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Coordinated Distribution or Client Introduce? Analysis of Energy Conservation and Emission Reduction in Canadian Logistics Enterprises

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Abstract: Due to the large area and small population of Canada, the efficiency of logistics enterprises is low, and each logistics enterprise needs to cooperate to save energy and reduce emissions. Considering that each logistics enterprise can realize the maximization of its own benefit by controlling the distribution volume and the input of facilities. In this article, the differential game model of individual distribution, coordinated distribution and paid introduction of customers for each logistics enterprise is constructed, the balanced distribution volume, capital input and social welfare functions of each logistics enterprise under the three modes are obtained, and the applicable conditions of various distribution cooperation channels are compared. The research results show that if the organizational cost between logistics enterprises is greater than the communication cost, the benefits of large-scale logistics enterprises under the introduction customer mode are greater than those under the collaborative distribution mode. However, only the communication cost and organizational cost are relatively small, and the profit of small-scale logistics enterprises under the introduction of the customer mode is smaller than that under the collaborative distribution mode.

Keywords: energy conservation and emission reduction; differential game; logistics enterprises; social benefits

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Citation: Bai, Y.; Gao, Y.; Li, D.; Liu, D. Coordinated Distribution or Client Introduce? Analysis of Energy Conservation and Emission Reduction in Canadian Logistics Enterprises. *Sustainability* **2022**, *14*, 16979. https://doi.org/10.3390/su142416979

Academic Editors: Ming Liu and Feifeng Zheng

Received: 18 November 2022
Accepted: 15 December 2022
Published: 18 December 2022

1. Introduction

Improving energy conservation and emission reduction in the logistics industry means achieving more efficiency at a lower cost. Balancing cost and efficiency is a difficult problem facing the express delivery industry [1]. Although the economies of some countries are developed, the efficiency of logistics enterprises is low. For example, Canada has a large land area of 9.98 million square kilometers and a population of about 37.4 million. With a low population density, Canada is a typical country with a large land area and sparse population [2]. It is difficult for Canada to achieve the advantage of regional cost-sharing, such as in China, Japan or Germany. As a result, the cost of online shopping in Canada is often higher than that of large-scale bulk procurement, which affects the logistics efficiency of Canada. However, logistics experience is one of the core aspects of e-commerce development. Due to the lack of good logistics, the development of e-commerce enterprises is limited, the customer experience is poor, and the customer repurchase rate is low, which further affects the scale economy of the logistics industry in Canada and thus leads to the reduction of logistics efficiency. In order to solve the above problems, logistics companies in a region of Canada need to cooperate with each other. Through the active cooperation of different logistics enterprises in Canada, the purpose of energy conservation and emission reduction for logistics enterprises can be realized. However, logistics enterprises have a variety of ways of cooperating, and the applicable conditions of each mode of cooperation are very important. For example, energy conservation and emission reduction can be achieved through coordinated distribution and the paid introduction of customer resources. The scope of application of these two modes of cooperation is different. Which mode of cooperation can most effectively realize the energy savings and emission reduction goals of Canadian logistics enterprises is an important issue. The research conclusion of this article can provide some reference for Canadian logistics enterprises when choosing cooperation mode.

The work related to this article mainly includes three aspects. They are: how to save energy and reduce emissions, the influencing factors of logistics efficiency, and how the improvement of emission reduction and logistics efficiency affects the environment. Some scholars have studied how to save energy and reduce emissions. For example, Shi analyzes the changes in the atmospheric environment and uses a genetic algorithm to study how to save energy and reduce emissions [3]. Sun et al. predicted the energy of traffic flow to promote energy conservation and emission reduction [4]. Adua considers that rich households should cut their carbon emissions [5]. Marcel et al. analyze how specific equipment achieves energy savings and emission reduction [6].

The impact of logistics mode, logistics technology and resource allocation on logistics efficiency have been studied by some scholars. For example, Merkert et al. studied consumers' preference for the last mile of logistics mode [7]. Chang et al. studied how automatic handling systems affect the efficiency of logistics operations [8]. Rodriguez et al. studied how to allocate aviation logistics resources to fight wildfires [9].

Some scholars have analyzed the impact of energy conservation and emission reduction in the logistics industry on the climate. For example, the added value of China's logistics industry is the most important factor affecting carbon emissions [10]. The popularity of electric vehicles can reduce the amount of polluting gases [11]. Some scholars have studied the conditions that need to be met for the popularization of new energy vehicles. For example, Zou et al. proposed a new type of upper and lower base voltage controller that is conducive to the popularization of electric vehicles [12]. Lim et al. think that the adoption of electric vehicles requires a successful business model [13]. Petrauskiene et al. studied what power mix scenarios in Lithuania could improve the local environment [14].

Some scholars analyze the energy savings and emission reduction of logistics vehicles from the perspective of operations research. For example, Zhao et al. optimized the distribution path of electric vehicles in urban fresh food cold chain distribution [15]. Naor et al. study vertically integrated supply chain systems for batteries, electric vehicles and charging infrastructure from the perspective of constraint theory [16]. The vehicle optimization of cold chain logistics is studied to achieve low carbon [17]. Some scholars have studied the impact of technology on logistics vehicles. For example, Kang et al. studied localized peer-to-peer power transactions in electric vehicles using consortium blockchains [18]. Yu et al. analyze the optimization of vehicle transportation by IoT technology [19]. How do real-time traffic conditions of road networks affect carbon emissions from cold chain logistics? [20].

