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The SD Model Analysis of Remanufacturing Supply Chain Considering Consumer Education

Yuting Li[1], De Xia[1], Wanting Zhao[1] and Yundong Zhang

[1]Wuhan University of Technology Wuhan China

Abstract. The development of remanufacturing industry cannot be separated from the acceptance and support of consumers. To some extent, it can promote the development of remanufacturing industry by improving consumers' environmental awareness. Based on the system dynamics, this paper established a two-level supply chain composed of manufacturer and the third-party recycler with government subsidies. Meanwhile, manufacturer educate consumers on environmental awareness by investing in green advertising. The research shows that consumer education can promote the development of remanufacturing supply chain, and in the early stage of remanufacturing, manufacturer can improve the profit level of remanufacturing supply chain by means of consumer education in the absence of government subsidies. But government participation in subsidies is more conducive to the long-term development of the remanufacturing industry. Compared with different government subsidies, when the government subsidize manufacturers, the effect of consumer education is the best, and the profit level of supply chain members is relatively high.

Keywords: remanufacturing, system dynamics, consumer education.

1. Introduction

With the development of economy and society, environmental protection and resource conservation have become the focus of discussion in all walks of life. As an important part of the closed-loop supply chain, remanufacturing can not only help the supply chain improve its economic benefits, but also attract the attention of manufacturers, governments and other social groups because of its environmental benefits. According to the existing remanufacturing practice, auto parts remanufacturing can recover about 70% of the added value contained in scrap products. Compared with original manufacturing, remanufacturing can save energy consumption by 60%, save material by more than 70%, reduce manufacturing cost by 30% to 50%, and the adverse impact on the environment is significantly lower than that of new manufacturing. Although the academic research on closed-loop supply chain and remanufacturing industry has gradually matured, the development of remanufacturing industry is still in its infancy in reality. In addition to remanufacturing technology, another important reason for the slow development of remanufacturing industry is the lack of recognition of remanufactured products by consumers. If consumers lack recognition of the remanufacturing industry, it will become a major barrier to the development of the remanufacturing industry. Besides developing the technology of the remanufacturing industry, the education of consumers' environmental awareness should be another important issue that the remanufacturing industry should pay attention to.

2. LITERATURE REVIEW

The development of remanufacturing industry cannot be separated from the promotion and encouragement of the government. How should the government regulate and provide subsidy policies has been widely concerned by the industry and academia. Xia et al.[1]analyzed the benefits of game subjects and consumers under three government subsidy scenarios: no subsidy, subsidy for remanufacturing enterprises and subsidy for remanufacturing consumers; Esenduran et al.[2] studied the influence of government recycling regulation on competition between original manufacturers and remanufacturers, and the results showed that government strengthening regulation could not always guarantee a higher remanufacturing rate. Meng et al.[3] started from the perspective of consumption subsidies provided by the government, and believed that if government subsidies could achieve coordinated distribution between manufacturers and consumers, profits of both manufacturers and consumers could be improved at the same time. But He at el.[4]

put forward while the government improve the level of subsidy is beneficial to the economic interests of the consumers and the whole supply chain, but may not be beneficial to the environment.

With the implementation of carbon emission policies around the world, the government has also put forward requirements for the manufacturing industry. Liu et al.[5] compared the implementation of carbon tax, carbon cap-andtrade policy and no carbon emission constraint, believed that carbon cap-and-trade policy was more conducive to the rapid development of remanufacturing industry. Xu et al.[6] further believed that the implementation of cap-and-trade policy in a closed-loop supply chain with professional recycling channels and facilities is more conducive to reducing carbon emissions.Through the study of carbon tax policies, Yenipazarli[7] found that a moderate carbon tax ratio can motivate enterprises to increase their investment in green R&D. but in the context of China, Hu et al.[8] proposed that on the premise of controlling total carbon emissions, carbon trading policies are more conducive to the development of remanufacturing.

