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The Decision-Making Analysis on End-of-Life Vehicle Recycling and Remanufacturing under Extended Producer Responsibility Policy

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Abstract: This research develops a dual-cycle ELV recycling and remanufacturing system to better understand and improve the efficiency of the ELV recycling and remanufacturing businesses. For the flawless operation of this system, the researchers employed evolutionary game theory to establish a game model between original vehicle manufacturers (OVMs) and third-party recyclers with the government involved. This research presents evolutionary stable strategies (ESS) that could promote an ELV recycling and remanufacturing system. Results show that OVMs' expected profit difference between choosing and not choosing authorization is crucial in their ESS. The licensing fee plays a part of OVMs' expected profit difference. Based on the results, optimal ESS could be achieved when the OVMs' expected profit difference between choosing authorization and not choosing authorization and the third-party recyclers' profit when paying the licensing fee are both positive. Then, the two groups' involvement in dual-cycle ELV recycling and the remanufacturing system can be ensured. This research implicates the government to devise appropriate reward and punishment strategy to encourage OVMs and third-party recyclers to collaborate for efficient recycling and remanufacturing systems. Particularly, the government is suggested to impose strict restrictions on OVMs to carry ELV recycling and provide support to promote recycling quantity standards. Hence, the ELV recycling and remanufacturing system would be strengthened, thus improving waste management which is crucial for both environmental and resource efficiency.

Keywords: end-of-life vehicle; authorization; recycling and remanufacturing; double-cycle system; circular economy

1. Introduction

Over the last decade, China has dominated the whole world in terms of vehicle sales. Such rapid growth in vehicle sales has also resulted in a substantial increase in the country's total number of end-of-life vehicles (ELVs) [1]. Due to this, China is currently facing a significant challenge of car recycling where a vast quantity of ELVs need to be disposed of or recycled. Dismantling such a large number of ELVs can cause severe pollution to the surroundings [2]. Hence, there would be a significant increase in China's total quantity of waste if these ELVs are not adequately recycled [3]. On the other hand, these ELVs can significantly contribute to efficient resource utilization and economic development through proper recycling. Meanwhile, with the influential circular economy concept, the ELVs have gained significant attention from researchers. It is estimated that 89% of recycled ELVs would be contributing to the Gross Domestic Product (GDP) of Europe by 2030 [4]. Many developed countries, including Germany, America, the United Kingdom, and Japan, have recycled more than 85% of their ELVs [5]. However, compared with developed countries, the recycling system in China is still immature and lacks efficiency and performance [6]. Although Chinese authorities are developing various strategies to achieve an 85% recycling rate for ELVs, it is still tricky for the recyclers to achieve this target. It is reported that only 14.1% ELVs were collected in 2019 through official recycling channels [7]. There are various practical reasons behind the low recycling rate, for instance, lack of recycling technologies, inefficient recycling system, incomplete laws, and lack of environmental awareness among people [8]. Considering these, an efficient recycling system and perfect recycling policy have become major challenges that need to be aggressively addressed by the government of China [3].

In China, ELVs are being recycled through two main ways, including legal and illegal recycling channels. The legal channel, which constitutes licensed companies, plays a major role in the recycling industry, whereas the illegal recovery sector is also present for various socioeconomic reasons [9]. The legal channel is considered a rational utilization of resources as it provides economic benefits and environmental protection [10]. On the other hand, the illegal channel is causing severe adversities to both environment and society [11]. Similarly, nonstandard and inefficient recycling practices also cause tremendous environmental damage. Hence, the government of China has implemented various policies to promote legal and standard ELV recycling. The extended producer responsibility (EPR) policy has been implemented as a standard for remanufacturing to enact essential regulations on ELV recycling [12].

The EPR policy has become a popular tool that holds producers liable for their end-of-life products. It requires original vehicle manufacturers (OVMs) to take responsibility for the entire life cycle of a product, including collection, dismantling, and recycling at its end of life [13]. In turn, EPR reverses the underlying roles in the product life cycle by pursuing a dual objective, where it aims to put the responsibility on the producers for the cost of waste management. On the other hand, it also intends to improve product design to reduce those costs [14]. In doing this, EPR also forces producers to consider environmental aspects of their operations [15]. EPR also aims to promote waste management by incentivizing producers to consider environmental protections and implement effective recycling processes [16]. EPR has been widely adopted in Europe and other developed countries, resulting in improved resource recovery from waste material. However, it is observed that it does not provide valuable incentives for achieving higher levels of the waste hierarchy. Nevertheless, authorities in Europe have started to promote reuse activities under EPR schemes [17].

The Chinese authorities have recently implemented an EPR policy that requires OVMs to take responsibility for the entire life cycle of a product, including collection, dismantling, and recycling at its end of life [13]. EPR is adopted to ensure efficient legal recycling of ELVs, further sustaining consumer confidence in the OVMs. However, OVMs hesitate to invest in recycling because they fear losing their new product market share [1]. Various existing studies implied that the profitability of ELV remanufacturing plays a crucial role in OVMs' decision-making on ELV recycling [18]. It is difficult for legal OVMs to afford recycling costs, mainly when they fear losing their new product market share. Due to the stiff competition in China, most OVMs hold down their prices for new vehicles to win market share [1]. Suppose they take responsibility for their vehicles' whole life cycle; in that case, along with recycling ELVs, they also have to tackle environmental adversities by following expensive and standard processes. Besides, it is also a challenge to recover heavy investments in recycling the ELVs [19]. Thus, OVMs hesitate to undertake the ELV recycling business.

