the market at a retail price . After a certain period time, some products reach their				
	end-of-use and become the objects of used products collection. The used product	13		
is acqu	ired by the collector at a certain acquisition price and in a quantity of . The collector p	performs		

inspection, sorting, and cleaning tasks under a random recovery yield . The portions of the collected

products that are remanufacturable are then transferred to the manufacturer at a price as the inputs for the remanufacturing process. The quantity of remanufactured products made by the manufacturer is dependent





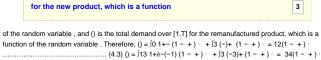
	a change in the price of the remanufactured product 13 : remanufactured product'	21	
s price	sensitivity,		
	i.e., the sensitivity of the demand for the remanufactured	32	
produc	t to a change		
	in the price of the remanufactured product : new product's cross -price	2	
sensitiv	vity, i.e., the sensitivity of the		
	demand for the remanufactured product to a change in the price of the new product	13	
	random variable as the multiplicative uncertainty of the demand for the	37	
new pr	oduct; [0,1] :		
	random variable as the multiplicative uncertainty of the demand for the	37	
applied	ufactured product; [0,1] : random yield of the product's return; [0,1] : unit shorta t to the collector by the manufacturer : unit shortage penalty applied to the manufactur : unit salvage value : unit raw material cost of producing the new product :		
	unit manufacturing cost of producing the new product : unit remanufacturing cost of producing and selling the remanufactured product : unit collection cost	34	
: coefficient in the return rate function : exponent of the power function in the return rate function, which determines the curve's steepness; [0,1] 4. OPTIMIZATION The optimization model uses a sequentia decision-making approach under the condition of			
	a Stackelberg game, with the manufacturer as the leader. The objective of the	50	
	pricing model is to maximize the profits of all of the	94	
	yers through the payment flows, shown in Figure 3. 14 4.1 Retailer's Optimization Th decision is very important because the demands are random and price-sensitive, whi		
	prices of both the new product and the remanufactured	84	
the det move i	t. Hence, in our proposed model, the retail prices, together with the demand's random erminants of the quantity of demand. As the Stackelberg leader, the manufacturer ma n the game by releasing the initial wholesale prices and . The retailer then optimizes in a sequential approach, as presented in (4.1) and (4.2). First, the retailer computes the sequential approach as presented in (4.1) and (4.2).	ikes the firs its retail pri	
	quantities of new and remanufactured products (,) that maximize its profit	1	
	he conditions of random demand for each product, given the predetermined retail pric imum quantities are utilized to calculate the optimal retail prices. Figure 3. Flow of pay		

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determine the size of the demands. 15 As the Stackelberg leader, the manufacturer makes the first move in the game by releasing the initial wholesale prices and . The retailer then optimizes its retail prices using a sequential approach, as shown in (4.1) and (4.2). First, the retailer calculates the optimum

quantities of new and remanufactured products (,) that maximize its profit



 $(4.6) \text{ where } 12 = 1 \quad ((1+)^{-}) ((3^{-})^{+}) \qquad ((4.6) \text{ Proposition 1 The retailer's expected order quantities}$

for new and remanufactured products to maximize its profit

(4.2) under the given (retail) prices and are: = $12(1 - +)^{-1}()$(4.7) = $34(1 - +)^{-1}()$(4.7) = (4.8) Proof: First, let = 12(1-+), which is the value of the random variable when () = , and = 34(1-+), which is the value of the random variable when () = . These variables are similar to the stocking factor that is proposed by Li et al. (2009). The first term in (4.2) can be expressed as [$\cdot \min(0)$,]= $\cdot (\min(0)$,]= $\cdot (00)(1 + 10)$] = $\cdot (00)(1 + 0)$].