While studying the internal mechanism of the remanufacturing supply chain, more and more scholars bega n to consider the impact of consumer education on theremanufacturing industry. Zsoka et al.[9] proved empirically that environmental education can improve the awareness of sustainable consumption, while Abbey et al.[10] also proved that green consumers and those who agree with the green attributes of remanufactured products are more inclined to choose remanufactured products. Obviously, the education of consumer environmental awareness has become a crucial part of the development of remanufacturing industry. Zhou et al.[11] defined consumer education as a process in which stakeholders carry out marketing and publicity activities to increase the number of consumers willing to accept remanufactured products, and proposed that appropriate consumer education is conducive to remanufacturing; Giovanni[12] believed that through the combined maximization incentive mechanism of retailers, manufacturers could increase their efforts in green advertising and increase the recovery rate of waste products; Xiang et al.[13] on the basis of big data marketing, believed that the overconfidence of network recycling platform (IRPS) is conducive to improving the overall profit of closed-loop supply chain; Taboubi[14] proposed that manufacturers provide both price and green advertising incentives as channel coordination through dynamic game, and advertising can improve brand goodwill.

Many scholars adopted the system dynamics method to solve the remanufacturing problem in the closed-loop supply chain. Tian et al.[15] used the system dynamics model to study the role of government policy regulation in the environmental recovery of waste household appliances; Chang et al.[16] discussed the remanufacturing of auto parts under different policies such as carbon tax and subsidy. Further, Fu et al. [17] explored the role of government regulation in the ecological dismantling of waste products based on system dynamics and evolutionary game. Zhang et al.[18] constructed a system dynamics model for quality control of remanufactured products, believing that the manufacturer's production technology level has a great influence on the quality performance of remanufactured products.

To sum up, many scholars have discussed government subsidies in the remanufacturing supply chain or the impact of consumers' environmental awareness on remanufacturing. In this paper, consumer education and government subsidies are combined to establish a cross-border system dynamics model and try to solve the following problems :(1) what is the impact of consumer education on manufacturer's own profit and the profits of the overall supply chain? (2) Under the same level of government subsidy, how should the government choose the subsidy target in order to improve consumers' environmental awareness? (3) How will the profits of supply chain members change under different subsidy policies and consumer education intensity?

3. System Dynamic Analysis

3.1. Background of Model

This paper established a two-level supply chain composed of manufacturer and the third-party recycler, manufacturer is responsible for the production of new products and manufacturing products again. At the same time, the green advertising of remanufactured products is put into the market, in order to improve consumers' green awareness of remanufactured products and carry out consumer education. The third-party recycler is responsible for cleaning of waste products, dismantling detection and other businesses, recycling

and processing into usable remanufactured parts to sell to manufacturers, while the third-party recycler regularly updates the equipment to improve the availability of waste products. The government subsidizes the remanufacturing supply chain to promote the development of the remanufacturing industry. According to different subsidy objects, there are three subsidy strategies: no subsidy, subsidizing manufacturers and subsidizing the third-party recyclers. And the government allocates a certain carbon quota according to the production capacity of the manufacturer. When the annual carbon emission of the manufacturer is less than the carbon quota stipulated by the government, the manufacturer can trade in the carbon trading market. After years of research, environmental accounting has clarified the definition of environmental profit and environmental cost. According to the definition of environmental cost and environmental profit by Wang[19] and Meng[20], In this paper, the manufacturer's environmental profit includes the net profit obtained from the production of remanufactured products, carbon emission trading volume, government subsidies for remanufactured products, and the manufacturer's environmental cost includes the cost to be paid for the production of remanufactured products, green advertising investment .The environmental profit of the third party recycler includes the net profit obtained by recycling and processing waste products and the government's subsidy for recycling and processing waste products. And the environmental cost of the third-party recycler includes the recycling and processing cost of waste products and the cost of updating the recycling and processing equipment.

3.2. Analysis of Systematic Causality

Firstly, from the perspective of the manufacturer and the third-party recycler, the causal flow chart of their participation in the remanufacturing process was drawn respectively, and the relevant influencing factors and their relationship were analyzed.As Fig.1 showed.

