Study on Cost Control of Reverse Supply Chain Considering Inspection Error

Mengyao Wang, Qiaolun Gu

School of Economics and Management, Tianjin University of Technology and Education, Tianjin 300222, China.

missmeng1994wmy@163.com

Abstract

With the acceleration of product turnover and the increasingly fierce market competition, people begin to pay attention to the cost control of reverse supply chain. In this paper, starting from the inspection error of used product recycle, the cost control of the two-echelon reverse supply chain is studied by using the game theory method. By numerical example, we analyze the impacts of inspection error and reinvestment cost on the pricing decision and profits of the remanufacturer and the recycler. The results show that the reduction of inspection error can greatly improve the profits of remanufacturer. The profits of supply chain will increase with the increase of the reinvestment cost, and the profit of the recycler will lose accordingly.

Keywords

Reverse supply chain, Game theory, Inspection error, Cost control.

1. Introduction

In recent years, with the continuous development of economic globalization, production efficiency has gradually improved, and technological measures have been innovated accordingly, and competition between enterprises has ushered in an increasingly fierce wave. However, companies have a tendency to assimilate in terms of product quality and service, and the control of capital flow and cost reduction are still very urgent and necessary [1]. With the positive supply chain approaching maturity, companies have begun to explore new ideas to reduce costs, and more and more companies have begun to pay attention to the recycling and remanufacturing of used products and recycling resources. Reverse supply chain has become an important magic weapon for enterprise competition by reducing resource consumption and the cost of products and services. Since the reverse supply chain provides a new idea for environmental protection, effective use of resources and the realization of sustainable development, the related research of reverse supply chain has received extensive attention from scholars at home and abroad.

Research on the issue of pricing decision and cost control in reverse supply chain, Gu used game theory to study the pricing strategy of reverse supply chain, obtained the equilibrium solution of non-cooperative game and cooperative game, and analyzed the efficiency problem of pricing strategy, and drew the conclusion that the total profit of the system could be maximized only when the two parties coordinated the pricing decision [2]. Wang et al. conducted a research on pricing decision-making on a closed-loop supply chain composed of a single remanufacturer and a single retailer [3]. Liu et al. studied the uncertainty of recycling quality of used electronic products in the pricing model of three-echelon reverse supply chain system, and analyzed the influence of quality difference on pricing strategy and corporate profits through MATLAB simulation under the two situations of cooperative game and non-cooperative game [4]. Guo et al. used game theory to study the coordination strategy between recyclers and processors in the recycling process of electrical and electronic equipment [5]. Wu et al. discussed the impact of remanufacturing costs on the coordination strategy of enterprise’s production and systems for a closed-loop supply chain composed of one remanufacturer and two competing retailers [6]. Ding et al. established a game theory model to study the pricing decision of the reverse supply chain of electronics and appliances, discussed the difference in cost recycle under the mode of monopoly and competition, and proposed relevant strategies to achieve a win-win situation for supply chain enterprises [7].

In real life, the recycling quality of used products is uncertain, and there are quality differences in used products. Therefore, in order to save disassembling time and cost, we need to inspect the quality information of used products in the early stage of recycling, but the quality inspection of used products is not necessarily completely accurate, so some scholars have conducted related research on the recovery inspection error. Gu analyzed the impact of the difference of inspection error rates on the profits of members of the two-echelon reverse supply chain by using the system dynamics methodology, and provided a reasonable range to reduce the inspection error rates [8]. Luk et al. took Re Cellular's mobile phone quality classification standard as an example to study how the recycling inspection error affects the remanufacturer in a reverse supply chain consisting of a remanufacturer and multiple recyclers optimal recycle decisions and benefits [9]. Teunter et al. studied the situation of obtaining unclassified used products from recyclers or third-party recyclers, and given the different quality grades of used products, proposed the optimal acquisition and remanufacturing strategy for determining demand and random demand [10]. Gu studied how to establish a contractual relationship to reduce the loss of pricing strategy when the number of used products with inspection error did not meet the needs of remanufacturers [11]. Xue applied game theory to study the recycling pricing strategy of used products led by remanufacturers, and analyzed the impact of recycling inspection error on used product recycling prices and supply chain profits [12]. Based on the two-echelon reverse supply chain composed of recyclers and remanufacturers, GU et al. used game theory to study recycler's optimal recycle quantity and remanufacturer's optimal orders under definite or random demand with inspection error. It analyzed the influence of inspection error on the optimal recovery quantity of recycler [13].