Similarly, the second term in (4 .2) can be written as

 $[\cdot \min((),)] = \cdot {\{ j0()() + \overline{()}\}},$

where $(\bar{j} = 1 - (j) \text{ and } (\bar{j} = 1 - (j).$ 16

The optimization problem (4.2) thus becomes max, $\Pi = m, a, x \left[\cdot \left(j_0 \left(i \right) + \overline{0} \right) - 1 + \cdot \left(j_0 \left(i \right) + \overline{0} \right) - 1 \right]$(4.9) As = 1 2(1++) ad 1 = 34(1++), then $\Pi = \cdot (12(1++)) \overline{1}(1++) \overline{0} - 12(1-()+)) = 0$ (4.10) $\Pi = \cdot (34(13-4(1-++))(1+\overline{0}) - 34(1-(+))) = 0$ (4.11) Simplifying the equations, we find: 17 $\overline{(12(1++))} = \dots$(4.12) $\overline{(34(1++))} = \dots$(4.13) so that the optimal quantities are , where = 12(1 - +)^{-1} () and = 34(1 - +)^{-1} () [qed]. Proposition 2 The optimal retail prices that maximize the retailer's profit (4.1) on the order quantities of and are and, which satisfies the nonlinear system: $12(1 - 2 + 1)\Phi () - (-) (2) \Phi' () + 34\Psi () (-) = 0 \dots$(4.15) where = 12(1 - +), and = 34(1 - +); \Phi () = -1() and Ψ

() = -1(); and $\Phi'() = (-1())$ and $\Psi'() = (-1())$.

Proof: Substituting and in (4.1), the optimization problem becomes: max, $\Pi(I, I)(I, I) = 12(1 - +)^{-1}(I (-) + 34(1 - +)^{-1}(I (-) - ...(4.16))$ Thus, the first derivative conditions are: $\Pi = 12(1 - 2 + +)^{-1}(I + 12(1 - +)(-) - 1(I) + 34^{-1}(I (-) = 0)$, and $\Pi = 34(1 - 2 + +)^{-1}(I + 34(1 - +)(-) - 1(I) + 12^{-1}(I (-) = 0)$. As $[-1, 0] = -(2) \Phi'(I)$ and $[-1, 0] = -(2) \Psi'(I)$, the resulting linear system is (4.14) and (4.15) [qed]. The optimal retail prices and are influenced by the price elasticity and the uncertainty of the respective

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However, when ascertaining the optimal retail prices, it is difficult to provide closed-form solutions. Thus, we utilize a computational approach and leave the analysis to the numerical study. 4.2. Collector's Optimization The collector's problem is significantly influenced by the random recovery yield, as only a portion () of the returned



returns is influenced by the acquisition price ; an approach that has been used in several previous studies, including Qiaolun

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et al. (2008), Li et al. (2009) and El Saadany & Jaber (2010).

The collector inspects and sorts the acquired returns and then transfers the remanufacturable items to the manufacturer at a transfer price of . Returns that do not meet the quality requirement are discarded. Because the collector determines the collected quantity of remanufacturable items before the random recovery yield is realized, the actual quantity of remanufacturable items may be higher or lower than the manufacturer's order quantity . Therefore, a shortage penalty and a salvage value are incorporated in the model. The recovery yield is a

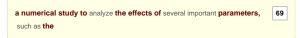
random variable with the density function h () and the cumulative distribution function ().

The governing equation for the collection

quantity, as a function of the acquisition price,

a closed-form solution is difficult to obtain, we

will use



parameters for , , , and the yield's randomness. 4.3. Manufacturer' Optimization During the third stage, the manufacturer tracks the prices set and the quantities ordered by the retailer, as well as the actual quantity of remanufacturable items supplied by the collector, after the random recovery yield has been realized. Therefore, the manufacturer

is not necessarily always able to supply the retailer's order quantities of the 77

remanufactured product because the ability of the manufacturer

to meet the retailer's order-quantity is dependent on the ability of the

collector to meet the quantity requirements. Consequently, a shortage penalty may be imposed on the manufacturer by the retailer to increase the level of order fulfillment. Thus, the manufacturer's optimization problem is expressed as: Optim 4: max, $\Pi = (- -) + [min(,) \cdot (- -) - [-]+]$(4.22) where and

are the unit raw material cost and the unit manufacturing cost, respectively, for the new product,