The main feedback loops in the manufacturer's remanufacturing process are shown below.

(1)Manufacturer's environmental profit→+ manufacturer's green advertising investment→+ consumption enthusiasm→+remanufacturing product sales volume → + manufacturer's environmental profit.

(2)Manufacturer's environmental profit→+ manufacturer'sgreen advertising investment→+ consumption enthusiasm → +remanufacturing product sales volume → + government subsidy →+ manufacturer's environmental profit.

(3)Manufacturer's environmental profit→ + production of remanufactured product → + manufacturer's carbon trading income→+ manufacturer's environmental profit.

(4)Manufacturer's environmental profit→+ manufacturer's green advertising investment → + manufacturer's environmental cost →- manufacturer's environmental profit.

The main feedback loops in the remanufacturing process involving third-party recyclers are shown below. As Fig.2 showed.

(1)The third party recycler‘s environmental profit → +production of remanufactured component → + sales of remanufactured parts → + government subsidy→ + the third party recycler‘s environmental profit.

(2)The third party recycler‘s environmental profit → +renewal cost of recycling processing equipment→+ production of remanufactured parts + sales volume of remanufactured parts→+ the third party recycler‘s environmental profit

(3)The third party recycler‘s environmental profit→+ the cost of upgrading the recycling processing equipment→+ thethird party recycler 's environmental cost→ - The third party recycler‘s environmental profit.

3.3. Stock Flow Chart

Part of the experimental data in this paper is obtained from the existing actual production. According to BMW's remanufacturing practices, remanufacturing can reduce the average carbon emission of vehicles in the whole life cycle by at least 40% compared with the 2019 level, including 20% reduction at the supply chain end, 80% reduction at the production level. The survey shows that the average monthly sales volume of most new energy vehicles is 1,000 to 2,000, and the average international scrap rate is 4%-6%. Remanufactured products cost about 40 to 60 percent of the new ones.

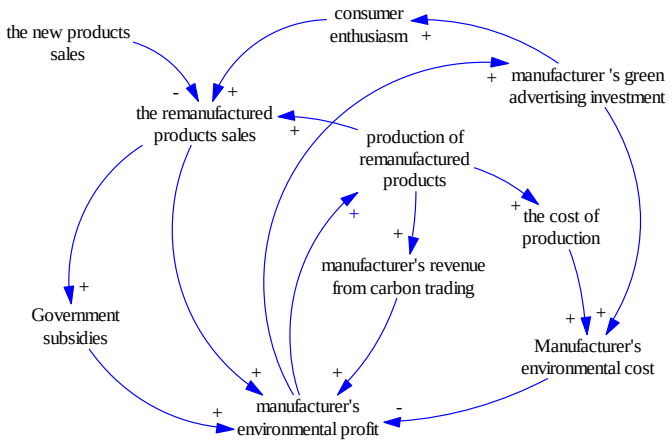

Fig. 1: Manufacturer's remanufacturing process causal diagram.

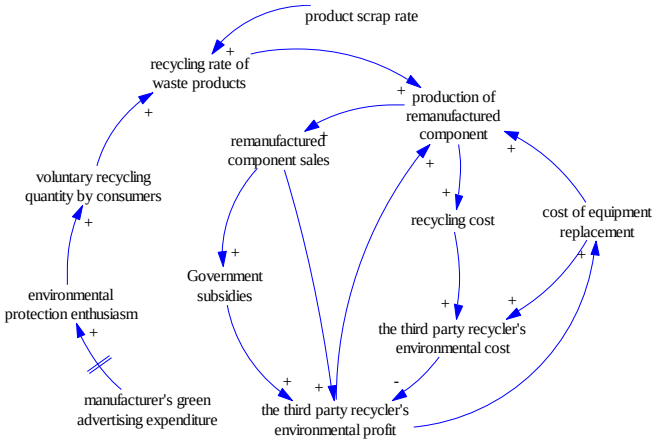

Fig. 2: The third-party recycling's remanufacturing process causal diagram.

