Strategies for Reverse Logistics of E-commerce Company Electronic Waste based on Game Theory

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Abstract: The main parties involved in the process of implementing reverse logistics for electronic waste include e-commerce companies, service agencies, and individual consumers. This study utilizes game theory models and modern applied mathematics to focus on analyzing the interest relationships between e-commerce companies and various service agencies, as well as between e-commerce companies and individual consumers in China. An economic game relationship model is constructed to analyze the specific strategies and choices of each party. Game relationship between e-commerce companies and service agencies reveals that regulatory intensity and economic incentive mechanisms play a decisive role in motivating companies to participate in reverse logistics. By increasing rewards or penalties, service agencies can effectively promote companies to implement reverse logistics, achieving a balance between resource recovery and ecological protection. Game relationship between e-commerce companies and consumers indicates that consumers' environmental awareness and reporting behavior significantly influence corporate decisions. When consumers lack the willingness to participate due to high costs or low rewards, companies are more inclined not to implement reverse logistics. Conversely, appropriately increasing consumer reporting rewards and enhancing environmental awareness can drive companies to more actively establish reverse logistics systems.

Keywords: Reverse Logistics; Game Theory; Electronic Waste

1. Introduction

According to the 2021 online shopping market survey results from the China Internet Network Information Center (CNNIC), over 90% of electronic waste in China are purchased by consumers via e-commerce websites. However, due to rapid technological development and increasing consumer level, electronic waste is quickly becoming obsolete, generating a large amount of electronic waste. This waste includes discarded computers, mobile phones, and other electronic devices from households and businesses. Often, this electronic waste contains complex components, including recyclable precious metals like copper, gold, and silver, as well as toxic substances like mercury and chromium, emitting significant amounts of sulfur dioxide, carbon dioxide, and other gases, causing irreversible damage to the ecological environment.

This study has found that while scholars mainly focus on the issues of reverse logistics for electronic waste, there is a lack of game theory on the different interest relationships among the main participants in the implementation of reverse logistics for electronic waste. This paper adopts a scientific method that combines qualitative and quantitative approaches, using game theory and commonly used mathematical methods to construct a game analysis model between e-commerce companies and service agencies, as well as between e-commerce companies and consumers. The paper analyzes the specific strategies and choices of each game participant and then makes corresponding suggestions for the development of reverse logistics for electronic waste.

2. Literature Review

In recent years, the field of reverse logistics has received significant attention due to its crucial role in sustainable development and resource conservation. Various studies have explored different aspects of reverse logistics. Brito and Dekker (2004) provided an early framework for reverse logistics, emphasizing its importance in modern supply chains [1]. Kannan et al. (2015) conducted a comprehensive review of reverse logistics and closed-loop supply chain research to identify gaps and suggest future research directions [2]. Osman et al. (2019) developed a fuzzy mixed integer location-allocation model for the reverse logistics network of end-of-life vehicles [3]. U-Dominic et al. (2021) analyzed the barriers to reverse logistics implementation using a hybrid model [4]. Fanta and Pretorius (2022) investigated the role of reverse logistics in facilitating the circular economy in the healthcare sector and the impact of Industry 4.0 digital technologies [5]. Sun et al. (2022) defined Reverse Logistics 4.0 and proposed a conceptual framework for its smart and sustainable transformation [6]. Egri et al. (2023) focused on robust facility location in reverse logistics, considering economies of scale and the robustness of the problem [7].

Dabo and Hosseinian-Far (2023) proposed an integrated method combining binary logistic regression and decision trees to optimize reverse logistics flows and networks within the Industry 5.0 framework, emphasizing the integration of advanced technologies and human-centered approaches [8]. Biancolin et al. (2024) systematically reviewed scientific articles to understand how circular economy principles apply to reverse logistics processes and detect changes based on different factors [9]. Salas-Navarro et al. (2024) conducted a bibliometric analysis on reverse logistics and sustainability, identifying research trends and potential applications [10].

Previous research has provided valuable insights for this study. However, specific research on the game theory of reverse logistics in the electronics industry is relatively limited. This paper aims to fill this gap by conducting a detailed game theory analysis of reverse logistics in the electronics sector, considering various stakeholders and their strategic interactions.