Therefore, this paper studies the cost control of reverse supply chain enterprises with inspection error, and analyzes the impact of inspection error rates on the profits of remanufacturers and recyclers.

2. Problem Description

2.1 Structure Description

The following figure studied in this paper is a typical single-channel two-echelon reverse supply chain model structure. As shown in Fig. 1, recyclers use traditional recycling channel to recycle used products from end consumers at a certain price. After quality inspecting, they treatment "non-remanufacturable product" and sell "remanufacturable product" to remanufacturer. The remanufacturer will disassemble the used products purchased from the recyclers. After disassembling, the non-remanufactured products will be treatmented, and the remanufacturable products will be processed into remanufactured products and put on the market.

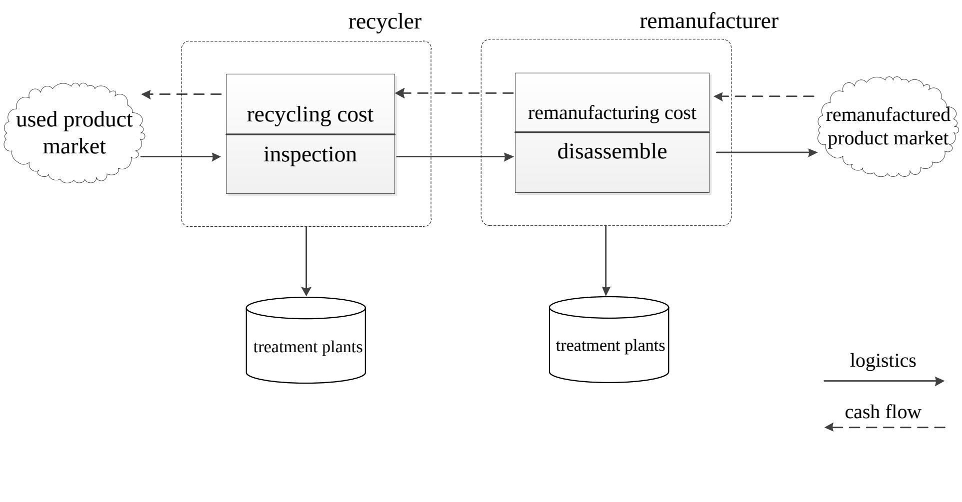

Fig. 1 Model structure diagram

2.2 Notations

For the convenience of research, the notations involved and their meanings are listed below in Table 1:

Table 1 Symbol description

Variables	Meaning
P_0	The unit sales price of remanufactured products. It is a certain constant.
C_{dis}	The unit disassembly cost of used products.
C_{td}	The unit treatment cost of products of a non-remanufacturable product.
C_m	The unit remanufacturing cost of a remanufactured product.
P_m	The unit reclaiming price of a "remanufacturable product" from recycler by the remanufacturer, $0 < P_m \le P_0 - C_m - C_{dis}$
C_r	The unit operating cost of recycler (including inventory, transportation, etc.)
P_r	The unit recycling price (yuan / piece) of used products recycled from consumers by recycles. It is a decision variable of the recycler. r $(0 < r < 1)$ is the profit margin of the recycler, $P_r = (1-r)P_m$
C_{ins}	The cost of the recycler inspecting used products, $C_{ins} = C_0 + v/a$
C_0	The recycler's unit fixed inspection cost of used product in the initial state
Δt	The additional inspecting cost invested by recycler on used products to reduce inspection error
C_t	Unit cost for the recycler to disassemble of the inspected "non-remanufacturable product"
q	The percentage of used products that can be remanufactured to the total products that the recycler collects from final consumers, that is, the remanufacturing rate.
a	Recycling inspection error I is the ratio of non-remanufacturable products are inspected as remanufactured products, namely, "remanufacturable products", $0 < a < 1$
b	Recycling inspection error II means some remanufacturable products are inspected as non-remanufacturable products, namely, "non-remanufacturable products", $0 < b < 1$
D	Market ownership of used products
Q	When the unit recycling price is P_r, the recycling quantity of used products. Suppose: $Q = f(P_r) = d(P_r)^k, d > 0, 0 < k < 1$, d is the positive constant, k is price elasticity coefficient.
π_m	The profit of remanufacturer
π_r	The profit of recycler
π	The total profit of reverse supply chain with inspection error, $\pi = \pi_m + \pi_r$

2.3 Research Hypothesis

In order to solve the research problem of this article, we make the following assumptions according to the symbol description in the above table:

(1) Both remanufacturers and recyclers conduct research based on complete information, that is, they know each other's costs, pricing, and strategies.