Moreover, there have been many qualified and professional ELV recyclers called third-party recyclers in China. They acquire the ELVs from the consumers and directly remanufacture them to be reused. In this process, these recyclers also generate economic benefits by selling the leftover parts and materials (metals and plastics) from ELVs [8]. Hence, in compliance with EPR, OVMs can ease their burden by collaborating with these third-party recyclers for ELV recycling and remanufacturing [20]. The Chinese government has also broadened the product range for ELV parts remanufacturing since 2020. It is an opportunity for the OVMs to benefit from ELV parts remanufacturing where ELVs are disassembled and their parts are repaired to be reused as new products. ELV remanufacturing operations are often required to adopt high-quality standards to improve OVM's brand equity and customers loyalty [18]. Further, ELV remanufacturing also reduces raw material costs, resulting in the lower price of the new product. Still, OVMs have to bear higher processing costs, so, they cannot offer competitive prices to the owners of ELVs. Resultantly, illegal recyclers take this opportunity and grab the market by providing higher prices as they do not consider standard processes and environmental protection [3]. This is the reason why authorities have to devise strategies to encourage OVMs to adopt standard recycling and remanufacturing business.

Various existing studies have investigated multiple recycling modes in the context of China. For instance, Wang et al. [21] state that OVMs select recycling mode depending on the quality of their waste products. Under the constraints of transfer payment and manufacturing cost, Tong [22] established a recovery model that associates the recovery channel's choice with the recovery rate. Next, Zhang et al. [23] analyzed three recycling modes with the manufacturer, retailer, and third-party involvement; their results showed that the third-party recyclers require high investment efficiency in the ELV recycling business. Similarly, Liu et al. [24] investigated different ELV recycling channels and suggested that collaboration-based recycling between OVMs and vehicle retailers is the best recycling mode. A collaboration-based strategy is also supported by the work of Ferrao and Amaral [25], which illustrated the interconnectedness of subsystems under the recycling industry. Considering China's national conditions, various other studies [26] have also analyzed recycling modes and concluded that third-party recycling could be a better choice as a recycling mode. Mainly, an inter-enterprise alliance could play a vital role in developing China's ELV recycling industry. Yang and Song [27] showed that acquisition price competition among recyclers significantly promotes the overall recycling rate.

Regarding the EPR system, Li and Zhu [28] analyzed ELV recycling to replace the new vehicles with the old ones. Their results show that the cost structure and ELV processing capability affect the OVMs' decision on third-party alliances for recycling. Similarly, Cao and Wu [29] conducted an in-depth analysis of the reward and punishment mechanism of the ELV recycling rate under the EPR policy. Their results suggested that although the reward and punishment system may enhance the number of collected ELVs, ELV part remanufacturing plays a more crucial role in OVMs' decision-making. According to Oersdemir et al. [30], ELVs' quality is the main factor determining recyclers' decision-making on remanufacturing rate, as both OVMs and independent remanufacturers prefer high-quality ELVs to maximize their profits by utilizing good quality ELV parts. Several studies [31,32] have also analyzed competition between OVMs and independent remanufacturers involved in ELV recycling and remanufacturing. Bulmus et al. [31] reported that the acquisition price of independent remanufacturers does not influence OVMs' acquisition price. Xia et al. [32] suggested that the OVMs should outsource the remanufacturing services to strengthen their competitive position and maximize their profits. Further, the literature also indicates that the government's environmental regulations and standard recycling processes play an essential role in improving value creation and reducing the ecological impact of ELV processing [33]. Several researchers have also focused on regulatory aspects of ELV recycling and remanufacturing. For example, Shih et al. [34] suggested that it is necessary to establish an environmental fund for ELV recycling and remanufacturing, and the government should take the responsibility of managing this environmental fund.

Similarly, Brain and Ravi [35] explored the environmental and economic performance of ELV recycling within an EPR program, and their results showed that EPR significantly enhances the ELV recycling rate and improves the environmental performance of the ELV recycling industry. The authors of [36] also argue that OVMs should share the responsibility of ELV recycling. Further, Duberg et al. [37] suggest that the government provide financial support to the OVMs to facilitate ELV remanufacturing. They also state that OVMs with mature vehicle manufacturing technology have the best capability for carrying ELV remanufacturing business.