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101

3

whereas is the remanufacturing cost and is the unit shortage penalty. Proposition 4 The optimal wholesale prices are and , which satisfies: $\Phi'()(--) + \Phi() = 0$ (4.23) 1 $\Psi'()[(--)()] + \Phi() = 0$ ()] + (+ $\int 0(-)h()$) = 0(4.24) Proof: As the retailer's optimum quantities are given in (4.7) and (4.8), the optimization problem becomes: max, $\Pi = \Phi$ () (- -) + [min (Ψ () ,) \cdot (- -) - [Ψ () -]+] (4.25) Let = 34(1-+)-1() Ψ (), which represents the value of the random recovery = yield when = . Therefore, the optimization problem can be expressed as: max, $\Pi = \Phi$ $()(--)+(--)+(--+)\int ((-)h)$ (4.26) As is a function of , taking the first derivative of can be accomplished by applying the chain rule with $= \Psi'()$ 1. Therefore, the first derivative conditions h() = 0, which can be simplified into (4.24) [qed]. The optimal

	wholesale price for the new product depends on the retailer's price, the	3		
	raw material and			
manufacturing unit costs, and the cumulative				
	distribution function of the random variable governing the randomness of	91		

new

product's demand function. It is interesting that even though the

demand for the

the

new product is sensitive to the retail price of the remanufactured product, 2

the optimal wholesale price does not depend on any parameter in the remanufacturing process flow. As for the optimal wholesale

price of the remanufactured product, along with the parallel factors in the	42
new product's optimal wholesale price calculation, the	

quantity of the collection, the recovery yield randomness, and the penalty factor all affect the optimum, as well as the

new product's retail price. The retailer'

s order quantity may change in response to the optimal wholesale prices, which are decided by the manufacturer. However, increases in wholesale prices, compared with the respective original wholesale

	prices of the new and remanufactured products, will reduce the retailer's order quantities	24		
under	this responsive system. Furthermore, as			
	it is difficult to obtain closed-form	44		
solutio	solutions, we will use a			
	numerical approach to study the effects of	44		
several important factors. 5. NUMERICAL EXAMPLE The price sensitiveness of the demands for				
	new and remanufactured products are given as	8		

= 0.003, = 0.0001, = 0,004, and = 0,0002. The demand capacity of the new product contains the

parameters , 0, and , such that 12 = 4000, whereas the demand capacity of the remanufactured product involves the parameters , 0, and , such that 34 = 1500. The unit raw material

cost for the new product is = 50; the unit manufacturing cost is = 40; the	2
unit remanufacturing cost is = 20; and the unit collecting cost is	102

0 = 4. The parameters of the return rate function are = 0.1 and = 0.7. The collector's shortage penalty and salvage value are = 5 and = 8, respectively, whereas the manufacturer's shortage penalty is = 50. The transfer price is = 40. The initial

	wholesale prices released by the manufacturer are	8
= 120 a	and = 80	
	for the new and remanufactured products, respectively. We use a uniform distribution for the	24

random variables in the demand functions and the recovery yield. This type of distribution is previously applied in Li et al. (2014) and Mukhopadhyay & Ma (2009). Furthermore, , , and are random variables with a uniform distribution that have finite support [0,1]. The optimization problems are solved using Matlab. We performed sensitivity analyses for several factors that are important for the pricing decision, namely, the unit remanufacturing cost, the manufacturer's shortage penalty, and the parameters of the random yield. The results are shown in Tables 1-4. The



optimization problem is revealed using a graphical approach, whereby we plot the profit functions over the domain of the decision variables. These

 plots can be seen in Figure 4, Figure 5, and Figure 6 for the retailer's, the
 33

 collector's, and the

manufacturer's profit functions, respectively. Table 1 shows that

an increase in the remanufacturing cost will lower the 5	
profits of the retailer and the manufacturer, although the 83	

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collector's profit is unaffected by remanufacturing cost changes. Moreover, the remanufacturing cost

does not affect the retailer's

or the 24 collector's pricing decisions, as shown in the analytical model, but it does affect



manufacturer responds by increasing the

retailer's and the manufacturer's profits

wholesale price of the remanufactured product rather than decreasing the the

quantity produced, as shown in Figure 7. Therefore, both the retailer and the manufacturer receive lower profits, although the manufacturer's profit decreases twice as quickly as the retailer's. Similarly, as shown in Table 2, when the manufacturer's shortage penalty increases, the

decrease, whereas the collector's profit is again unaffected. In this scenario, the manufacturer reacts by simultaneously increasing