3. Development Status of Reverse Logistics for Electronic Waste

The logistics distribution system usually includes forward logistics and reverse logistics, with the term "logistics" mainly referring to forward logistics. The term "reverse logistics" was first mentioned by the renowned scholar Stock in a research report for the American Transportation Management Association in the 1990s, mainly referring to the recycling of waste items and the return and exchange process of problem products, with rational disposal.

In recent years, with the rapid development of the economy and technology, various new electronic products have rapidly become popular [11]. In China, as an emerging high-tech populous country, produces a huge amount of electronic waste items. According to data released by the China Recycling Resources Recycling Association, since 2020, the number of various electronic waste discarded annually in China has exceeded 160 million units, many of which have not been properly recycled and processed.

At present, China's forward logistics has developed from its initial formation to now having a considerable operating scale through years of effort and development. Continuous breakthroughs in infrastructure equipment technology have played a certain driving effect on the long-term healthy development of China's reverse logistics for electronic waste. For instance, the Qingdao Haier Group has successfully established China's first demonstration base for recycling and processing waste household appliances. Such infrastructure achievements have played a leading role in the development of China's environmental protection efforts.

At present, the companies in China that implement reverse logistics models for electronic waste mainly include large home appliance enterprises such as Haier, Suning, and Gome Online. These companies have the advantage of strong financial resources, which enables them to withstand various risks; they also have a strong sense of social responsibility and actively respond to the national call for "carbon reduction." Apart from these, there are very few e-commerce companies that implement a reverse logistics system for electronic waste in the market. Many companies only handle the sale of electronic waste to consumers and provide warranty and exchange services for electronic waste within a certain period, without establishing or joining a reverse logistics system. As a result, there is currently no sound regulatory system for reverse logistics of electronic waste, and individual participants often have disagreements over issues such as the recycling prices of waste electronic waste. Some even use counterfeit electronic waste to meet quotas, making the management process of reverse logistics for electronic waste even more difficult.

In the process of implementing reverse logistics for electronic waste, e-commerce companies mainly face difficulties such as high recycling costs, expensive waste treatment equipment, and complex technology. Waste from electronic waste usually produces a large amount of carcinogenic substances, radioactive elements, and other harmful materials. If not handled timely or properly, long-term exposure can harm human health and nature. Handling these electronic waste requires professional technology and specialized equipment. The types and versions are not uniform, and the newness, disassembly level, and source of reverse logistics electronic waste vary greatly, increasing the operational difficulties for staff and invisibly increasing the operational costs and time costs for companies. In addition, factors such as equipment safety and social influence must also be considered, and e-commerce companies implementing reverse logistics for electronic waste need to bear the processing costs and risks.

4. Game Theory Analysis of Reverse Logistics for Electronic Waste

In a context where environmental awareness is increasingly valued, e-commerce companies are gradually realizing the importance of conducting reverse logistics for electronic waste. However, the implementation process requires significant investments of time, manpower, and resources, and most e-commerce companies are still reluctant to build a reverse logistics system for electronic waste. Intensity of policy implementation and consumers' awareness of protecting their own legal interests will affect the enthusiasm of e-commerce companies to build a reverse logistics system. This paper constructs a game theory model about reverse logistics for electronic waste based on the interests of all three parties, conducts a game analysis, and establishes a long-term cooperative relationship of interests between e-commerce companies and service agencies, as well as between e-commerce companies and consumers.

4.1 Game Theory Analysis between E-commerce Companies and Service Agencies

4.1.1 Model assumptions

Only e-commerce companies and service agencies participate in this game, and both parties are bounded rational during the game process. E-commerce companies can choose strategies for reverse logistics: Implement (denoted as Z_1) or Not Implement (denoted as Z_2), thus their strategy space is $K_1\{Z_1,Z_2\}$. Service agencies can freely choose to regulate (denoted as J_1) or not regulate (denoted as J_2) based on whether e-commerce companies implement reverse logistics, and the agency's strategy space is $K_2\{J_1,J_2\}$. In the process of successfully implementing reverse logistics, e-commerce companies ultimately earn a profit of Q_1 and pay a cost of B_1. Therefore, the profit for companies not implementing reverse logistics is Q_1+B_1.