The above research includes the factors affecting energy conservation and emission reduction, how to carry out energy conservation and emission reduction, and the impact of energy conservation and emission reduction on the environment. At the same time, how to save energy and reduce emissions is analyzed from the perspective of operational research. However, the above studies did not analyze how to save energy and reduce emissions from the perspective of cooperation. At the same time, the distribution of logistics enterprises is a dynamic process. In other words, new goods are delivered every day. These studies do not reflect this dynamic process.

Differential game refers to a time-continuous game played by multiple players in a time-continuous system. It has the goal of optimizing the independence and conflict of each player and can finally obtain the strategy of each player evolving over time and reaching the Nash equilibrium. At present, it is mainly applied in the fields of epidemic prevention mechanisms [21], emergency product supply chains [22], advertising decisions [23] and pollution control [24,25]. The existing literature has not found the use of differential games from the perspective of collaborative distribution, customer introduction and other forms of cooperation to study the energy conservation and emission reduction of logistics enterprises.

2. Methodology

2.1. Hypothesis, Problem Description and Variable Definition

2.1.1. Hypothesis

(1) For the sake of discussion, this study assumes that there are two logistics enterprises in a certain region of Canada, namely logistics enterprise 1 and logistics enterprise 2. Logistics Enterprise 1 is a large-scale enterprise in the logistics industry of this region. It has a large scale and has received more logistics orders. However, in the off-season, logistics facilities and personnel are easily left idle. Logistics Company 2 is the second small company. Compared with logistics enterprise 1, logistics enterprise 2 has a smaller scale. Limited by its scale, it will lose a lot of customers, resulting in a certain opportunity cost. For example, Yusen Logistics, based in Canada, provides services such as international freight forwarding (by air or sea), contract logistics (e.g., warehousing) and transportation (e.g., trucking). Its main business is not in Canada. The company is constantly cooperating with other logistics enterprises. These services can act as standalone services or as part of our broader offering as a supply chain provider [26].

(2) Only the distribution link is selected in this study. Logistics activities are divided into transportation, loading, unloading, handling, storage, circulation processing, distribution and other links. The way these processes create value is different. Distribution involves preparation, storage, sorting and distribution, assembly, distribution, transportation, delivery and many other processes. Therefore, the logistics distribution link is the most complex and tedious of the whole logistics process. It is mainly in accordance with the user's order requirements, in the logistics base for tallying work, and in the distribution of good goods to the consignee of a logistics mode. The efficiency of distribution has a great impact on green logistics. Therefore, this study chooses the distribution link as the representative for analysis. When analyzing other links in logistics, the conclusions of this study can be used as a reference.

(3) The distribution decisions of the two companies are in a continuous changing process. Logistics distribution is mainly according to the user order requirements in the logistics base for tallying work and the distribution of good goods to the consignee of a logistics mode. In recent years, Canadian e-commerce has developed rapidly. Logistics distribution activities are also increasing year by year. A company makes distribution decisions in order to maximize profits. However, that decision has an impact on another company's decision. Because the two companies have a certain competitive relationship, the decisions of other companies have a further impact on our company. Management itself is a decision-making process. Decision-making is always present in the operation process of logistics enterprises. Over time, the cycle repeats, and the distribution decisions of the two companies are constantly changing. And their distribution decisions are always influenced by other logistics companies.

2.1.2. Problem Description

In order to improve efficiency, save energy and reduce emissions, Canadian logistics enterprises can adopt three operation modes:

(1) Independent distribution, cooperative operation and service purchase. Separate distribution mode. In the market environment of perfect competition in the logistics industry, all enterprises take the logistics distribution service separately for the sake of maximizing their own interests.

(2) Joint distribution model. Canada is large and sparsely populated. If each company in the logistics industry operates separately, it will cause a waste of resources. Therefore, it is necessary for every company in the logistics industry to establish cooperation.

For example, when an order from one logistics company cannot be fulfilled, the order is sent to another logistics company.

(3) The model of introducing customers. Only when logistics enterprises trust each other will they send orders to other logistics enterprises free of charge. However, the relationships between logistics companies themselves are competitive, and trust is low in most cases. Therefore, in order for the cooperation to proceed smoothly, it is necessary to pay for the order service.

The operation modes of two different scale logistics enterprises are shown in Figure 1.