	the wholesale price of the remanufactured product (enough to cover the risk of	22
it recei	ving shortage penalties)	
	and decreasing the produced quantity of the remanufactured product. Although both the	5

manufacturer and the retailer are hurt by the lowered profits, in this scenario, the retailer's profit decreases slightly faster than the manufacturer's (see Figure 8). Retailers profit function x 10 4 10 8 Retailers profit 6 4 2 0 250 200 300 150 250 200 100 150 pr pn Figure 4. The Retailer's Profit Function Collectors profit function 1000 500 0 Collectors profit -500 -1000 -1500 -2000 2 1 Manufacturer profit 0 -1 -2 -3 -4 20 40 60 80 100 120 140 160 180 200 gc Figure 5. The Collector's Profit Function Manufacturers profit function x 10 4 -5 200 180 160 140 120 100 200 300 prv 80 60 100 pnv Figure 6. The Manufacturer's Profit Function Table 1. Effects of changes to the remanufacturing cost 30 20 10 5 Wholesale price of new product () 171.09 171.09 171.09 171.09 Retail price of new product () 252.19 252.19 252.19 252.19 Quantity of new product () 337.62 337.62 337.62 337.62 Wholesale price of remanufactured product () 150.93 148.46 146.12 144.99 Retail price of remanufactured product () 190.44 190.44 190.44 190.44 Quantity of remanufactured product () 73 11 76 56 79 73 81 21 Acquisition price of used product () 8 26 8 26 8 26 8 26 Quantity of used product collected () 241.20 241.20 241.20 241.20 Manufacturer's profit (П) 32,458.81 33,207.42 33,989.07 34,391.43 Retailer's profit (Π) 30,267.95 30,592.69 30,912.68 31,070.33 Collector's profit (П) 1,207.78 1,207.78 1,207.78 1,207.78 Total system's profit (П) 63,934.54 65,007.89 66,109.53 66,669.54 Table 2. Effects of changes to the manufacturer's shortage penalty 70 50 30 10 Wholesale price of new product () 171.09 171.09 171.09 171.09 Retail price of new product () 252.19 252.19 252.19 252.19 Quantity of new product () 337.62 337.62 337.62 337.62 Wholesale price of remanufactured product () 151.35 148.46 144.99 140.65 Retail price of remanufactured product () 190.44 190.44 190.44 190.44 Quantity of remanufactured product () 72.51 76.56 81.21 86.64 Acquisition price of used product () 8.26 8.26 8.26 8.26 Quantity of used product collected () 241.20 241.20 241.20 241.20 Manufacturer's profit (Π) 32,855.83 33,207.42 33,616.15 34,391.43 Retailer's profit (П) 30,213.35 30,592.69 31,070.17 31,692.54 Collector's profit (П) 1,207.78 1,207.78 1,207.78 1,207.78 Total system's profit (П) 64,276.96 65,007.89 65,894.10 67,001.09 The shift in the mean value of the random yield influences the profits received by all three parties in a positive direction, as presented in Table 3. As the expected value of the random yield increases, a larger portion of the collected used products will meet the remanufacturing requirements. Hence, the probability of supplying less than the order quantity

decreases, and the total quantity of the remanufactured product increases. Furthermore, the 10

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collection price also increases to escalate the collection quantity as a response to the higher order

quantities of the remanufactured product. All of the

members' profits increase as the expected value of the random yield increases, as a result of increased order fulfillment and reduced or fewer penalties. Consequently, the collector's percentage profit increase is significantly higher than those of the others because the recovery yield of product returns is isolated to the collector's inspection and sorting process. Table 3. Effects of changes to the mean value of the random yield U[0.1,0.7] ~[,] U[0.2,0.8] U[0.3,0.9] Wholesale price of new product () 175.84 175.84 175.84 Retail price of new product () 251.69 251.69 251.69 Quantity of new product () 318.56 318.56 318.56 Wholesale price of remanufactured product () 152.77 152.50 152.50 Retail price of remanufactured product () 152.77 152.50 152.50 Retail price of remanufactured product () 152.77 152.50 152.50 Retail price of remanufacturer's profit (Π) 26.68.70 26.702.54 26.719.45 Retailer's profit (Π) 25.601.45 25.623.28 25.645.37 Collector's profit (Π) 801.20 957.67 1,116.61 Total system's profit (Π) 53.088.36 53.283.49 53.481.43 A similar argument applies for the variance of the random yield, as shown in Table 4.