From the agency's perspective, to recycle resources and reduce the damage of electronic waste to the ecological environment, agencies award bonuses (denoted as M) to encourage companies to actively carry out reverse logistics for electronic waste. When companies respond to policy calls, the agency obtains the maximum benefit of Q_2; otherwise, the agency's benefit is Q_3. When the agency regulates the company's behavior throughout, it incurs a corresponding regulation cost of B_2. Under the condition of agency regulation, if the company successfully implements reverse logistics, the agency gives a certain level of reward (denoted as M_1); otherwise, it imposes a penalty on the company (denoted as D). When the agency does not regulate the company's behavior, the economic losses caused by environmental pollution due to the company not implementing reverse logistics are compensated by the service agency, with the post-compensation cost denoted as B_3.

Thus, there are four possible outcomes of the game between e-commerce companies and agencies: (Implement, Regulate), (Implement, Not Regulate), (Not Implement, Regulate), and (Not Implement, Not Regulate). The respective benefits in these four scenarios are shown in Table 1.

4.1.2 Game process analysis Assumptions:

E-commerce companies and agencies can

freely choose their strategies and can engage in repeated games;

Table 1. Benefits in Four Game Scenarios

		Agency Regulate ($\mathbf{J_1}$)	Agency Not Regulate ($\mathbf{J_2}$)
e-commerce company	Implement (Z_1)	Q_1+M+M_1, Q_2-B_2-M_1-M	Q_1+B_1+M-D, Q_3-M-B_2+D
	Not Implement (Z_2)	Q_1 + M, Q_2-M	Q_1+B_1+M,Q_3-M-B_3

At the beginning of the game, the probability that the agency chooses to regulate the e-commerce company's behavior is X (0<X<1), so the probability of the agency refusing to regulate is 1-X;

Similarly, the probability that the company chooses to implement reverse logistics is Y (0 < Y < 1), and the probability of refusing to implement is 1-Y.

From the agency's interest perspective, when choosing the regulation strategy, the agency's expected benefit is:

$$E_X = Y(Q_2 - B_2 - M_1 - M) + (1 - Y)(Q_3 - M - B_2 + D) \quad (1)$$

When choosing the non-regulation strategy, the agency's expected benefit is:

$$E_{1-X} = Y(Q_2 - M) + (1 - Y)(Q_3 - M - B_3) \quad (2)$$

Then, the agency's expected benefit from choosing a mixed strategy of regulation and non-regulation is:

$$E_G = XE_X + (1 - X)E_{1-X} \quad (3)$$

Similarly, expected benefits of the company for implementing reverse logistics are:

$$E_Y = X(Q_1 + M + M_1) + (1 - X)(Q_1 + M) \quad (4)$$

$$E_{1-Y} = X(Q_1 + B_1 + M - D) + (1 - X)(Q_1 + B_1 + M) \quad (5)$$

$$E_C = YE_Y + (1 - Y)E_{1-Y} \quad (6)$$

Because the interest game between agencies and e-commerce companies is long-term and complex, time factors need to be considered comprehensively. Therefore, dynamic equation for the agency choosing the regulation strategy and the company choosing the implementation strategy is:

$$\begin{cases} \frac{dx}{dt} = X(E_X - E_G) \\ \frac{dy}{dt} = Y(E_Y - E_C) \end{cases} \quad (7)$$

Substituting equations (1) ~ (6) into (7), we obtain:

$$\begin{aligned} \frac{dx}{dt} &= X(1 - X)[Y(- M_1 - B_2) + (1 - Y)(B_3 - B_2 + D)] \\ \frac{dy}{dt} &= Y(1 - Y)[X(M_1 - B_1 + D) + (1 - X)(- B_1)] \end{aligned} \quad (8)$$

According to equilibrium theory, for the game players to have stable strategies, it needs to simultaneously satisfy:

$$\begin{cases} \frac{dx}{dt} = 0 \\ \frac{dy}{dt} = 0 \end{cases}$$

Solving this yields:

$$X_1 = 0, X_2 = 1, X_3 = \frac{B_1}{M_1 + D}; \; Y_1 = 0, Y_2 = 1, Y_3 = \frac{B_3 - B_2 + D}{B_3 + M_1 + D}$$

In summary, there are five possible outcomes of the game between agencies and e-commerce companies: (0,0), (0,1), (1,0), (1,1), and $(\frac{B_1}{M_1+D}, \frac{B_3-B_2+D}{B_3+M_1+D})$.