Based on the causal diagram, the inventory and flow are distinguished and the inventory flow diagram is further improved. The overall inventory flow diagram of the remanufacturing supply chain is shown in the Fig.3 below. The main relevant rate variables and main equations are shown below:

(1)State variable: Inventory of remanufactured parts =INTEG(recycling rate of used products *(1- scrap rate of used components)- sales rate of remanufactured components + availability of remanufactured parts improved by equipment updating and improvement,0) (Unit: vehicle).

Rate variable: Recycling rate of waste products =0.5* Scrap rate of products + voluntary recycling amount of waste products (Unit: vehicle /month).

Rate variable: Sales rate of remanufactured parts = Inventory of remanufactured parts * Sales ratio (unit: vehicles/month).

(2)State variable: the third-party recycler’s environmental profit =INTEG(the third-party recycler’s environmental profit - the third-party recycler’s environmental cost,0)(Unit: Ten thousand)

Rate variable: the third-party recycler’s environmental income = price of remanufactured components * sales rate of remanufactured components *(1+ government subsidy to the third-party recycler* Proportion of government subsidy per unit of remanufactured components)(Unit: ten thousand /month).

Rate variable: the third-party recycler’s environmental cost =the cost for updating and improving the recycling equipment + recycling price of waste products * Recycling rate of waste products (Unit: ten thousand /month).

Auxiliary variable: the cost for updating and improving the recycling equipment = IF THEN ELSE(the third-party recycler’s environmental profit>0, (the third-party recycler’s environmental profit /(Time+1))*0.01, 0)(Unit: ten thousand /month).

(3)State variable: Inventory of remanufactured products =INTEG(production rate of remanufactured products - sales rate of remanufactured products,0)(Unit: vehicle).

Rate variable: production rate of remanufactured products = sales rate of remanufactured components (Unit: vehicle/month)

Rate variable: sales rate of remanufactured products =(the inventory of remanufactured products * the sales ratio of remanufactured products)*(1-the market crowding factor + consumer enthusiasm).