Considering that OVMs still hesitate to invest in the recycling business because of their priority towards the new product market, researchers need to extensively analyze the ELV recycling industry and explore effective solutions to enhance the ELV recycling rate. Similarly, it is also important to understand the dynamics of OVMs' decision-making on ELV recycling. In addition to this, existing literature has also overlooked the concerns of OVMs concerning EPR policy and implementation. Only a few researchers have focused on both the recycling and remanufacturing under EPR while considering the collaboration of OVMs with third-party recyclers, which would ultimately shorten the payback period of ELV recovery for OVMs. To fill the aforementioned gap, this research aims to analyze China's ELVs recycling and remanufacturing system, consisting of three major parties: OVMs, third-party recyclers, and the government. Specifically, this research explores the ELV recycling market by developing an evolutionary game model between OVMs and third-party recyclers under the EPR policy. In this research model, we assumed that under EPR, the OVMs have the authority of ELV recycling and remanufacturing. At the same time, the OVMs and the third-party recyclers are both capable of acquiring ELVs from consumers. However, due to less accessibility to the consumers, third-party recyclers are more advantageous for recycling the ELVs. Due to the participants' information protection, it is challenging for the OVMs and third-party recyclers to rationalize their decision-making. So, it is assumed that both groups make decisions considering their profits with limited rationality. So, the evolutionary game theory was applied to analyze the group game between third-party recyclers and OVMs. Particularly, this research aims to explore the long-term evolution of the two groups (OVMs and the third-party recyclers) and provide an evolutionarily stable strategy, which can be the decision support for both OVMs and third-party recyclers to achieve a better Nash equilibrium.

This research provides policymakers a new dimension of understanding how OVMs make decisions regarding ELV recycling under EPR. Similarly, we also explore the potential role of third-party recyclers in facilitating efficient ELV recycling and remanufacturing system. This study can be the decision support for the OVMs to collaborate with third-party recyclers and provide the government an image of ELV recycling when both the OVMs and ELV recyclers exist in the market to devise better policies for facilitating ELV recycling and remanufacturing in China. Meanwhile, the analysis results also provide the government a full image of ELV recycling in terms of collaboration in the industry.

The remainder of this paper is organized as follows: Section 2 discusses the research method and developed evolutionary game model between OVMs, third-party recyclers, and the government. Next, Section 3 provides results and discussion. In the end, Section 4 presents concluding remarks and potential future research directions.

2. Research Model

2.1. Dual Recycling System

To explore the ELV recycling market under EPR policy, this research develops a dual recycling system by employing an evolutionary game model between OVMs and third-party recyclers under EPR policy. Under EPR, the authority of recycling ELV belongs to OVMs, which is also a way to avoid potential competitors for OVMs in the vehicle market. However, in our dual recycling system, both OVMs and third-party recyclers are considered capable of doing the recycling business. At the same time, the OVMs have expertise to remanufacture the ELV parts, whereas the third-party recyclers are more advantageous to acquire ELVs from consumers. So, the OVMs need to authorize the third-party recycler to recycle their ELVs by requiring a licensing fee. If the third-party recycler accepts the authorization, the OVM will buy the required disassembled auto parts from the third-party recycler and then decide the remanufacturing quantity. The third-party recycler will sell the left usable parts of ELVs to other manufacturers, such as the manufacturers for the recovery of metals and plastics.

Thus, the whole recycling and remanufacturing dual-cycle system can be established, as illustrated in Figure 1. The OVM leads one recycling cycle, and the third-party vehicle recycler leads the other cycle. The connection point between the two cycles is the third-party recycler. If the third-party recycler does not accept the authorization, the OVM has to build its own ELV recycling logistics. Implementing a dual cycle of ELV recycling and remanufacturing increases the value creation of ELV and decreases OVM's economic pressure from ELV remanufacturing. The ELV recycling strategy of OVM depends on the cost and benefit of ELV recycling and remanufacturing and the third-party recycler's acceptance of ELV recycling. In this dual-cycle system, the government acts as an external driving factor, ensuring the implementation of EPR and providing subsidies to OVM and third-party recyclers for promoting remanufacturing and recycling of ELVs.