4.1.3 Stability of game analysis results

The stability of game results requires analyzing stability of a mapping matrix of the game system.

Let a general form of the mapping matrix be: $A = \begin{bmatrix} e & f \\ g & h \end{bmatrix}$.

(1) Trace of the mapping matrix tr(A) = e + h < 0;

(2) Determinant of the mapping matrix det(A) = eh - gf > 0.

If the mapping matrix corresponding to the dynamic equation simultaneously meets the above two conditions, then the derived values are stable, and the corresponding strategies are also stable. For ease of analysis, equation (8) is processed to obtain:

$$f(X, Y) = X(1 - X)[Y(- M_1 - B_2) + (1 - Y)(B_3 - B_2 + D)]$$
$$g(X, Y) = Y(1 - Y)[X(M_1 - B_1 + D) + (1 - X)(- B_1)]$$

Then its mapping matrix can be represented as:

$$A(X, Y) = \begin{pmatrix} \frac{\partial f}{\partial X} & \frac{\partial f}{\partial Y} \\ \frac{\partial g}{\partial X} & \frac{\partial g}{\partial Y} \end{pmatrix} = \begin{pmatrix} (1 - 2x)[Y(- M_1 - B_2) + (1 - Y)(B_3 - B_2 + D)] & X(1 - X)(B_3 + M_1 + D) \\ Y(1 - Y)(M_1 + D) & (1 - 2Y)[X(M_1 - B_1 + D) - (1 - X)B_1] \end{pmatrix} \quad (9)$$

Substituting the above five results into equation (9) yields:

$$A(0,0) = \begin{pmatrix} B_3 - B_2 + D & 0 \\ 0 & - B_1 \end{pmatrix};$$

$$A(0,1) = \begin{pmatrix} - M_1 - B_2 & 0 \\ 0 & B_1 \end{pmatrix};$$

$$A(1,0) = \begin{pmatrix} B_2 - B_3 - D & 0 \\ 0 & M_1 - B_1 + D \end{pmatrix};$$

$$A(1,1) = \begin{pmatrix} M_1 + B_2 & 0 \\ 0 & B_1 - M_1 - D \end{pmatrix};$$

$$A\left(\frac{B_1}{M_1 + D}, \frac{B_3 - B_2 + D}{B_3 + M_1 + D}\right) = \begin{pmatrix} 0 & \frac{B_1(B_1 - M_1 - D)(B_3 + M_1 + D)}{(M_1 + D)2} \\ \frac{(B_3 + D - B_2)(Q_2 - B_2)(M_1 + D)}{(B_3 + M_1 + D)2} & 0 \end{pmatrix}$$

Organizing the various cases as shown in Table 2.

Table 2. Determinant and Trace Values of the Game Result Mapping Matrix

Equilibrium Point	det（A）	tr（A）
(0,0)	$-B_1(B_3-B_2+D)$	$(B_3-B_2+D)-B_1$
(0,1)	$-B_1(M_1+B_2)$	$B_1-(M_1+B_2)$
(1,0)	$(B_2-B_3-D)(M_1-B_1+D)$	$(B_2-B_3-D)+(M_1-B_1+D)$
(1,1)	$(M_1+B_2)(B_1-M_1-D)$	$(B_1-M_1-D)+(M_1+B_2)$
$(\frac{B_1}{M_1+D}, \frac{B_3-B_2+D}{B_3+M_1+D})$	$\frac{B_1(M_1-B_2)(B_1-M_1-D)(B_3-B_2+D)}{(M_1+D)(B_3+M_1+D)}$	0

The stability of the game model's equilibrium points needs to be judged by classifying and discussing the signs of B_3-B_2+D and M_1-B_1+D. The results of classification discussion are shown in Table 3.