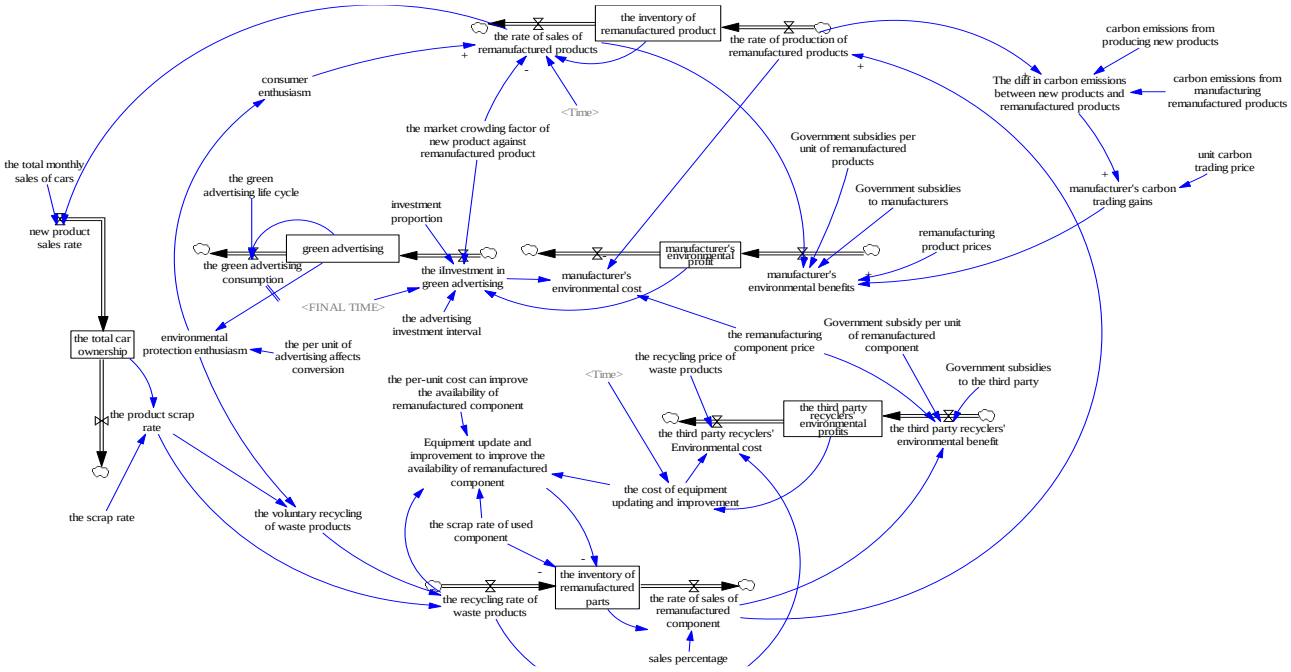

Fig. 3: Remanufacturing supply chain stock flow chart.

Auxiliary variable: environmental protection enthusiasm = (1-20/(green advertisement * conversion of influence per unit of advertisement +20))*STEP(1, 3)

(4)State variable: manufacturer's environmental profit =INTEG(manufacturer's environmental profit - manufacturer's environmental cost,0)(Unit: ten thousand).

Rate variable: manufacturer's environmental protection income=the price of remanufactured product *the sales rate of remanufactured product *(1+ proportion of government subsidies per unit of remanufactured product * manufacturer subsidized by government)+ manufacturer's carbon trading income (Unit: ten thousand/month).

Rate variable: manufacturer's environmental cost = production rate of remanufactured products * price of remanufactured components + investment in green advertising (Unit: ten thousand/month).

(5)State variable: Green advertisement =INTEG(investment in green advertisement - consumption of green advertisement,0)(Unit: ten thousand).

Rate variable: Green advertising investment =IF THEN ELSE(manufacturer's environmental profit >0 , 20*PULSE(0, 1)+ manufacturer's environmental profit *the market crowding factor * the investment ratio *PULSE TRAIN(advertising investment interval, 1, advertising investment interval, FINAL TIME), 0)(Unit: ten thousand/month)

Rate variable: Green advertising consumption =IF THEN ELSE(green advertising> 0, green advertising/green advertising life cycle, 0)(Unit: ten thousand/month).

(6) State variable: Total vehicle ownership =INTEG(New product sales rate - product scrap rate,100000).

4. Simulated Analysis

(1) Influence of consumer education

Conclusion 1: The higher the frequency of green advertising investment of manufacturers, the higher the environmental awareness of consumers, and gradually tend to saturation.

With the change of green advertising investment frequency of manufacturers, the profits of manufacturers and third-party recyclers will have different trends under the influence of consumers' environmental awareness. Obviously, it can be seen from FIG. 4 that if manufacturers maintain a high investment frequency in green advertising, consumers' enthusiasm for environmental protection will rise

significantly on the whole. In each interval, consumers' enthusiasm for environmental protection will first rise and then gradually decline. This may be because consumers' memory will gradually decline after a period of time, and consumers' freshness will gradually fade in the face of the same type of advertising. Therefore, consumers' enthusiasm for environmental protection will increase in the early stage of each stage when manufacturers reinvest, while it will relatively decline in the later stage.

Conclusion 2: Manufacturers' green advertising investment is beneficial to enterprises' long-term interests. The higher the frequency of manufacturers' green advertising investment, the greater the long-term interests of enterprises.

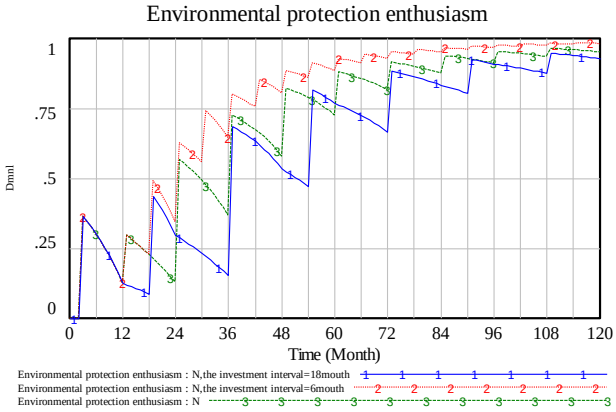

Fig. 4: Consumers' enthusiasm for environmental protection under different investment frequencies of green advertising.