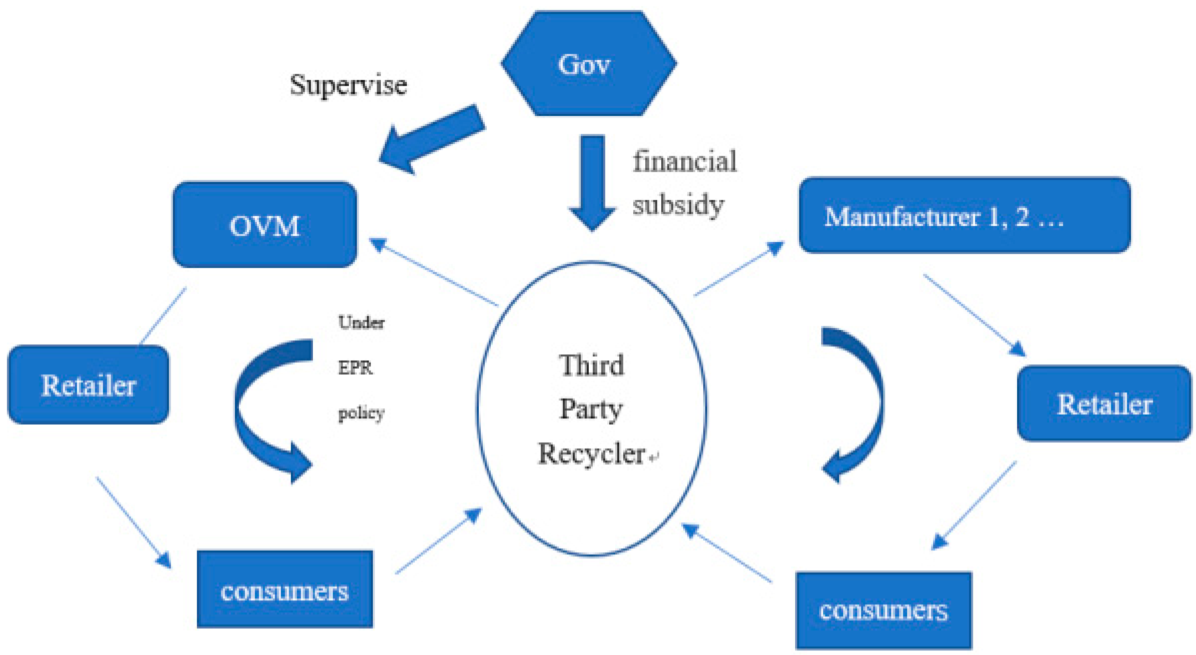

Figure 1. Dual-cycle ELV recycling and remanufacturing system.

When applying the dual-cycle recycling system to the ELV recycling and remanufacturing, we assumed that the two groups (OVMs and the third-party recyclers) have low rationality in decision-making on ELV recycling and remanufacturing. We used evolutionary game theory to analyze the decision-making of the two groups.

In this paper, for better modeling ELV recycling and remanufacturing, we assumed that under EPR, when the quantity of ELVs that the OVMs recycle reaches a certain level, the government decides whether the OVMs receive a penalty or reward based on the recycling standard. To soon achieve the circular economy, the government encourages OVMs to do ELV remanufacturing by providing valuable support. Besides, the ELVs needing to be recycled are the same in this model.

2.2. Model Construction and Analysis

One OVM decides whether to authorize one third-party recycler to do ELV recycling. If the OVM chooses to do authorization, the licensing fee (U) of their ELV recycling and the least ELV recycling quantity need to be determined. If the third-party recycler chooses to pay the licensing fee (U) to the OVM, it needs to acquire the ELVs from consumers and process them. Then the OVM buys the processed ELV parts from the third-party recycler for remanufacturing. In this research, we assumed the OVMs have no ELV recycling facilities, i.e., they need to invest more in acquiring ELV from consumers. If the OVM chooses to recycle the ELVs or the third-party recyclers do not pay the licensing fee, then the OVM builds its ELV recycling system and remanufactures the ELV parts. However, the OVM will not spare their resource for processing ELVs, which means they will have to dispose of the left parts of ELVs or sell them at a low price. So, the profit from the leftover parts of the ELVs almost offsets the treatment cost of the leftover parts of the ELVs. Hence, a successful dual cycle of ELV recycling and remanufacturing needs the two parties (OVM and the third-party recycler) to participate and cooperate in ELV recycling and remanufacturing. This paper also assumed that every OVM has a similar quantity and quality of ELVs in the market, and the selling price of remanufactured parts is the same.

Then, we set several variables and parameters as follows Q: the number of ELVs the third-party recycler decides to recycle, when the third-party recyclers choose to recycle the ELVs.

W: the number of ELVs that OVM will recycle from consumers when the third-party recycler refuses to accept the authority of ELV recycling, $W \leq Q$.

c_t: the unit processing cost of ELVs for third-party recyclers.

c_m: the unit processing cost of ELVs for OVMs before remanufacturing when the OVM chooses to do ELV recycling itself.

c_r: the unit remanufacturing cost for OVM.

p_t: the unit acquisition price of ELVs for third-party recyclers to pay, which includes all the cost before the ELVs arrive at the third-party recyclers' processing site. For all third-party recyclers in this model, it is assumed that p_t is the same.

p_o: the unit acquisition price of ELVs for OVMs to pay, which includes all the cost before the ELVs arrive at OVMs' processing site. For all OVMs in this model, it is assumed that p_t: is the same.

p_r: the unit purchasing price of ELVs for OVM buying the remanufacturable parts from the third-party recycler, $p_r > p_o$, $p_r > p_t$.

p_s: the unit price of the remanufactured parts, $p_s > p_r > p_o$, $p_s > p_r > p_t$.

p_d: the unit selling price of the leftover parts that are not to be bought by the OVM.

S: the subsidy amount per unit ELV for third-party recyclers processing the ELVs.

K: the ELV recycling quantity standard for OVM recycling the ELVs from consumers when the OVM needs to acquire the ELVs from consumers themselves.

T: the ELV remanufacturing standard for rewarding OVMs, T < K.

R: the unit reward for OVMs for the recycled ELVs that exceed K.

P: the unit penalty for OVMs for insufficient ELV recycling below K.

G: the remanufacturing quantity of the ELVs parts that OVM decides to remanufacture, and the purchasing quantity of ELV from the third-party recycler is the same as G.

U: the licensing fee the third-party recycler needs to pay the OVM when the third-party recycler accepts the ELV recycling authorization.

r: the unit reward for OVMs for the remanufacturing ELVs that exceed T.