 It is interesting to note that an increase in the variance of
 63

 the random yield is responded to by a lowering of the wholesale and collection prices and that this action increases the remanufactured product's quantity, which, in turn,
 123

Figure 9 and 10. However, the effect of the decrease in the wholesale and collection prices according to the increase in the variance of the random yield is more notable than that of changes to the mean value.

We find that the wholesale price of the remanufactured product and the

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collection price are more robust against a shift in the mean value of the random yield rather than against a change to the random yield's variance. Table 4. Effects of changes to the variance of the random yield U[0.2,0.8] -[,] U[0.1,0.9] U[0,1] Wholesale price of new product () 175.84 175.84 175.84 Retail price of new product () 251.69 251.69 251.69 201.69 251.6

decreases the optimal quantity of the remanufactured product, reduces	10	1
the		

manufacturer's profit, and increases the

wholesale price of the remanufactured product. However, in Li et al.

(2014), the effect of the shortage penalty on the remanufacturing quantity is not conclusive, and, unfortunately, such a situation does not occur in our model. In addition to the above results, by analyzing the whole

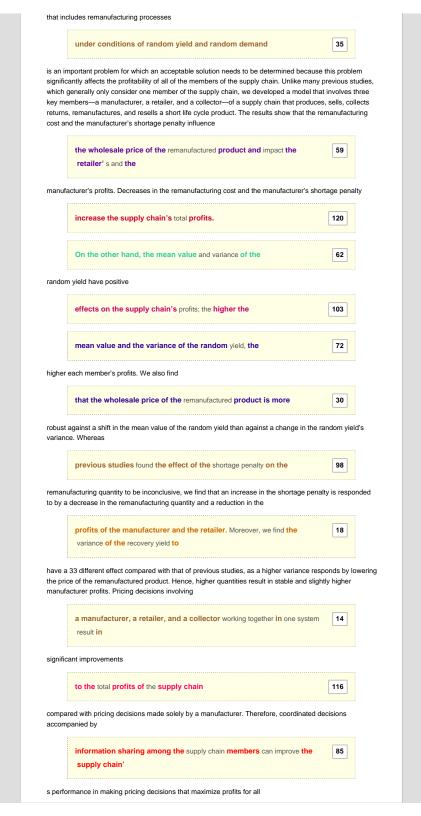
supply chain, we find that the	6
retailer's profit is also affected by changes to the	86

remanufacturing cost, in terms of the extended effects of the change in remanufacturing quantity, although the collector's profit remains unaffected in this situation. Figure 7. The effect of changes to the remanufacturing cost

	on the supply chain's profit Figure 8. The effect of	27	
change	es to the short- age penalty		
	on the supply chain's profit Figure 9. The effect of	27	
change	as to the yield's randomness on the wholesale price profit		
	Figure 10. The effect of changes to the yield's variance on the	106	
	chain's The price elasticity of the remanufactured product also has a consistent effect strated in Li's work (Li et al., 2009; 2014), which showed	ct, as prev	viousl
	that an increase in the price elasticity of the remanufactured product decreases the	23	
	optimal remanufacturing quantity, the wholesale price, the selling price, and the	5	
used p	roduct collection price,		
	which, in turn, decreases the total profits of the supply chain.	88	
Table 5	5 shows these results. However, we observed that the effect of an increase		
	in the price elasticity of the remanufactured product on the	2	