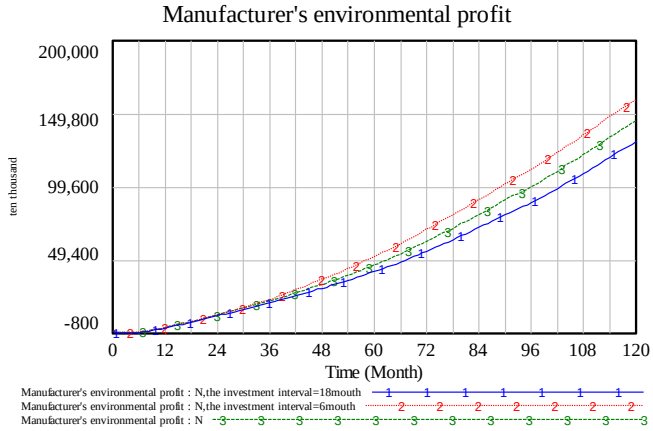

Fig. 5: Manufacturer's environmental profit under different investment frequencies of green advertising.

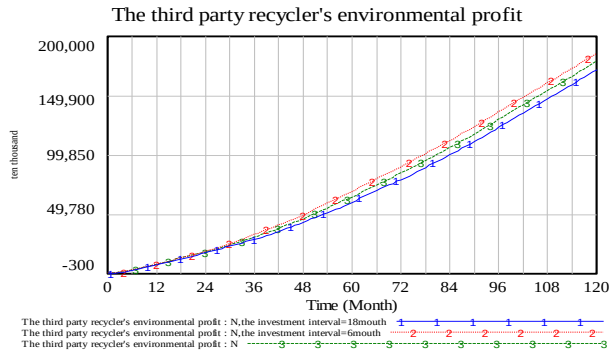

Fig. 6: The third-party recycler's environmental profit under different investment frequencies of green advertising.

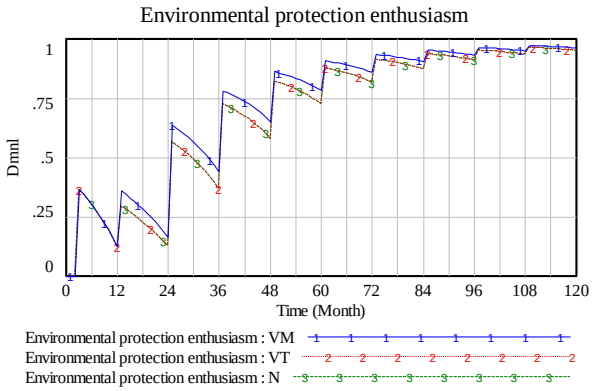

Fig. 7: Consumers' enthusiasm for environmental protection under different government subsidy policies.

From FIG.5 and FIG.6, in the early stage of green advertising investment by manufacturers, the effect of green advertising investment was not particularly significant, but starting from the third year, manufacturers green advertising investment frequency increase began to help manufacturers and the third-party recyclers profits rise, this is because manufacturers need to invest production costs and green advertising costs in the early stage, but consumers are still less receptive to remanufactured products at this time. For the third-party recyclers, the improvement of green advertising by manufacturers can help them to increase the voluntary recycling amount of waste products and expand the output of remanufactured parts.

(2) Comparison of government subsidy strategies

Conclusion 3: With the same level of government subsidies, government subsidies to manufacturers are more conducive to consumer education and profit improvement of supply chain members.