When the OVM chooses to authorize the third-party recycler to do ELV recycling, and the third-party recycler accepts to pay the licensing fee, the OVM's profit will be:

$$\pi_m^1 = G * p_s + (G - T) * r - G * c_r - G * p_r + U \quad (1)$$

The third-party recycler's profit is:

$$\pi_t^1 = G * p_r + (Q - G) * p_d - Q * p_t - Q * c_t + S * Q - U \quad (2)$$

When the OVM has to do recycling and remanufacturing, or the third-party recycler refuses to pay the licensing fee to the OVM, the OVM's profit will be:

$$\pi_m^2 = G * p_s + (G - T) * r + (W - K) * R - (K - W) * P - G * c_r - W * c_m - W * p_o \quad (3)$$

The third-party recycler's profit is:

$$\pi_t^2 = 0 \quad (4)$$

To further show the relationship between the OVMs and third-party recyclers in the dual-cycle model, the OVM and third-party recycler's decision tree on ELV recycling is given below (Figure 2).

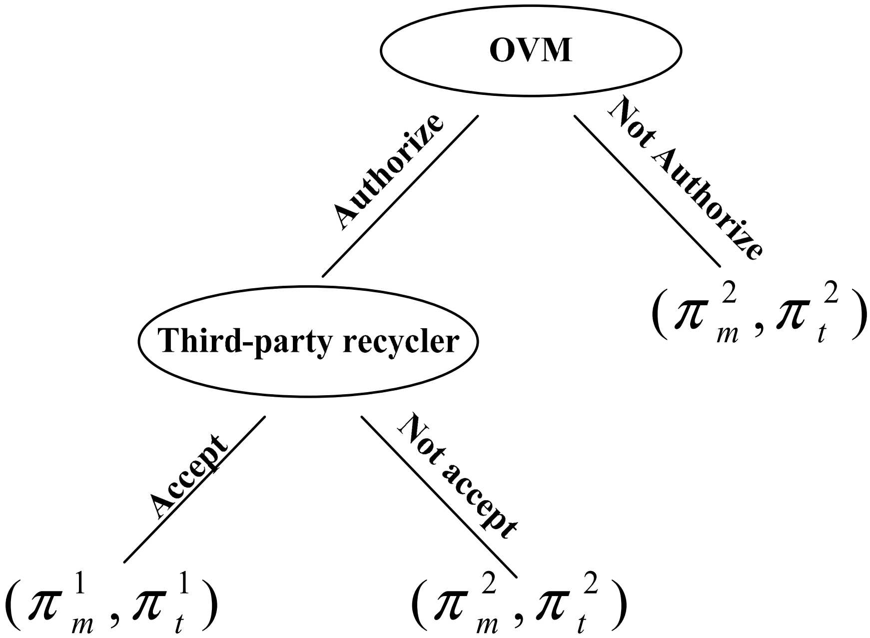

Figure 2. Decision tree on ELV recycling in the game model.

Here, we assumed that the proportion of the OVMs that choose to authorize the third-party recyclers to do ELV recycling is x,and $1 - x$ the proportion of the OVMs that choose not to do authorization of ELV recycling. Similarly, we assumed that y is the proportion of the third-party recyclers who decide to pay the licensing fee to OVM and do ELV recycling, and $1 - y$ is the proportion of the third-party recyclers who decide not to pay the licensing fee OVM. So, given that the OVMs and third-party recyclers have insufficient rationality during decision-making, we did the replicated dynamic analysis of this model.

Then, the expected profits for the OVMs that take different strategies are:

$$u_{m1} = y * \pi_m^1 + (1 - y) * \pi_m^2 \quad (5)$$

$$u_{m2} = \pi_m^2 \quad (6)$$

Then the average expected profit for the OVMs is:

$$\overline{u}_m = x * u_{m1} + (1 - x) * u_{m2} \quad (7)$$

The expected profits for the third-party recyclers that take different strategies are:

$$u_{t1} = x * \pi_t^1 \quad (8)$$

$$u_{t2} = 0 \quad (9)$$

Then, the average expected profit for the third-party recyclers is:

$$\overline{u}_t = xy * \pi_t^1 \tag{10}$$

The replicated dynamic equation of OVMs is:

$$\begin{aligned} \frac{dx}{dt} &= x * (1-x) * (u_{m1} - u_{m2}) \\ &= xy * (1-x) * (\pi_m^1 - \pi_m^2) \qquad (1 \geq x, y > 0) \\ &= xy * (1-x) * (U - G * p_r + W * p_0 + (K - W) * P - (W - K) * R) \end{aligned} \tag{11}$$

Because $y > 0$, we need focus on $\pi_m^1 - \pi_m^2$, When $\pi_m^1 - \pi_m^2 > 0$, $x* = 0$ and $x* = 1$ both are the stable state of OVMs. $x* = 1$ is the evolutionary stable state (ESS). While, when $\pi_m^1 - \pi_m^2 < 0$, $x* = 0$, and $x* = 1$ both are also the stable state of OVMs. However, the ESS is $x* = 0$ (See Figures 3 and 4). In addition, K and P both are proportional to the value of $\pi_m^1 - \pi_m^2$, while R has an inverse relationship with $\pi_m^1 - \pi_m^2$. The reward r for OVMs remanufacturing has no impact on the $\pi_m^1 - \pi_m^2$. U is positively affecting the value of $\pi_m^1 - \pi_m^2$. (Figures 3 and 4)