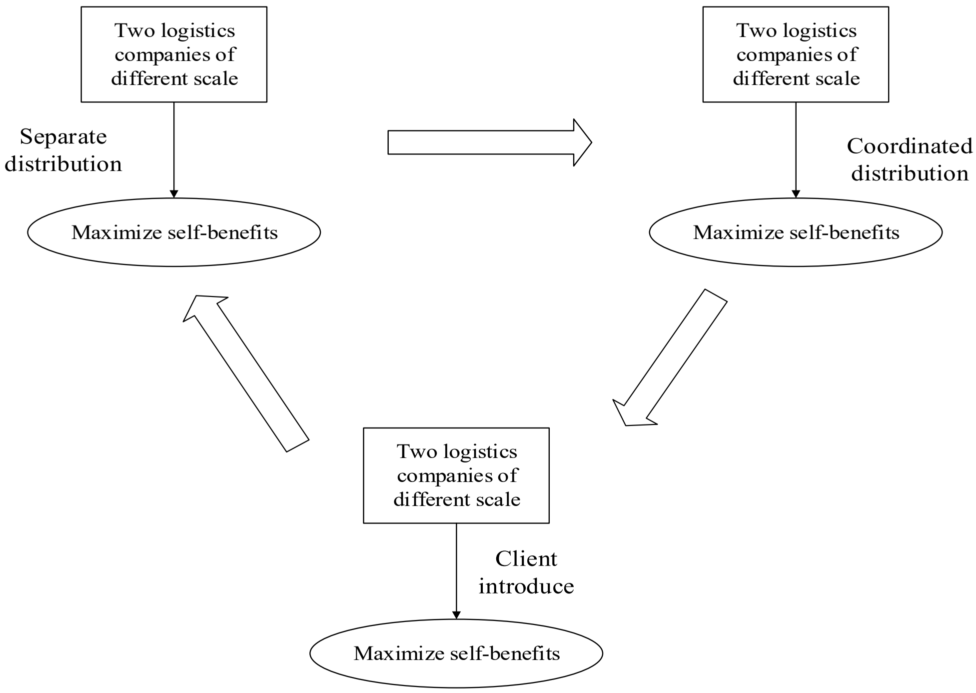

Figure 1. Various operation modes of two different scale logistics enterprises.

2.1.3. Variable Definition

Canadian logistics companies can obtain the most benefit by investing in distribution facilities and hiring people to carry out the distribution. The distribution volume and input capital of logistics enterprises are control variables. The distribution capacity of logistics enterprises is a state variable. Under the operation mode Y, the distribution volume $Q_{Yi}(t)$ of logistics enterprise i mainly employs distribution personnel to carry out distribution so as to obtain relevant distribution income. Under operation mode Y, the capital $A_{Yi}(t)$ invested by logistics enterprise i mainly consists of logistics distribution facilities, such as distribution vehicles and navigation systems. Logistics enterprise 1 is more likely to generate facility idle loss due to more input distribution facilities, while logistics enterprise 2 is more likely to generate opportunity cost due to fewer distribution facilities.

The distribution facilities of logistics enterprises will depreciate over time, which will lead to the attenuation of distribution capacity. The value range of δ is also (0,1). Only when a logistics enterprise has the distribution capacity can it distribute the goods. Therefore, the distribution capacity will have a positive impact on the benefits of logistics enterprises. Therefore, $l > 0$. In the process of distribution, the cost of the two logistics enterprises is not the same. The scale of logistics enterprise 1 is larger than that of logistics enterprise 2. In the distribution process, logistics enterprise 1 makes it easier to obtain the scale economy effect, and logistics enterprise 1 has a lower distribution cost. Distribution unit commodity logistics enterprise 2 pays more cost than logistics enterprise 1 is $c_r > 0$. In the distribution process, the input of logistics capital will not only make the distribution vehicle updated but also have a positive impact on the distribution capacity, so $\lambda > 0$.

2.2. Differential Game of Different Operating Models

2.2.1. Separate Distribution

Under the separate distribution mode, the expressions of the social welfare function of large-scale logistics enterprise 1 and small-scale logistics enterprise 2 are as follows:

$$J_{F1} = \int_0^{\infty} \left[bQ_{F1}(t) - \frac{c_1}{2} Q_{F1}^2(t) - p_1 A_{F1}(t) + l_1 x_{F1}(t) \right] e^{-\rho t} dt \quad (1)$$

$$J_{F2} = \int_0^{\infty} \left[bQ_{F2}(t) - \frac{(c_1 + c_r)}{2} Q_{F2}^2(t) - p_o A_{F2}^2(t) + l_2 x_{F2}(t) \right] e^{-\rho t} dt \quad (2)$$

In Equations (1) and (2), $bQ_{Fi}(t)$ represents the income obtained by the distribution of logistics enterprise i. $\frac{c_{F1}}{2} Q_{F1}^2(t)$ represents the distribution cost of logistics enterprise 1. $\frac{(c_{F1}+c_r)}{2} Q_{F2}^2(t)$ represents the distribution cost of logistics enterprise 2. $p_1 A_{F1}(t)$ represents the idle loss caused by the surplus of logistics assets. $p_o A_{F2}^2(t)$ represents the opportunity cost generated by insufficient logistics distribution assets. $l_i x_{Fi}(t)$ represents the impact of distribution capacity on social benefits.

At the same time, the change in distribution capacity of two logistics enterprises with different scales is as follows:

$$\dot{x}_{F1}(t) = \lambda (A_{F1}(t))^{\frac{1}{2}} - \delta x_{F1}(t) \quad (3)$$

$$\dot{x}_{F2}(t) = \lambda A_{F2}(t) - \delta x_{F2}(t) \quad (4)$$

where $\lambda \left(A_{F1}(t) \right)^{\frac{1}{2}}$ represents the positive impact of logistics assets input by enterprise 1 on distribution capacity. $\lambda A_{F2}(t)$ represents the positive impact of logistics assets input by enterprise 2 on distribution capacity. $\delta x_{Fi}(t)$ represents the decay in delivery capacity over time.

2.2.2. Coordinated Distribution

Under the cooperative distribution mode, the expression of the social welfare function of logistics enterprise 1 at large scale and logistics enterprise 2 at small scale is as follows:

$$J_{C1} = \int_0^{\infty} \left[bQ_{C1}(t) - \frac{c_1}{2} Q_{C1}^2(t) - (p_1 - p_o) A_{C1}(t) - C_o + l_1 x_{C1}(t) \right] e^{-\rho t} dt \quad (5)$$

$$J_{C2} = \int_0^{\infty} \left[bQ_{C2}(t) - \frac{c_1}{2} Q_{C2}^2(t) - p_o A_{C2}^2(t) - C_o + l_2 x_{C2}(t) \right] e^{-\rho t} dt \quad (6)$$

In Equations (5) and (6), $bQ_{Ci}(t)$ represents the income obtained by the distribution of logistics enterprise i. $\frac{c_1}{2} Q_{C1}^2(t)$ represents the distribution cost of logistics enterprise 1. $(p_1 - p_o) A_{C1}(t)$ represents the distribution cost of logistics enterprise 2. $p_o A_{C2}^2(t)$ represents the idle loss caused by the surplus of logistics assets. $l_i x_{Ci}(t)$ represents the opportunity cost generated by insufficient logistics distribution assets. Represents the impact of distribution capacity on social benefits. C_o represents the organization cost of two logistics enterprises.