The difference in government subsidies has an impact not only on the profits of manufacturers and third-party recyclers, but also on the environmental enthusiasm of consumers. As can be seen from FIG.7 and FIG.8, with the same level of government subsidies, government subsidies to manufacturers are more conducive to the improvement of consumer enthusiasm and manufacturer profits, while there is little difference between subsidizing third-party recyclers and not subsidizing them. This is because the investor of green advertising is the manufacturer. When the government subsidizes the third-party recyclers, manufacturers will not be prompted to increase the intensity and frequency of investment in green advertising. However, consumer enthusiasm and voluntary recycling of waste products can only be improved through consumer education. When the government subsidizes manufacturers, manufacturers will increase the frequency of green advertising, and consumers will also increase their enthusiasm for environmental protection and consumption. As can be seen from FIG.9, for the third-party recyclers, with the same level of government subsidies, the third-party recyclers will benefit more directly from government subsidies.

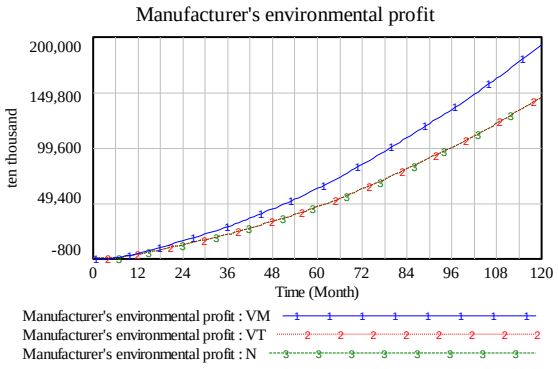

Fig. 8. Manufacturer's environmental profit under different government subsidy policies.

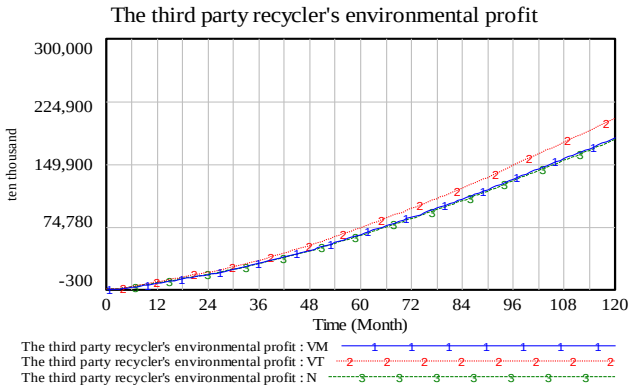

Fig. 9. The third-party recycler's environmental profit under different government subsidy policies.

5. Conclusions

Based on system dynamics, in the two-level supply chain composed of manufacturers and third-party recyclers, this paper discussed the problems of manufacturers investing in green advertising for consumer education and government subsidization for remanufacturing supply chain. Through simulation experiments, we get the following conclusions.

(1)In order to guide and promote the development of the remanufacturing industry, it is necessary for the government to participate in subsidizing the remanufacturing supply chain to regulate and restrict it. Meanwhile, the government's participation in subsidizing is also conducive to the improvement of consumers' enthusiasm for environmental protection. The results of this paper show that with the same level of government subsidies, government subsidies to manufacturers are more conducive to improving the profit level of the remanufacturing supply chain, and also more conducive to improving consumers' enthusiasm for environmental protection.

(2)Manufactures' green advertising investment has significant influence on the development of remanufacturing industry, with the deepening of the manufacturers of green advertising, more consumers would be willing to accept and buy remanufacturing product manufacturers to enhance green advertising at the same time, the profits will also increase, and the green advertising at the same time also benefits third-party recycler.

(3)In the early stage of remanufacturing, manufacturers' efforts in green advertising can make up for the lack of government subsidies, but the long-term development of remanufacturing industry needs the support of government subsidies.

The development of any industry is inseparable from the demand of consumers. Remanufacturing participants can not ignore the awakening of consumers' environmental awareness while improving their technical level. But the reality of consumers are influenced by environmental education is the process of the complex, need through the more ways, also provide inspiration and direction for future research. However, in reality, the process of consumers being affected by environmental education is complicated and needs to be described by more methods, which also provides inspiration and direction for future research.

6. Acknowledgements

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