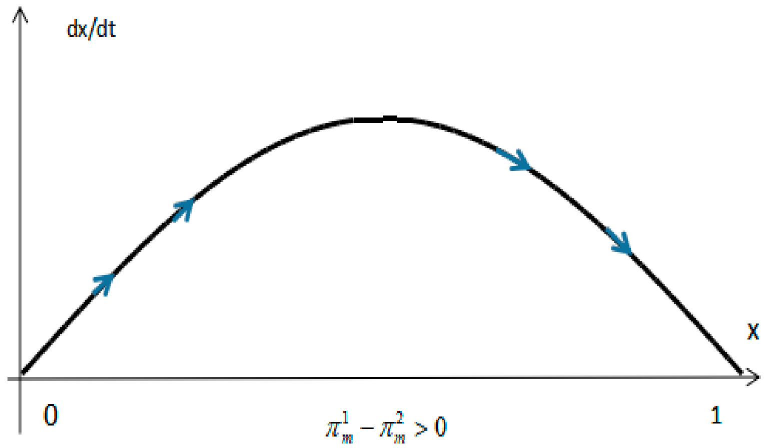

Figure 3. Replication dynamics phase diagram of OVMs when $\pi_m^1 - \pi_m^2 > 0$.

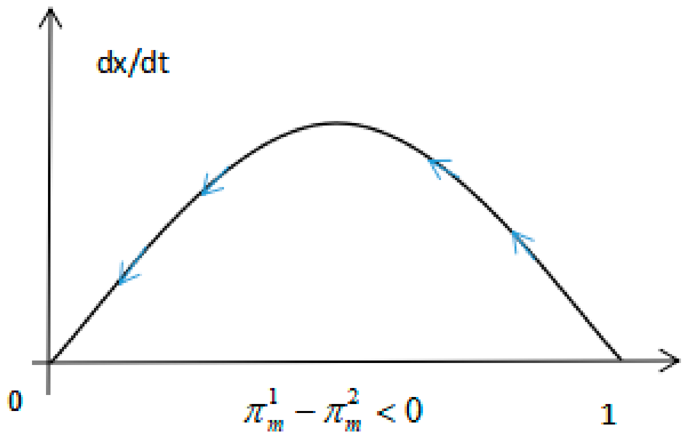

Figure 4. Replication dynamics phase diagram of OVMs when $\pi_m^1 - \pi_m^2 < 0$.

The replicated dynamic equation of the third-party recyclers is:

$$\begin{aligned} \frac{dy}{dt} &= y * (1-y) * (u_{ti} - u_{t2}) \\ &= xy * (1-y) * \pi_t^1 \qquad (1 \geq x, y \geq 0) \\ &= xy * (1-y) * (G * p_r + (Q - G) * p_d - Q * p_t - Q * c_t + S * Q - U) \end{aligned} \tag{12}$$

Similarly, when $\pi_t^1 > 0$, $y* = 0$ and $y* = 1$ both are the stable state of -party recyclers. $y* = 1$ is the evolutionary stable state (ESS). While, when $\pi_t^1 < 0$, $y* = 0$ and $y* = 1$

both are also the stable state of third-party recyclers. However, the ESS is $y* = 0$ (See Figures 5 and 6). Further, S is proportional to the value of π_t^1, while in third-party recyclers' replicated dynamic equation, U is negatively associated with π_t^1. (Figures 5 and 6).

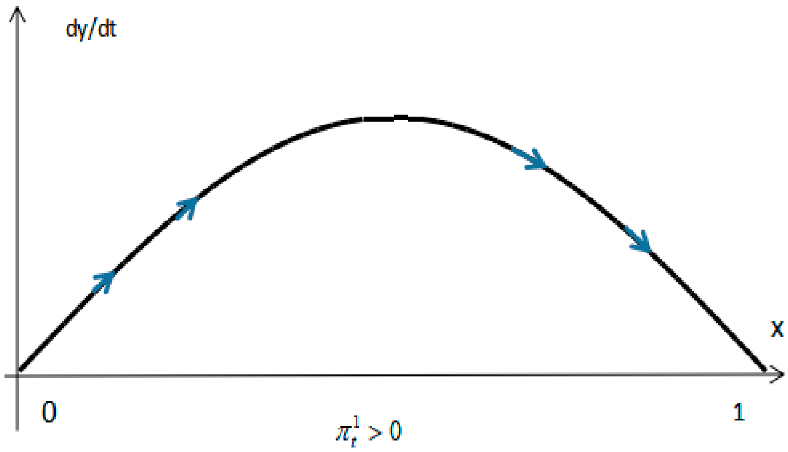

Figure 5. The replication dynamics phase diagram of third-party recyclers when $\pi_t^2 > 0$.

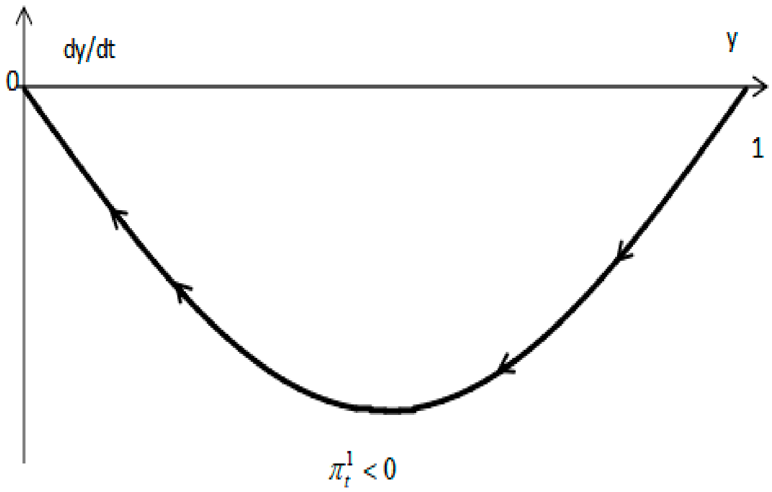

Figure 6. The replication dynamics phase diagram of third-party recyclers when $\pi_t^1 < 0$.