(2) There is no distinction between new products and remanufactured products in the entire supply chain.

(3) During the recycling process, both the remanufacturer and the retailer have benefits in the supply chain, which can make the reverse supply chain system operate normally.

(4) There is no restriction on the amount of recycling, that is, regardless of the interruption of the recycling of used products, the used products that are remanufactured in the course of recycling are much larger than the used products that cannot be remanufactured.

According to the influence of the recycle inspection error, the remanufacturer disassembles the recycled products and processes them to form recycled products or treat them. Therefore, for a given recycle price P_m and P_r, the profit function is:

$$\pi_{\mathrm{m}} = \{(P_0 - C_m)\cdot q(1-b) - C_{td}\cdot(1-q)a - (P_m + C_{dis})\cdot[q(1-b)+(1-q)a]\} f[(1-r)P_m] \quad (1)$$

$$\pi_{\mathrm{r}} = \{(P_m - C_r)\cdot[q(1-b)+(1-q)a] - [(1-r)P_m + C_{ins}] - C_t[qb+(1-q)(1-a)]\} f[(1-r)\cdot P_m] \quad (2)$$

$$\pi = \pi_m + \pi_r \quad (3)$$

To facilitate the calculation, we use symbols instead of expressions.

$$A = q(1-b)+(1-q)a$$

$$B = q\cdot b + (1-q)(1-a)$$

$$A_m = (P_0 - C_m)q(1-b) - C_{td}(1-q)a$$

$$Q = AC_r + C_{ins} + C_t B = AC_r + C_0 + \frac{v}{a} + C_t B$$

The optimal marginal profit margin of the recycler can be obtained by obtaining the first derivative, namely, the response function of the recycler:

$$\frac{\partial \pi_r}{\partial r} = d(1-r)^{k-1} P_m^k[-AP_m k + AC_r k + (k+1)(1-r)P_m + C_{ins}k + C_t Bk] \quad (4)$$

Let $\frac{\partial \pi_r}{\partial r}$=0, we can get the optimal value of the recycler decision.

$$r_0 = 1 - \frac{k(AP_m - AC_r - C_{ins} - C_t B)}{(k+1)P_m} \quad (5)$$

When the remanufacturer's recycling price P_m is given, the retailer can make the optimal decision, which is called the response curve of the recycler. By substituting r_0 into it, the following equation can be obtained:

$$\pi_m = d\left(\frac{k}{k+1}\right)^k (A_m - AC_0 - AP_m)(AP_m - Q)^k \quad (6)$$

$$\frac{\partial \pi_m}{\partial P_m} = d\left(\frac{k}{k+1}\right)^k A[k(A_m - AC_{diis})(AP_m - Q)^{k+1} - (AP_m - k)^k - kP_m A(AP_m - Q)^{k+1}] \quad (7)$$

Let $\frac{\partial \pi_m}{\partial P_m}$ =0, we get

$$P_m^* = \frac{k(A_m - AC_{dis}) + Q}{A(1+k)} \quad (8)$$

We can be concluded that the remanufacturer’s optimal pricing strategy, That is, the Stackelberg equilibrium as follows:

$$(P_m^*,\ r^*) = \left(\frac{k(A_m - AC_{dis}) + Q}{A(1+k)},\ 1 - \frac{k^2 A((A_m - AC_{dis}) - Q)}{(k+1)(k(A_m - AC_{dis}) + Q)}\right) \quad (9)$$