At the same time, the change of distribution capacity of two logistics enterprises with different scales is as follows:

$$\dot{x}_{C1}(t) = \lambda (A_{C1}(t))^{\frac{1}{2}} - \delta x_{C1}(t) \quad (7)$$

$$\dot{x}_{C2}(t) = \lambda A_{C2}(t) - \delta x_{C2}(t) \quad (8)$$

where $\lambda \left(A_{C1}(t) \right)^{\frac{1}{2}}$ represents the positive impact of logistics assets input by enterprise 1 on distribution capacity. $\lambda A_{C2}(t)$ represents the positive impact of logistics assets input by enterprise 2 on distribution capacity. $\delta x_{Ci}(t)$ represents the decay of delivery capacity over time.

2.2.3. Client Introduce

Under the client introduce mode, the expressions of social welfare function of large-scale logistics enterprise 1 and small-scale logistics enterprise 2 are, respectively, as follows:

$$J_{B1} = \int_0^{\infty} \left[b(Q_{B1}(t) + h) - \frac{c_1}{2}(Q_{B1}(t) + h)^2 - (p_1 - p_o)A_{B1}(t) - c_B h + l_1 x_{B1}(t) \right] e^{-\rho t} dt \quad (9)$$

$$J_{B2} = \int_0^{\infty} \left[bQ_{B2}(t) - \frac{(c_1 + c_r)}{2} Q_{B2}^2(t) - p_o A_{B2}^2(t) + c_B h + l_2 x_{B2}(t) \right] e^{-\rho t} dt \quad (10)$$

In Equations (9) and (10), $b(Q_{B1}(t) + h)$ represents the income obtained by distribution of logistics enterprise 1. $bQ_{B2}(t)$ represents the income obtained by distribution of logistics enterprise 2. $\frac{c_1}{2} Q_{B1}^2(t)$ represents the distribution cost of logistics enterprise 1. $\frac{(c_1+c_r)}{2} Q_{B2}^2(t)$ represents the distribution cost of logistics enterprise 2. $p_1 A_{B1}(t)$ represents the idle loss caused by the surplus of logistics assets. $p_o A_{B2}^2(t)$ represents the opportunity cost generated by insufficient logistics distribution assets. $l_i x_{Bi}(t)$ represents the impact of distribution capacity on social benefits.

At the same time, the change in distribution capacity of two logistics enterprises with different scales is as follows:

$$\dot{x}_{B1}(t) = \lambda (A_{B1}(t))^{\frac{1}{2}} - \delta x_{B1}(t) \quad (11)$$

$$\dot{x}_{B2}(t) = \lambda A_{B2}(t) - \delta x_{B2}(t) \quad (12)$$

where $\lambda (A_{B1}(t))^{\frac{1}{2}}$ represents the positive impact of logistics assets input by enterprise 1 on distribution capacity. $\lambda A_{B2}(t)$ represents the positive impact of logistics assets input by enterprise 2 on distribution capacity. $\delta x_{Bi}(t)$ represents the decay of delivery capacity over time.

3. Results

The economic benefits and social welfare functions obtained by the logistics industry are not only affected by the control variables and parameters but also constantly change with the influence of time, state and state on social welfare. In order to better obtain a balanced transport volume, support degree, economic benefits and social benefits, the HJB formula is used in this article. The formula is based on the dynamic programming proposed by Richard Behrman and his colleagues in the 1950s. The HJB formula is a partial differential equation, which is the core of optimal control.

3.1. HJB Formula

If two logistics enterprises both adopt a separate distribution mode, then in time $t \in [0, +\infty)$, the HJB formula of the economic benefits and social welfare functions of logistics enterprises 1 and 2 in this mode is:

$$\rho V_{F1} = \max_{Q_{F1}(t), A_{F1}(t)} \left\{ \left[bQ_{F1}(t) - \frac{c_1}{2} Q_{F1}^2(t) - p_1 A_{F1}(t) + l_1 x_{F1}(t) \right] + \frac{\partial V_{F1}}{\partial x_{F1}} \left[\lambda (A_{F1}(t))^{\frac{1}{2}} - \delta x_{F1}(t) \right] \right\} \quad (13)$$

$$\rho V_{F2} = \max_{Q_{F2}(t), A_{F2}(t)} \left\{ \left[bQ_{F2}(t) - \frac{(c_1 + c_r)}{2} Q_{F2}^2(t) - p_o A_{F2}^2(t) + l_2 x_{F2}(t) \right] + \frac{\partial V_{F2}}{\partial x_{F2}} [\lambda A_{F2}(t) - \delta x_{F2}(t)] \right\} \quad (14)$$