Table 3. Summary of Stability Analysis on Game Results

Condition	Strategy Point	det(A)	tr(A)	Result
$B_3-B_2+D<0$, $M_1-B_1+D<0$	(0, 0)	+	-	stable point
	(0, 1)	-	+/-	unstable point
	(1, 0)	-	-	unstable point
	(1, 1)	+	+	unstable point
$B_3-B_2+D<0$, $M_1-B_1+D>0$	(0, 0)	+	-	stable point
	(0, 1)	-	+/-	unstable point
	(1, 0)	+	+	unstable point
	(1, 1)	-	+	unstable point
$B_3-B_2+D>0$, $M_1-B_1+D<0$	(0, 0)	-	+/-	unstable point
	(0, 1)	-	+/-	unstable point
	(1, 0)	+	-	stable point
	(1, 1)	+	+	unstable point
	(X_3, Y_3)		0	saddle point
$B_3-B_2+D>0$, $M_1-B_1+D>0$	(0, 0)	-	+/-	unstable point
	(0, 1)	-	+/-	unstable point
	(1, 0)	-	+/-	unstable point
	(1, 1)	-	+/-	unstable point
	(X_3, Y_3)		0	saddle point

Summarizing the results in Table 3, the following conclusions can be drawn:

(1) When B_3-B_2+D<0, regardless of the signs of M_1-B_1+D, the game process only has (0,0) as a stable strategy. Understanding this situation, when the cost of agency regulation B_2 is less than or equal to the sum of the remedial cost B_3 caused by non-regulation and corresponding penalty D imposed on e-commerce companies, without considering the impact of time, agencies generally choose to refuse regulation due to the high cost, and most companies also refuse to build a reverse logistics system for electronic waste due to the small penalty D, which has a minimal impact on their operations. However, this behavior of e-commerce companies seriously harms nature, reduces the effective regeneration and recycling of resources, and affects consumer health, posing certain threats to achieving "carbon reduction" and building an environmentally friendly society. From the overall perspective of the game, there is Pareto improvement. To achieve social Pareto improvement, agencies should strive to reduce the costs incurred by regulating e-commerce companies, while increasing the penalties for companies that refuse to implement reverse logistics for electronic waste, promoting e-commerce companies to actively respond to policies and build reverse logistics systems for electronic waste.

(2) When B_3-B_2+D>0 and M_1-B_1+D<0, the game process only has (1,0) as a stable strategy. Understanding this situation, when the cost of agency regulation on e-commerce companies B_2 is less than the sum of the compensable cost B_3 and corresponding penalty D caused by non-regulation, and the cost of the company choosing the implementation strategy B_1 is greater than the sum of the penalty D and the reward M_1

obtained by the company under regulation, without considering the impact of time, agencies will choose the regulating strategy because the compensable cost B_3 is greater than the cost B_2+D during regulation. Meanwhile, companies also refuse to implement reverse logistics for electronic waste due to high implementation costs and low penalties D and rewards M_1. In this case, agencies should appropriately increase the rewards for companies choosing the implementation strategy, and on the other hand, increase the penalties for companies choosing the non-implementation strategy, making companies actively build a reverse logistics system for electronic waste due to the immense pressure of penalties and the temptation of bonuses. E-commerce companies should try to reduce implementation costs B_1 by improving electronic product R&D technology and improving the quality level of core employees, rapidly achieving Pareto improvement.

(3) When $B_3-B_2+D>0$ and $M_1-B_1+D>0$, that is, the sum of compensable cost B_3 caused by agency non-regulation and the penalty D for refusing to implement is higher than the cost B_2 incurred by the agency choosing the regulation strategy, and the sum of the reward M_1 obtained by the company for implementing reverse logistics and the penalty D is higher than the implementation cost B_1, then (0,0), (0,1), (1,0), and (1,1) are not stable points.

4.2 Game Theory Analysis Between E-commerce Companies and Consumers

4.2.1 Model assumptions

Only e-commerce companies and consumers participate in the game, and both parties are bounded rational during the game. For the company's poor business practices, consumers can freely choose to disclose (denoted as W_1) or not disclose (denoted as W_2), so the consumer's strategy space is K_3 $\{W_1, W_2\}$.

If consumers choose to disclose, the cost of disclosure is denoted as B_4. If the situation reported by the consumer is true, the agency rewards the consumer as M_2 and imposes a penalty on the disclosed e-commerce company (denoted as D). If the situation is not true, the agency imposes a penalty on the consumer (denoted as d) and gives a certain reward to the e-commerce company (denoted as M_1). The benefits of implementing strategies for companies are denoted as F_1, and the benefits of not implementing strategies are denoted as F_2. From the perspective of real consumption, consumers often overlook the poor business practices of enterprises due to their weak environmental awareness, resulting in some companies not implementing reverse logistics for electronic waste, which over time causes damage to consumers themselves (denoted as B_5).