Therefore, we can get the optimal decision of recycling price of used products and total profit of the reverse supply chain system by substituting equations (9) into π_m, π_r, P_r. The results as follows:

$$\pi_m^* = dk^{2k}\frac{[A_m - AC_{dis} - (AC_r + C_0 + \frac{v}{a} + C_t B)]^{k+1}}{(k+1)^{2k+1}} \quad (10)$$

$$\pi_r^* = dk^{2k+1}\frac{[A_m - AC_{dis} - (AC_r + C_0 + \frac{v}{a} + C_t B)]^{k+1}}{(k+1)^{2k+2}} \quad (11)$$

$$P_r^* = \frac{k^2[A_m - AC_{dis} - (AC_r + C_0 + \frac{v}{a} + C_t B)}{(k+1)^2} \quad (12)$$

$$\pi^* = \pi_m^* + \pi_r^* \quad (13)$$

3. Numerical Examples

According to the above model, the simulation operation is performed by MATLAB. In order to analyze the impact of recycle inspection error rates on recycle price and profit, the values of relevant parameters are set as Table 2.

Table 2 Setting for parameters

Parameters	Values
P_0	1600
C_m	200
C_r	60
C_{dis}	20
C_{td}	4
C_t	1
C_0	20
d	10
q	0.8
k	0.8

We set the inspection error $b = 0.8 * a$. When the cost investment v=10, the impact of the recycling inspection error a on the recycling price, profit and quantity of used products is shown in Fig. 2 to Fig. 4.