If two logistics enterprises both adopt the coordinated distribution mode, then in time $t \in [0, +\infty)$, the HJB formula of the economic benefits and social welfare functions of logistics enterprises 1 and 2 in this mode is:

$$\begin{aligned} \rho V_{C1} = \max_{Q_{C1}(t), A_{C1}(t)} \Big\{ & \left[bQ_{C1}(t) - \tfrac{c_1}{2} Q_{C1}^2(t) - (p_1 - p_o) A_{C1}(t) - C_o + l_1 x_{C1}(t) \right] \\ & + \tfrac{\partial V_{C1}}{\partial x_{C1}} \left[\lambda (A_{C1}(t))^{\frac{1}{2}} - \delta x_{C1}(t) \right] \Big\} \end{aligned} \quad (15)$$

$$\rho V_{C2} = \max_{Q_{C2}(t), A_{C2}(t)} \left\{ \left[bQ_{C2}(t) - \frac{c_1}{2} Q_{C2}^2(t) - p_o A_{C2}^2(t) - C_o + l_2 x_{C2}(t) \right] + \frac{\partial V_{C2}}{\partial x_{C2}} [\lambda A_{C2}(t) - \delta x_{C2}(t)] \right\} \tag{16}$$

If both logistics enterprises adopt the client introduce mode, then in time $t \in [0, +\infty)$, the HJB formula of the economic benefits and social welfare functions of logistics enterprises 1 and 2 in this mode is:

$$\begin{aligned} \rho V_{B1} = \max_{Q_{B1}(t), A_{B1}(t)} \Big\{ & \left[b(Q_{B1}(t) + h) - \tfrac{c_1}{2} (Q_{B1}(t) + h)^2 - (p_1 - p_o) A_{B1}(t) - c_B h + l_1 x_{B1}(t) \right] \\ & + \tfrac{\partial V_{B1}}{\partial x_{B1}} \left[\lambda (A_{B1}(t))^{\frac{1}{2}} - \delta x_{B1}(t) \right] \Big\} \end{aligned} \tag{17}$$

$$\begin{aligned} \rho V_{B2} = \max_{Q_{B2}(t), A_{B2}(t)} \Big\{ & \left[bQ_{B2}(t) - \tfrac{(c_1 + c_r)}{2} Q_{B2}^2(t) - p_o A_{B2}^2(t) + c_B h + l_2 x_{B2}(t) \right] \\ & + \tfrac{\partial V_{B2}}{\partial x_{B2}} [\lambda A_{B2}(t) - \delta x_{B2}(t)] \Big\} \end{aligned} \tag{18}$$

3.2. Result of Equilibrium

3.2.1. Separate Distribution

Proposition 1: Under the separate distribution mode of each logistics enterprise, the balanced distribution volume, logistics capital input and social benefits of two logistics enterprises with different scales are, respectively (see Appendix A for the specific solution process):

$$Q_{F1}^*(t) = \frac{b}{c_1},\ A_{F1}^*(t) = \frac{\lambda^2}{4p_1^2} \left(\frac{l_1}{\rho + \delta} \right)^2 \tag{19}$$

$$Q_{F2}^*(t) = \frac{b}{c_1 + c_r},\ A_{F2}^*(t) = \frac{\lambda}{2p_o} \left(\frac{l_2}{\rho + \delta} \right) \tag{20}$$

$$V_{F1}^* = \frac{l_1}{\rho + \delta} x_{F1} + \frac{1}{\rho} \left[b\frac{b}{c_1} - \frac{c_1}{2} \left(\frac{b}{c_1} \right)^2 - p_1 \frac{\lambda^2}{4p_1^2} \left(\frac{l_1}{\rho + \delta} \right)^2 \right] + \frac{1}{\rho} \frac{l_1}{\rho + \delta} \lambda \frac{\lambda}{2p_1} \left(\frac{l_1}{\rho + \delta} \right) \tag{21}$$

$$V_{F2}^* = \frac{l_2}{\rho + \delta} x_{F2} + \frac{1}{\rho} \left[b\frac{b}{c_1 + c_r} - \frac{(c_1 + c_r)}{2} \left(\frac{b}{c_1 + c_r} \right)^2 - p_o \frac{\lambda^2}{4p_o^2} \left(\frac{l_2}{\rho + \delta} \right)^2 \right] + \frac{1}{\rho} \frac{l_2}{\rho + \delta} \lambda \frac{\lambda}{2p_o} \left(\frac{l_2}{\rho + \delta} \right) \tag{22}$$

Conclusion 1: In the separate distribution mode, the larger the distribution cost, the less the balanced distribution volume. The greater the distribution income, the greater the balanced distribution volume. The loss caused by vacant logistics facilities is inversely proportional to the balanced logistics capital input. In the logistics industry, the balanced distribution quantity of large-scale enterprises is greater than the optimal distribution quantity of small-scale enterprises.

3.2.2. Coordinated Distribution

Proposition 2: Under the coordinated distribution mode, the balanced distribution volume, logistics capital input and social benefits of two logistics enterprises with different scales are, respectively (see Appendix B for the specific solution process):

$$Q_{C1}^*(t) = \frac{b}{c_1},\ A_{C1}^*(t) = \frac{\lambda^2}{4(p_1 - p_o)^2} \left(\frac{l_1}{\rho + \delta} \right)^2 > A_{F1}^*(t) \tag{23}$$

$$Q_{C2}^*(t) = \frac{b}{c_1} > Q_{F2}^*(t),\ A_{C2}^*(t) = \frac{\lambda}{2p_o} \left(\frac{l_2}{\rho + \delta} \right) \tag{24}$$

$$V_{C1}^* = \frac{l_1}{\rho + \delta} x_{C1} + \frac{1}{\rho} \left[b\frac{b}{c_1} - \frac{c_1}{2} \left(\frac{b}{c_1} \right)^2 - (p_1 - p_o) \frac{\lambda^2}{4(p_1 - p_o)^2} \left(\frac{l_1}{\rho + \delta} \right)^2 - C_o \right] + \frac{1}{\rho} \lambda \frac{\lambda}{2(p_1 - p_o)} \left(\frac{l_1}{\rho + \delta} \right)^2 \tag{25}$$

$$V_{C2}^{*} = \frac{l_2}{\rho+\delta}x_{C2} + \frac{1}{\rho}\left[b\frac{b}{c_1} - \frac{c_1}{2}\left(\frac{b}{c_1}\right)^2 - p_o\frac{\lambda^2}{4(p_o)^2}\left(\frac{l_2}{\rho+\delta}\right)^2 - C_o\right] + \frac{l_2}{\rho+\delta}\frac{1}{\rho}\left[\lambda\frac{\lambda}{2p_o}\left(\frac{l_2}{\rho+\delta}\right)\right] \tag{26}$$