So, there are four game scenarios between e-commerce companies and consumers, namely:(implementation, disclosure), (implementation, not disclosure), (not implementation, disclosure), and (not implementation, not disclosure). In these four scenarios, their respective benefits are shown in Table 4.

Table 4. Benefits in Four Game Scenarios

		disclosure(W_1)	not disclosure(W_2)
e-commerce companies	Implementation (Z_1)	$Q_1+M_1,$ F_1-B_4-d	$Q_1,$ F_1-B_5
	Not implementation (Z_1)	$Q_1+B_1-D,$ $F_2-B_4+M_2$	$Q_1+B_1,$ F_2-B_5

4.2.2 Game process analysis

Assumptions:

Similar to the assumptions in section 4.1, at the beginning of the game, the probabilities of consumers choosing to disclose or not disclose are Z ($0<Z<1$) and 1-Z, respectively. The assumptions regarding e-commerce companies are the same as in section 4.1. For reverse logistics of electronic waste, the expected profits for companies choosing to implement, refuse to implement, and option for a mixed strategy are:

$$L_Y = Z(Q_1 + M_1) + (1 - Z)Q_1 \quad (10)$$

$$L_{1-Y} = Z(Q_1 + B_1 - D) + (1 - Z)(Q_1 + B_1) \quad (11)$$

$$L_C = YL_Y + (1 - Y)L_{1-Y} \quad (12)$$

Thus, dynamic equation for companies choosing to implement the strategy is:

$$dy/dt = Y(L_Y - L_C) \quad (13)$$

Similarly, the dynamics for consumers choosing to disclose are given by:

$$L_Z = Y(F_1 - B_4 - d) + (1 - Y)(F_2 - B_4 + M_2) \quad (14)$$

$$L_{1-Z} = Y(F_1 - B_5) + (1 - Y)(F_2 - B_5) \quad (15)$$

$$L_R = ZL_Z + (1 - Z)L_{1-Z} \quad (16)$$

$$dy/dt = Z(L_Z - L_R) \quad (17)$$

Substituting equations (10)-(12) into equation (13) and equations (14)-(16) into equation (17) results in the following game outcomes: (0,0), (0,1), (1,0), (1,1), $(\frac{M_2+B_5-B_4}{M_2+d}, \frac{B_1}{M_1+D})$.

4.2.3 Stability analysis of game results

The corresponding mapping matrix is shown below:

$$N(0,0) = \begin{pmatrix} -B_1 & 0 \\ 0 & M_2+B_5-B_4 \end{pmatrix};$$

$$N(0,1) = \begin{pmatrix} M_1+D-B_1 & 0 \\ 0 & B_4-M_2-B_5 \end{pmatrix};$$

$$N(1,0) = \begin{pmatrix} B_1 & 0 \\ 0 & B_5+B_4-d \end{pmatrix};$$

$$N(1,1) = \begin{pmatrix} B_1-M_1-D & 0 \\ 0 & B_4+d-B_5 \end{pmatrix};$$

$$N\left(\frac{M_2+B_5-B_4}{M_2+d}, \frac{B_1}{M_1+D}\right) = \begin{pmatrix} 0 & \frac{(M_1+D)(M_2+B_5-B_4)(B_4+d-B_5)}{(M_2+d)2} \\ \frac{-B_1(M_2+d)(M_1+D-B_1)}{(M_1+D)2} & 0 \end{pmatrix}$$

The various cases are organized as shown in Table 5.