So, in this game between OVMs and the third-party recyclers, there are two evolutionary stable strategies: $x* = 1, y* = 1$, and $x* = 0, y* = 0$. We can see the relationship and stability of the replication dynamics of OVMs and third-party recyclers in Table 1. The ESS is associated with the value of $\pi_m^1 - \pi_m^2$ and π_t^1, which are given below:

$$\begin{aligned}\pi_m^1 - \pi_m^2 &= U - G * p_r + W * p_0 + (K - W) * P - (W - K) * R \\ &= U - G * p_r + W * (p_0 - P - R) + K * (P + R) \\ &= U - G * p_r + (K - W)(P + R) + W p_0\end{aligned} \tag{13}$$

$$\begin{aligned}\pi_t^1 &= G * p_r + (Q - G) * p_d - Q * p_t - Q * c_t + S * Q - U \\ &= G * (p_r - p_d) + Q * (p_d - p_t - c_t + S) - U\end{aligned} \tag{14}$$

Table 1. ESS Results.

Condition	ESS
$\pi_m^1 - \pi_m^2 > 0, \pi_t^1 > 0$	(1, 1)
$\pi_m^1 - \pi_m^2 < 0, \pi_t^1 < 0$	(0, 0)
$\pi_m^1 - \pi_m^2 > 0, \pi_t^1 < 0$	(0, 0)
$\pi_m^1 - \pi_m^2 < 0, \pi_t^1 > 0$	(0, 0)

So, in this study the ESS of the group game on ELV recycling between OVMs and third-party recyclers depends on OVM's profit difference between the third-party recycler taking the authorization and not taking the authorization of ELV recycling, and third-party recycler's profit when he takes the ELV recycling authorization. The unit price of the remanufactured parts, p_s, has no impact on the ESS.

3. Results and Discussion

The successful dual-cycle evolution mainly depends on the participation of OVMs and third-party recyclers. The results show that OVMs' ESS of authorization depends on the expected profit difference between choosing authorization and not choosing authorization. Besides, results reveal that the licensing fee determined by the OVMs for third-party recyclers is also crucial; it positively influences the OVMs to take the authorization strategy but negatively affects the third-party recyclers to pay the licensing fee. The optimal ESS is that all the OVMs choose to do authorization, and all the third-party recyclers pay the licensing fee to the OVMs. Based on the results, optimal ESS is achieved through the evolutionary process when the OVMs' expected profit difference between choosing authorization and not choosing authorization and the third-party recyclers' profit when choosing to pay the licensing fee are both positive. Then, the two groups' involvement in dual-cycle ELV recycling and the remanufacturing system can be ensured. On the other hand, results show that the selling price of remanufactured parts has no impact on ESS. It is noteworthy that the remanufacturing quantity of ELVs is negative with the OVMs' expected profit difference between choosing authorization and not choosing authorization, which means that the increasing of the remanufacturing quantity of ELVs will reduce the cooperation possibility between OVMs and third-party recyclers. The quantity of remanufacturing is affected by market demand and the cost of remanufacturing business, while the purchasing price of remanufactured ELV parts negatively affects ESS, which is the basic reason for the cooperation between OVMs and third-party recyclers on ELV recycling. Whether the related decisions can influence ESS depends on the connections between ELV authorization and associated decisions. In addition, the EPR policy restriction on OVMs also plays a positive role in the optimal ESS. Due to EPR, the OVMs have to participate in ELV recycling and remanufacturing. Further, the increasing of reward and penalty for OVMs on recycling quantity and the recycling quantity standard (K) of ELV will enhance the possibility of both groups' participation in the dual cycle of ELV recycling. When the recycling quantity standard (K) is higher than the ELV recycling quantity that OVM can acquire from consumers, the three parameters (reward and penalty for OVMs on recycling quantity and the recycling quantity standard (K) of ELV) have a positive relationship with OVMs' expected profit difference between choosing authorization and not choosing authorization.

However, like other developing countries, the cost of recycling and remanufacturing in China is still high; therefore, this system needs the government's support [38]. The results suggest that under EPR policy, the government could encourage the OVMs to do authorization by providing rewards when they choose to engage in the ELV recycling system. These findings are consistent with the existing studies [39,40], which suggest that the EPR provides the government the advantage of supervising ELV recycling and remanufacturing and makes OVMs undertake extra cost burdens for a long time. Moreover, cooperation with third-party recyclers can be a good solution for OVMs to manage the cost of recycling and remanufacturing of ELVs. The OVMs can do ELV recycling and remanufacturing, but they profit from the ELVs only through remanufacturing. The OVMs need to afford the ELVs' acquisition and processing costs and penalties when they cannot reach the ELV recycling standard. Therefore, they will probably choose to authorize third-party recyclers to do the ELV recycling if the recycling standard and penalty are high.