Conclusion 2: Under the coordinated distribution mode, large enterprises in the logistics industry will invest more logistics capital. Smaller companies in the logistics industry deliver more.

3.2.3. Client Introduce

Proposition 3: Under the mode that logistics enterprises introduce customers with compensation to each other, the balanced distribution volume, logistics capital input and social benefits of two logistics enterprises with different scales are, respectively (see Appendix C for the specific solution process):

$$Q_{B1}^{*}(t) = \frac{b}{c_1} - h,\ A_{B1}^{*}(t) = \frac{\lambda^2}{4(p_1-p_o)^2}\left(\frac{l_1}{\rho+\delta}\right)^2 \tag{27}$$

$$Q_{B2}^{*}(t) = \frac{b}{c_1+c_r},\ A_{B2}^{*}(t) = \frac{\lambda}{2p_o}\frac{l_2}{\rho+\delta} \tag{28}$$

$$\begin{aligned} V_{B1}^{*} = \tfrac{l_1}{\rho+\delta}x_{B1} + \tfrac{1}{\rho}\left[b\left(\tfrac{b}{c_1}\right) - \tfrac{c_1}{2}\left(\tfrac{b}{c_1}\right)^2 - (p_1-p_o)\tfrac{\lambda^2}{4(p_1-p_o)^2}\left(\tfrac{l_1}{\rho+\delta}\right)^2 - c_B h\right] \\ +\tfrac{1}{\rho}\tfrac{l_1}{\rho+\delta}\lambda\tfrac{\lambda}{2(p_1-p_o)}\left(\tfrac{l_1}{\rho+\delta}\right) \end{aligned} \tag{29}$$

$$\begin{aligned} V_{B2}^{*} = \tfrac{l_2}{\rho+\delta}x_{B2} + \tfrac{1}{\rho}\left[b\tfrac{b}{c_1+c_r} - \tfrac{(c_1+c_r)}{2}\left(\tfrac{b}{c_1+c_r}\right)^2 - p_o\left(\tfrac{\lambda}{2p_o}\right)^2\left(\tfrac{l_2}{\rho+\delta}\right)^2 + c_B h\right] \\ +\tfrac{l_2}{\rho+\delta}\tfrac{1}{\rho}\lambda\tfrac{\lambda}{2p_o}\left(\tfrac{l_2}{\rho+\delta}\right) \end{aligned} \tag{30}$$

Conclusion 3: No matter whether large or small-scale enterprises in the logistics industry are introduced, if customers are introduced, the balanced distribution volume is smaller than that under the cooperative operation mode. The logistics capital invested by large-scale enterprises under the customer mode is larger than that under the single distribution mode.

3.3. Comparison of Equilibrium Results

If the distribution capacity in Canadian enterprises under different distribution modes is the same, that is, $x_{Fi} = x_{Ci} = x_{Bi}$. Then the difference of social benefits under different modes is:

$$V_{C1}^{*} - V_{F1}^{*} = \frac{1}{\rho}\frac{\lambda^2}{4(p_1-p_o)}\left(\frac{l_1}{\rho+\delta}\right)^2 - \frac{1}{\rho}C_o - \frac{1}{\rho}\frac{\lambda^2}{4p_1}\left(\frac{l_1}{\rho+\delta}\right)^2 \tag{31}$$

$$V_{C2}^{*} - V_{F2}^{*} = \frac{1}{\rho}\frac{b^2}{2c_1} - \frac{1}{\rho}C_o - \frac{1}{\rho}\frac{b^2}{2(c_1+c_r)} \tag{32}$$

Conclusion 4: If the organization cost of two logistics enterprises is large in the process of cooperation, the social benefits of coordinated distribution mode are greater than those of separate distribution mode. On the contrary, the social benefits under the coordinated distribution mode are smaller than those under the separate distribution mode.

$$V_{B1}^{*} - V_{F1}^{*} = -\frac{1}{\rho}c_B h + \frac{1}{\rho}\frac{\lambda^2}{4(p_1-p_o)}\left(\frac{l_1}{\rho+\delta}\right)^2 - \frac{1}{\rho}\frac{\lambda^2}{4p_1}\left(\frac{l_1}{\rho+\delta}\right)^2 \tag{33}$$

$$V_{B2}^{*} - V_{F2}^{*} = \frac{1}{\rho}c_B h \tag{34}$$

Conclusion 5: Due to the small size of the small business, its revenue under the introduction customer mode is greater than that under the separate distribution mode. However, when the communication cost is small, the profit of large enterprises under the introduction mode is greater than that under the separate distribution mode. However, when the communication cost is large, the profits of large enterprises under the introduction customer mode are smaller than those under the separate distribution mode.