Table 5. Determinant Values and Trace of the Game Result Mapping Matrix

Equilibrium Point	Det(N)	tr(N)
(0,0)	$-B_1(M_2+B_5-B_4)$	$(M_2+B_5-B_4)$-B_1
(0,1)	$(M_1+D-B_1)(B_4-M_2-B_5)$	$(M_1+D-B_1)+(B_4-M_2-B_5)$
(1,0)	$B_1(B_5+B_4-d)$	B_1+(B_5+B_4-d)
(1,1)	$(B_1-M_1-D)(B_4+d-B_5)$	(B_1-M_1-D)+(B_4+d-B_5)
$(\frac{\mathbf{M_2+B_5-B_4}}{\mathbf{M_2+d}},\frac{\mathbf{B_1}}{\mathbf{M_1+D}})$	$\frac{B_1(M_1+D-B_1)(M_2+B_5-B_4)(B_4+d-B_5)}{(M_1+D)(M_2+d)}$	0

By analyzing and discussing the signs of M_2+B_5-B_4, M_1+D-B_1 and B_4+d-B_5, we can determine the stable points of the game model. The results are summarized in Table 6.

4.2.4 Summary of Results from Table 6:

(1) When $M_2+B_5-B_4<0$, regardless of the signs of M_1+D-B_1 and B4+d-B_5, the game process only has (0,0) as a stable strategy. This occurs when the additional cost B_4 that consumers pay during the disclosure process is greater than the reward M_2 received for truthful disclosure plus the damage B_5 incurred from not disclosing. Typically, in this case, consumers are likely to choose not to disclose, and e-commerce companies are likely not to implement reverse logistics for electronic waste.

(2) When $M_2+B_5-B_4<0$ and (0,0) is a stable strategy in the game process, $M_1+D-B_1>0$ and $B_4+d-B_5<0$, meaning the reward M_1 and penalty D that the company receives for implementing reverse logistics exceed the additional cost B_1 of implementing reverse logistics for electronic waste. Meanwhile, the cost B_4 that consumers pay for disclosure plus the penalty d for untruthful disclosure is less than the potential harm B_5 caused by not disclosing the poor business practices of e-commerce companies, then (1,1) is a stable strategy in the game. In such cases, consumers are likely to choose the disclosure strategy, and e-commerce companies are likely to choose to implement it.

(3) When $M_2+B_5-B_4>0$ and $M_1+D-B_1<0$, i.e., the sum of the reward M_2 for truthful disclosure and the potential harm B_5 from not disclosing exceeds the cost B_4 of disclosure, while the sum of the penalty D for refusing to implement reverse logistics and the reward M_1 for implementation is less than the cost B_1 of implementing reverse logistics, then (0,1) is a stable strategy in the game. Under these circumstances, e-commerce companies usually choose not to implement, while consumers might opt to disclose due to the lower cost of disclosure or the significant harm caused by not disclosing the poor business practices of the company.

5. Effective Measures for Reverse Logistics of Electronic Waste

5.1 Improve Laws and Regulations Related to Reverse Logistics

Given the global focus on climate warming, China continuously proposes measures to reduce carbon emissions, but the issue of reverse logistics for electronic waste significantly hampers the goal of "carbon reduction." Although China implemented the "Regulation on Pollution Control of Electronic Information Products" in March 2007, which to some extent reduced environmental pollution caused by electronic waste and effectively protected the living environment and human health, there is still a need to further develop and perfect administrative laws and regulations concerning reverse logistics for electronic waste to manage reverse logistics activities from the source.