On the other hand, the results also suggest government should encourage third-party recyclers to pay the licensing fee to OVMs by providing subsidies on the ELV recycling cost. The licensing fee is a part of OVM's profit, but it is also part of third-party recyclers' cost. Therefore, the profit of third-party recyclers when they decide to accept the ELV recycling authorization should be ensured. Although recycling costs are the primary factor for third-party recyclers, remanufacturing quantity should also be considered. Hence, this research implicates that lower recycling costs and higher purchase of remanufacturable parts can enhance the third-party recyclers' decision to cooperate with OVMs.

Further, it is also found that the government reward for OVMs' ELV remanufacturing does not affect the OVMs' ESS, because it is provided under both strategies of authorization and not authorization. However, it is suggested that the government reward for OVMs' ELV remanufacturing will affect the remanufacturing quantity of OVMs [41]. In this research, EPR makes government policy connect with OVMs' profit of remanufacturing directly, which is an effective way to maximize the value of ELV considering OVMs' capabilities, such as understanding their products structure materials and owning the reutilization channel of remanufactured parts.

Their decisions are also dependent on the prices of remanufacturable auto parts and the remaining parts of ELVs, which means the consumers' recognition of the ELV parts affects the operation of the dual-cycle ELV recycling remanufacturing system [42,43]. The recognition of the remanufacturing vehicles determines the demand for ELV remanufacturing; further, the recognition of the other parts of ELVs also influences the selling price and the revenue of third-party recyclers. Hence, the consumers' recognition of the ELV parts could also be an important driving factor for the dual-cycle ELV recycling and remanufacturing system.

4. Conclusions and Policy Implications

However, compared with the ELVs quantity generated in China, the ELV recycling rate in China is still low due to the inefficient recycling system. Therefore, authorities and researchers are continuously looking for the optimal solutions to promote and strengthen the ELV recycling and remanufacturing system in China. Hence, this research aims to improve the efficiency and value creation ability of the ELV recycling and remanufacturing sector through developing a dual-cycle recycling and remanufacturing system for ELVs. Then, a recycling and remanufacturing game model between OVMs and third-party recyclers with the government involved under EPR policy is established and analyzed. We employed evolutionary game theory to investigate the evolutionary stable state of two players. Results show that though the OVMs and third-party recyclers have limited rationality in decision-making, the ESS of the game is significantly dependent on the OVMs' profit difference between choosing authorization and not choosing authorization. Similarly, the ESS of the game is also related to the profit of third-party recyclers. Moreover, the recycling quantity standard and penalty for OVMs recycling is positively correlated with the dual-cycle ELV recycling and remanufacturing system operation. Further, it is also found that the reward for OVMs doing remanufacturing has no impact on the final ESS of the game. However, the licensing fee fixed by OVMs is found to play a crucial role in the ESS.

Based on the findings, this research provides various policy implications for the government to strengthen dual-cycle recycling and remanufacturing system operations. Most importantly, it implicates that the government should focus on the cost and profit structure of the OVMs and the third-party recyclers when improving ELV recycling rates and efficiency, especially when the ELV recycling and remanufacturing industries are still in an early stage. Various cost components such as technology, infrastructure, and labor costs play a crucial role in restraining both OVMs and third-party recyclers from carrying ELV recycling operations. In addition, before setting the reward and penalty and the ELV recycling quantity standard for the OVMs, the OVMs' capability of ELV recycling from consumers should be understood. Next, the government should also develop subsidy strategies to support and encourage third-party recyclers to implement standard recycling processes. Regarding EPR policy, the government should also resolve concerns of OVMs to help and encourage them to efficiently utilize ELVs. The government should also influence OVMs to authorize third-party collaboration by setting high recycling standards and imposing penalties.

Moreover, it is also implicated that the dual-cycle ELV recycling and remanufacturing system would help improve ELV recycling rates and efficiency. Hence, this dual-cycle ELV recycling and remanufacturing system would ultimately assist in protecting environment and enhancing resource efficiency. In addition, OVMs and third-party recyclers are suggested to understand each other's cost/profit structure, so that the authorization fee cannot be the barrier to their cooperation. Meanwhile, both groups should also continuously improve their technologies and reputation of ELV recycling and remanufacturing, which can significantly reduce their ELV processing costs. For OVMs, the remanufacturing quantity can enhance the possibility of dual-cycle ELV recycling implementation, and for the third-party recyclers, recycling quantity from consumers also can enhance the collaboration with OVMs.

Limitations and Future Research Directions

i. In terms of limitations, this research has developed its model based on the immature recycling and remanufacturing market, while different markets have different ELV recycling and remanufacturing levels. Therefore, it would be crucial to consider other markets and different city development levels in future studies.
ii. Besides, with the development of the circular economy and increasing market of remanufactured products, researchers should also conduct in-depth exploration of the competition between remanufactured vehicles and new vehicles in the future research.
iii. As our research model is a particular case for the ELV market, therefore, we also suggest researchers to extend the dual-cycle recycling and remanufacturing system to the other end-of-life product markets.
iv. At last, different research methodologies should also be incorporated in the future to explore better insights. For instance, survey methods and advanced evolutionary game theory could be useful in estimating more accurate results in the future.

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