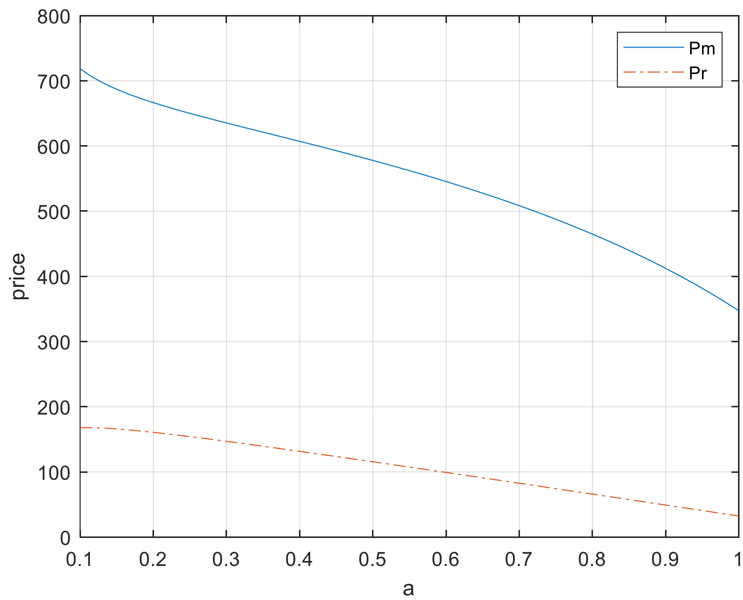

Fig. 2 The effects of inspection error a on pricing

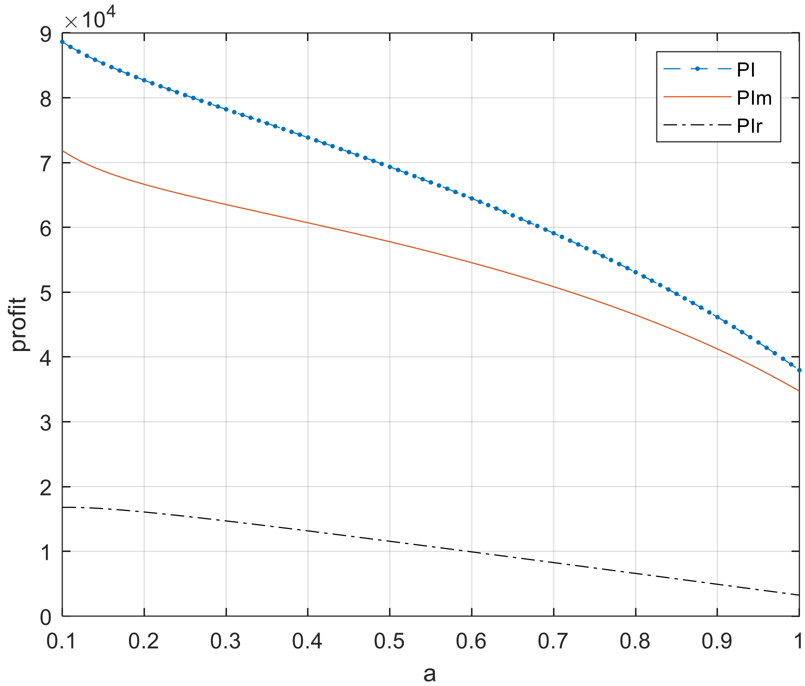

Fig. 3 The effect of inspection error a on profit

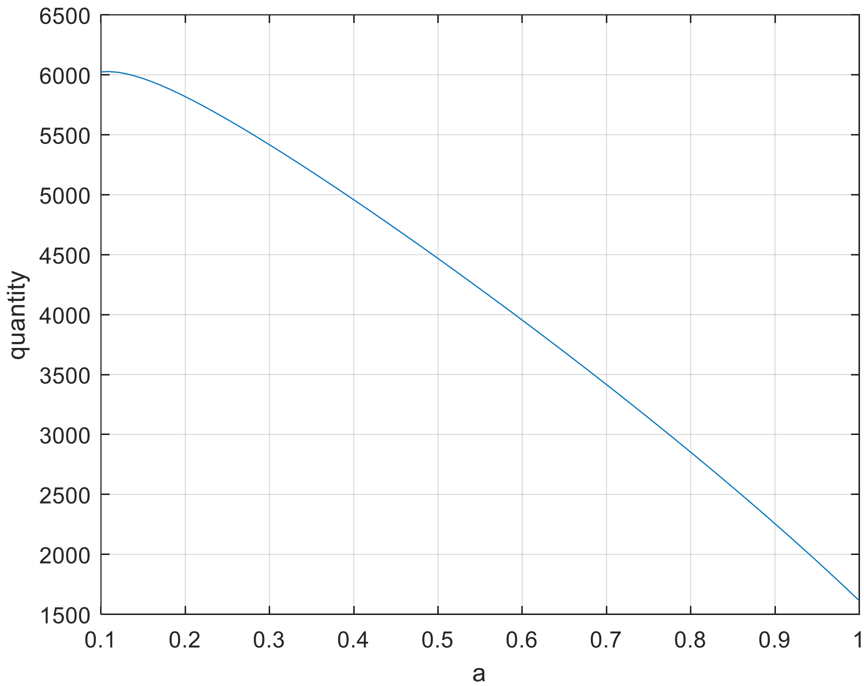

Fig. 4 The effect inspection error a on collection quantity

The influence of the inspection error a on profit, pricing and quantity is shown in Fig. 2 to Fig. 4. Manufacturers' and recycler’s profits are rising as the test error rate for non-remanufactured products is reduced. When the inspection error is the smallest, the remanufacturer can obtain the highest profit. The smaller the inspection error rate is, the higher the recycling quantity and price of used products. The recycling quantity is inversely proportional to the inspection error rate. The recycling quantity and price of used products are maximized when the inspection error rate a approximately is 0.11, and the recycler can get the maximum profit.

In order to analyze the impact of the reinvestment cost on the profit and pricing, we perform a sensitivity analysis on the parameter v. The analysis results are shown in Table 3 and Table 4. In the reverse supply chain consisting of a remanufacturer and a recycler under the Stackelberg equilibrium decision, by comparing the same inspection error, the reinvestment cost v is taken as 10, 12, 14, 16, 18 and 20, and the influence of the reinvestment cost v on the recycle price, quantity and profit can be obtained. The reinvestment cost v is in direct proportion to the recycle price of the remanufacturer. The lower the reinvestment cost v of the reverse supply chain is, the higher the recycle price of the recycler is, and the higher the recycle quantity is.