	values of the optimum transfer price for the manufacturer and the	19
ollect	or conflict. When the problem is addressed only	
	from the point-of-view of the manufacturer's problem, the conflict between the	25
ffect	Im transfer price values for the manufacturer and the collector may not be observed. No of the remanufactured product's elasticity in relation to the new product's pricing can b odel. For example, an increase	loreover, th
	in the price elasticity of the remanufactured product decreases the new product's	2
	wholesale and retail prices, as well as	114
	mal quantity, which, taken together, result in new product pricing rates that are signific lose of the remanufactured product. The development of a pricing model that involves	three mem
f	a closed-loop supply chain shows a discriminated effect of the ary yield's randomness. A higher degree of uncertainty in the recovery yield results in a wholesale price of the remanufactured product, which leads to increases in	three mem
f	nose of the remanufactured product. The development of a pricing model that involves a closed-loop supply chain shows a discriminated effect of the any yield's randomness. A higher degree of uncertainty in the recovery yield results in a	92 a lowering o
f	a closed-loop supply chain shows a discriminated effect of the rry yield's randomness. A higher degree of uncertainty in the recovery yield results in a wholesale price of the remanufactured product, which leads to increases in the	92 a lowering o 3 5
f ecove	a closed-loop supply chain shows a discriminated effect of the rry yield's randomness. A higher degree of uncertainty in the recovery yield results in a wholesale price of the remanufactured product, which leads to increases in the optimal remanufacturing quantity and the manufacturer's profit. gh Li et al. (2009) find that recovery yield randomness does not influence the manufact	92 a lowering o 3 5
f Ithou xpect	a closed-loop supply chain shows a discriminated effect of the ary yield's randomness. A higher degree of uncertainty in the recovery yield results in a wholesale price of the remanufactured product, which leads to increases in the optimal remanufacturing quantity and the manufacturer's profit. gh Li et al. (2009) find that recovery yield randomness does not influence the manufac ted profit, Li et al. (2014) show that an increase in the recovery yield's variance can lead to an increase in the price of the remanufactured product, which then	92 a lowering o 3 sturer's
f Ithou xpect	a closed-loop supply chain shows a discriminated effect of the ary yield's randomness. A higher degree of uncertainty in the recovery yield results in a wholesale price of the remanufactured product, which leads to increases in the optimal remanufacturing quantity and the manufacturer's profit. gh Li et al. (2009) find that recovery yield randomness does not influence the manufac ted profit, Li et al. (2014) show that an increase in the recovery yield's variance can lead to an increase in the price of the remanufactured product, which then decreases the	92 a lowering o 3 sturer's

recovery yield randomness can be mitigated and, further, can even slightly improve the total profits of the system. Table 5. Effects of changes to the price elasticity of the remanufactured product 0.003 0.004 C 0.005 0.006 Wholesale price of new product () 171.91 171.09 170.61 170.29 Retail price of new product () 253.82 252.19 251.22 250.58 Quantity of new product () 338.72 337.62 336.84 336.23 Wholesale price of remanufactured product () 179.74 148.46 129.08 115.75 Retail price of remanufactured product () 238.57 190.44 160.88 140.75 Quantity of remanufactured product () 86.64 76.56 59.72 45.75 Acquisition price of used product () 143.8.26 6.43 4.89 Quantity of used product collected () 285.55 241.20 201.76 166.13 Manufacturer's profit (Π) 38,018.70 33,207.42 30,619.36 29,094.53 Retailer's profit (Π) 33,453.26 30,592.69 29,051.39 28,139.37 Collector's profit (Π) 483.10 1,207.78 1,483.51 1,473.85 Total system's profit (Π) 71,95.06 65,007.89 61,154.26 58,707.75 6. CONCLUSION The



of the supply chain members. Finally, this

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model could be extended to include coordinated decisions, which would be an important future research step. 7. REFERENCES Ahiska, S. S., & Kurtul, E. (2014). Modeling and analysis of a product substitution strategy for a stochastic manufacturing/remanufacturing system. Computers & Industrial Engineering, 72, 1-11. Atasu, A., Guide, V. D. R. J., & Wassenhove, L. N. Van. (2010). So what if remanufacturing cannibalizes my new product sales? California Management Review, 52(2), 56-76. Atasu, A., Sarvary, M., & Wassenhove, L. N. Van. (2008). Remanufacturing as a marketing strategy. Management Science, 54(10), 1731-1746. Bakal, I. S., & Akcali, E. (2006). Effects of Random Yield in Remanufacturing with Price-Sensitive Supply and Demand. Production and Operations Management, 15(3), 407-420. Cai, X., Chen, J., Xiao, Y., & Xu, X. (2010). Optimization and coordination of fresh product supply chain with freshness keeping effort. Production and Operations Management, 19(3), 261-278. 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