$$V_{B1}^* - V_{C1}^* = -\frac{1}{\rho}c_B h + \frac{1}{\rho}C_o \quad (35)$$

$$V_{B2}^* - V_{C2}^* = \frac{1}{\rho}c_B h - \frac{1}{\rho}\frac{b^2}{2c_1} + \frac{1}{\rho}C_o + \frac{1}{\rho}\frac{b^2}{2(c_1 + c_r)} \quad (36)$$

Conclusion 6: If the organizational cost between logistics enterprises is greater than the communication cost, the benefits of large-scale enterprises in the introduction customer mode are greater than those in the collaborative distribution mode. If the organizational cost between logistics enterprises is less than the communication cost, the benefits of large-scale enterprises in the introduction customer mode are less than those in the collaborative distribution mode. However, only the communication cost and organizational cost are relatively small, and the profit of small enterprises under the introduction customer mode is smaller than that under the collaborative distribution mode. When logistics enterprise 2 pays more costs than logistics enterprise 1, the profit of small-scale enterprises under the customer mode is less than that under the collaborative distribution mode.

4. Discussion

The energy saving and emission reduction modes of logistics enterprises in Canada provide a reference for energy saving and emission reduction of other industries in the country. Unlike countries such as China, Japan and Western Europe, Canada has a large area and a small population density. In the context of global "carbon neutral and carbon peak", such geographical factors put forward higher requirements for distribution modes. This article analyzes the energy saving and emission reduction mode of the logistics industry in Canada, which is not only conducive to the need for energy saving and emission reduction in the logistics industry but also provides a reference for other industries.

Two logistics companies can jointly establish an organization or set up a loose alliance to achieve logistics cooperation. Both of these methods can improve the efficiency and effect of distribution, thus achieving energy conservation and emission reduction. However, if an organization is formed, the organization needs to incur organizational costs. And to form a loose alliance, the two logistics companies need to exchange costs. The size of communication costs and organizational costs can have a significant impact on the distribution model.

Compared with the cooperative operation model, the introduction of the customer model has more externalities. When the relationship between parties contains a large number of potential externalities and communication costs are high for different firms, it would be beneficial to reduce the external options of the parties. There's a lot of inertia around the boundaries of the company. If a company has high organizational costs, parties can reduce these costs by obscuring the contributions of parties within the company without easily changing the boundaries of the company [27].

If an enterprise is a large-scale enterprise in the logistics industry of the region, it is prone to the situation of idle logistics assets. This will allow it to reduce the placement of logistics facilities, which can be fully operational by accepting a portion of orders from other companies if the company partners with other companies. At this time, large-scale enterprises in the regional logistics industry will invest more logistics capital. If the two logistics enterprises cooperate, the small enterprises in the industry can make full use of the brand advantages of the large enterprises so as to improve the delivery order quantity of the small enterprises in the industry.

Other scholars have suggested that there is a Pareto improvement in cooperation between firms [28]. This paper is different from the research results of other scholars. This paper studies the cooperation between Canadian logistics enterprises to obtain the optimal solution. These include optimal distribution volume, optimal investment volume and optimal social benefits. Compared with the Pareto improvement, the optimal result plays a better role in improving the efficiency of logistics enterprises.

5. Conclusions

Due to the large area and small population in Canada, the distribution efficiency of traditional logistics is low. In order to improve the distribution efficiency, different companies can rationally allocate logistics resources through cooperative operations and by introducing customers. Although cooperative operations can improve the delivery volume, they will incur organizational costs. Although introducing the customer model can prevent the waste of idle logistics facilities, it will generate the communication costs of different logistics enterprises. Therefore, the application scope of various distribution cooperation modes is an important issue in this article. Since most of the existing research uses optimization, empirical data analysis and other methods, they have not yet involved the use of differential games to save energy and reduce emissions in Canada. Moreover, it has not been found that cooperation is divided into collaborative distribution and customer introduction. In this article, the differential game is applied to the field of energy conservation and emission reduction of logistics enterprises in Canada, especially considering how each country achieves energy conservation and emission reduction under the condition of different company sizes being inconsistent.

This article assumes that logistics in Canada can achieve energy conservation and emission reduction through two modes: cooperative distribution and customer introduction. Considering that large-scale logistics enterprises are prone to idle logistics facilities, while small-scale enterprises are prone to opportunity costs. This article constructs the differential game model of individual distribution, collaborative distribution and customer introduction of each Canadian logistics enterprise and makes a comparative analysis of it. The contribution of this article is as follows: First, the study of this paper has an important reference significance for the energy conservation and emission reduction efforts of the logistics industry in developed countries such as Canada, which has a large area and a small population. Second, this article makes a comparative analysis of the three distribution modes and obtains the scope of use for each. If the organizational cost between logistics enterprises is greater than the communication cost, the benefits of large-scale logistics enterprises in the introduction customer mode are greater than those in the collaborative distribution mode. However, only the communication cost and organizational cost are relatively small, and the profit of small-scale logistics enterprises under the introduction customer mode is smaller than that under the collaborative distribution mode.

The research in this article can also be extended to some extent. For example, this article only considers the situation that there are two logistics and the distribution mode is divided into two forms: collaborative distribution and customer introduction. In future research, it may be possible to consider multiple logistics enterprises and mixed distribution modes to study related issues. In addition, this study is not only applicable to the problem of energy conservation and emission reduction but also has a certain reference significance for enterprise pollution, natural disasters and other related issues.

Author Contributions: Conceptualization, Y.B.; Methodology, Y.B., D.L. (Delong Li) and D.L. (Dehai Liu); Validation, Y.B.; Formal analysis, D.L. (Delong Li); Investigation, Y.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Doctoral Research Foundation of Shandong University of Management, sdmud2023001.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The main definition of variables and parameters in this article.