Table 3 Pricing and quantity comparison for recycling with different values of parameter a and v

v \ a		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
10	P_m^*	718.5	666.5	635.3	607.1	577.8	545.5	508.4	464.8	412.2	347.3
	P_r^*	167.8	160.7	146.9	131.6	115.5	99.14	82.58	65.91	49.16	32.35
	Q	6024	5818	5416	4958	4468	3954	3416	2852	2256	1614
12	P_m^*	733.2	674.3	640.8	611.5	581.6	548.9	511.6	467.9	415.3	350.4
	P_r^*	163.9	158.7	145.6	130.6	114.7	98.48	82.02	65.42	48.72	31.95
	Q	5910	5760	5377	4928	4443	3933	3397	2835	2239	1598
14	P_m^*	747.9	682.1	646.3	616	585.5	552.4	514.8	471	418.4	353.5
	P_r^*	159.9	156.7	144.3	129.6	113.9	97.83	81.46	64.92	48.28	31.56
	Q	5796	5703	5338	4898	4419	3912	3379	2818	2223	1582
16	P_m^*	762.6	689.9	651.9	620.4	589.3	555.8	518.1	474.1	421.4	356.5
	P_r^*	156	154.7	143	128.6	113.1	97.17	80.89	64.43	47.84	31.16
	Q	5681	5645	5299	4868	4394	3891	3360	2801	2207	1566
18	P_m^*	777.3	697.7	657.4	624.9	593.1	559.3	521.3	477.2	424.5	359.6
	P_r^*	152	152.8	141.7	127.6	112.4	96.51	80.33	63.93	47.4	30.77
	Q	5566	5588	5260	4838	4370	3869	3341	2783	2191	1551
20	P_m^*	792	705.5	663	629.3	597	562.7	524.5	480.3	427.5	362.7
	P_r^*	148.1	150.8	140.3	126.6	111.6	95.85	79.76	63.44	46.96	30.37
	Q	5450	5530	5221	4808	4345	3848	3322	2766	2175	1535

Table 4 Profits comparison for reverse supply chain with different values of parameter a and v

v \ a		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
10	π_m	71852	66645	63525	60707	57780	54545	50839	46480	41225	34728
	π_r	16782	16067	14693	13155	11551	9914	8258	6591	4916	3235
	π	88634	82712	78218	73862	69331	64459	59098	53071	46140	37963
12	π_m	73322	67426	64080	61152	58163	54891	51162	46790	41530	35037
	π_r	16387	15869	14562	13056	11472	9848	8202	6542	4872	3195
	π	89709	83295	78641	74208	69635	64739	59364	53331	46402	38232
14	π_m	74792	68206	64634	61597	58546	55236	51485	47100	41836	35346
	π_r	15992	15672	14430	12958	11393	9783	8146	6492	4828	3156
	π	90784	83878	79064	74555	69939	65019	59630	53592	46664	38501
16	π_m	76261	68986	65188	62042	58929	55582	51807	47410	42142	35654
	π_r	15597	15474	14298	12859	11314	9717	8089	6443	4784	3116
	π	91858	84461	79487	74901	70243	65298	59896	53853	46926	38771
18	π_m	77731	69767	65743	62487	59312	55927	52130	47720	42447	35963
	π_r	15202	15277	14167	12760	11235	9651	8033	6393	4740	3077
	π	92933	85043	79910	75247	70547	65578	60163	54113	47187	39040
20	π_m	79201	70547	66297	62932	59695	56273	52453	48030	42753	36272
	π_r	14807	15079	14035	12661	11156	9585	7976	6344	4696	3037
	π	94008	85626	80332	75594	70852	65858	60429	54374	47449	39309

4. Conclusion

Based on the reverse supply chain system composed of a single manufacturer and a single retailer, this paper use game theory to construct the model, starts with the reinvestment cost to reducing inspection error of used product recycle, and draws the conclusion from the analysis. The reduction of recycle inspection error can greatly improve the profits of remanufacturers, recyclers and the whole supply chain.

The higher the reinvestment cost, the higher the profits of the remanufacturer and the overall supply chain, and the profits of the recyclers will increase with the reinvestment cost. Therefore, remanufacturers can consider increasing recycling price to encourage recyclers to reinvest costs and increase recycler’s enthusiasm for reducing inspection errors, so that more used products can be obtained, which can promote the increase of supply chain profits.

This article only considers the impact of reinvestment cost differences in a single-period supply chain on profits and pricing decisions. It only approximates the impact of inspection error factors in the real environment on the profits of remanufacturers and recyclers. The problems in the real recycling process are more complex and diverse, so the model needs more data and parameters for simulation and analysis in the future.

Acknowledgements

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