Table 6. Summary of Game Results Stability Analysis

Condition	Strategy Point	det(N)	tr(N)	Result
$M_2+B_5-B_4<0$ $M_1+D-B_1<0$ $B_4+d-B_5<0$	(0, 0)	+	-	Stable Point
	(0, 1)	-	+/-	Unstable Point
	(1, 0)	+	+	Unstable Point
	(1, 1)	-	+/-	Unstable Point
$M_2+B_5-B_4<0$ $M_1+D-B_1<0$ $B_4+d-B_5>0$	(0, 0)	+	-	Stable Point
	(0, 1)	-	+/-	Unstable Point
	(1, 0)	-	+/-	Unstable Point
	(1, 1)	+	+	Unstable Point
$M_2+B_5-B_4<0$ $M_1+D-B_1>0$ $B_4+d-B_5>0$	(0, 0)	+	-	Stable Point
	(0, 1)	+	+	Unstable Point
	(1, 0)	-	+/-	Unstable Point
	(1, 1)	-	+/-	Unstable Point
$M_2+B_5-B_4<0$ $M_1+D-B_1>0$ $B_4+d-B_5<0$	(0, 0)	+	-	Stable Point
	(0, 1)	+	+	Unstable Point
	(1, 0)	+	+	Unstable Point
	(1, 1)	+	-	Stable Point
$M_2+B_5-B_4>0$ $M_1+D-B_1<0$ $B_4+d-B_5<0$	(0, 0)	-	+/-	Unstable Point
	(0, 1)	+	-	Stable Point
	(1, 0)	+	+	Unstable Point
	(1, 1)	-	+/-	Unstable Point
	$(\frac{M_2+B_5-B_4}{M_2+d},\frac{B_1}{M_1+D})$		0	Saddle Point
$M_2+B_5-B_4>0$ $M_1+D-B_1<0$ $B_4+d-B_5>0$	(0, 0)	-	+/-	Unstable Point
	(0, 1)	+	-	Unstable Point
	(1, 0)	-	+/-	Unstable Point
	(1, 1)	+	+	Unstable Point
	$(\frac{M_2+B_5-B_4}{M_2+d},\frac{B_1}{M_1+D})$		0	Saddle Point
$M_2+B_5-B_4>0$ $M_1+D-B_1>0$ $B_4+d-B_5>0$	(0, 0)	-	+/-	Unstable Point
	(0, 1)	-	+/-	Unstable Point
	(1, 0)	-	+/-	Unstable Point
	(1, 1)	-	+/-	Unstable Point
	$(\frac{M_2+B_5-B_4}{M_2+d},\frac{B_1}{M_1+D})$		0	Saddle Point
$M_2+B_5-B_4>0$ $M_1+D-B_1>0$ $B_4+d-B_5<0$	(0, 0)	-	+/-	Unstable Point
	(0, 1)	-	+/-	Unstable Point
	(1, 0)	+	+	Unstable Point
	(1, 1)	-	+/-	Unstable Point
	$(\frac{M_2+B_5-B_4}{M_2+d},\frac{B_1}{M_1+D})$		0	Saddle Point

5.2 Reduce Blindness through Pilot and Demonstration Projects

At this stage, the construction of the consumer electronics reverse logistics system in China is relatively late, and there is no comprehensive mature experience and technical model to refer to. To effectively reduce blindness, it is advisable to start research demonstrations in key areas of the country during the early stage of system construction. Selecting better demonstration areas to establish reverse logistics demonstration and promotion projects is more conducive to exploring the economies of scale of electronic waste reverse logistics, evaluating reverse logistics models at different stages in China, solving difficult problems often encountered in the development and construction of domestic electronic waste reverse logistics systems, and continuously summarizing and promoting advanced experiences to avoid detours and promote innovation.

5.3 Introduce Economic Incentives and Penalty Mechanisms

Appropriate rewards should be increased for e-commerce companies that successfully implement reverse logistics for electronic waste, while the penalties for those that refuse should be intensified. Under the pressure of interests from both sides, companies will tend to actively build a reverse logistics system for electronic waste.

5.4 Raise Environmental Awareness and Social Responsibility

Consumers should establish green environmental concepts, actively enhance environmental awareness, and strengthen social responsibility. Before purchasing electronic waste online, consumers should carefully consider the brand and model of the product to avoid discarding electronic waste arbitrarily later due to dislikes or poor quality. Meanwhile, they should actively sort and collectively process electronic waste collected at home through methods like "old-for-new." Furthermore, they should always monitor whether there are e-commerce companies or individuals who casually discard electronic waste around them, and disclose and supervise their actions.

6. Conclusion

By comparing and analyzing the game models between e-commerce companies and regulatory agencies as well as between e-commerce companies and consumers, it was found that whether companies actively build a reverse logistics system for electronic waste is closely related to whether agencies regulate the business practices of e-commerce companies and whether consumers disclose the companies' poor business practices to relevant agencies. In response to the national call for "carbon reduction," e-commerce companies, service agencies, and consumers all need to actively participate in the reverse logistics of electronic waste. E-commerce companies need to actively build reverse logistics systems for electronic waste and optimize the handling of electronic waste; service agencies need to regulate the business practices of e-commerce companies and enhance the companies' willingness to build reverse logistics systems through appropriate penalties or rewards; and consumers need to enhance their environmental awareness and disclose the poor business practices of e-commerce companies. Only in this way can e-commerce companies actively build reverse logistics systems for electronic waste, maximize social benefits, and promote China's green transformation pace.

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