Variables and Parameters	Specific Meaning
$Y = \{F,C,B\}$	three operating modes of logistics enterprises (separate distribution, coordinated distribution, client introduce)
independent variable	
$Q_{Yi}(t)$	distribution quantity of logistics enterprise i under operation mode Y
$A_{Yi}(t)$	the capital invested by logistics enterprise i under operation mode Y
$x_{Yi}(t)$	distribution capability of logistics enterprise i under operation mode Y
parameter	
ρ	the discount rate that occurs over time, which is the discount factor, $0 \leq \rho \leq 1$
δ	the decay rate of the distribution capacity of logistics enterprise i, $\delta > 0$
b	revenue per unit of delivery, $b > 0$
l_1	the positive impact of unit distribution capacity on logistics enterprise 1, $l_1 > 0$
l_2	the positive impact of unit distribution capacity on logistics enterprise 2, $l_2 > 0$
c_1	distribution unit goods logistics enterprise 1 cost, $c_1 > 0$
c_r	distribution unit commodity logistics enterprise 2 pays more cost than logistics enterprise 1, $c_r > 0$
p_1	loss caused by vacant logistics facilities of logistics enterprise 1, $p_1 > 0$
p_o	the opportunity cost of logistics enterprise 2 due to its small scale, $p_o > 0$
λ	the positive influence of logistics capital input on distribution capacity, $\lambda > 0$
function	
$J_{Yi}(t)$	the benefit function of logistics enterprise i under operation mode Y
$V_{Yi}(t)$	social benefits of logistics enterprise i under operation mode Y

Appendix A

Find the partial derivatives of $Q_{F1}(t)$ and $A_{F1}(t)$ with respect to (13), and find the partial derivatives of $Q_{F2}(t)$ and $A_{F2}(t)$ with respect to (14), and set them equal to zero, we can get:

$$Q_{F1}^{*}(t) = \frac{b}{c_1},\ A_{F1}^{*}(t) = \frac{\lambda^2}{4p_1^2}\left(\frac{\partial V_{F1}}{\partial x_{F1}}\right)^2 \tag{A1}$$

$$Q_{F2}^{*}(t) = \frac{b}{c_1 + c_r},\ A_{F2}^{*}(t) = \frac{\lambda}{2p_o}\left(\frac{\partial V_{F2}}{\partial x_{F2}}\right) \tag{A2}$$

Substituting (A1) and (A2) into equations (13) and (14), we get:

$$\rho V_{F1} = \left[b\frac{b}{c_1} - \frac{c_1}{2}\left(\frac{b}{c_1}\right)^2 - p_1\frac{\lambda^2}{4p_1^2}\left(\frac{\partial V_{F1}}{\partial x_{F1}}\right)^2 + l_1 x_{F1}(t)\right] + \frac{\partial V_{F1}}{\partial x_{F1}}\left[\lambda\frac{\lambda}{2p_1}\left(\frac{\partial V_{F1}}{\partial x_{F1}}\right) - \delta x_{F1}(t)\right] \tag{A3}$$

$$\rho V_{F2} = \left[\frac{b^2}{c_1 + c_r} - \frac{(c_1 + c_r)}{2}\left(\frac{b}{c_1 + c_r}\right)^2 - p_o\frac{\lambda^2}{4p_o^2}\left(\frac{\partial V_{F2}}{\partial x_{F2}}\right)^2 + l_2 x_{F2}(t)\right] + \frac{\partial V_{F2}}{\partial x_{F2}}\left[\frac{\lambda^2}{2p_o}\left(\frac{\partial V_{F2}}{\partial x_{F2}}\right) - \delta x_{F2}(t)\right] \tag{A4}$$

Let $V_{F1}^* = k_1 x_{F1} + k_2$, $V_{F2}^* = k_3 x_{F2} + k_4$, where k_1, k_2, k_3, k_4 are all constants. The parameters of the optimal social welfare function can be obtained by calculation as follows:

$$\begin{cases} k_1 = \frac{l_1}{\rho+\delta} \\ k_2 = \frac{1}{\rho}\left[b\frac{b}{c_1} - \frac{c_1}{2}\left(\frac{b}{c_1}\right)^2 - p_1\frac{\lambda^2}{4p_1^2}\left(\frac{l_1}{\rho+\delta}\right)^2\right] + \frac{1}{\rho}\frac{l_1}{\rho+\delta}\lambda\frac{\lambda}{2p_1}\left(\frac{l_1}{\rho+\delta}\right) \end{cases} \tag{A5}$$

$$\begin{cases} k_3 = \frac{l_2}{\rho+\delta} \\ k_4 = \frac{1}{\rho}\left[b\frac{b}{c_1+c_r} - \frac{(c_1+c_r)}{2}\left(\frac{b}{c_1+c_r}\right)^2 - p_o\frac{\lambda^2}{4p_o^2}\left(\frac{l_2}{\rho+\delta}\right)^2\right] + \frac{1}{\rho}\frac{l_2}{\rho+\delta}\lambda\frac{\lambda}{2p_o}\left(\frac{l_2}{\rho+\delta}\right) \end{cases} \tag{A6}$$

Therefore, the optimal social welfare function of the two logistics enterprises with different scales is:

$$V_{F1}^* = \frac{l_1}{\rho+\delta}x_{F1} + \frac{1}{\rho}\left[b\frac{b}{c_1} - \frac{c_1}{2}\left(\frac{b}{c_1}\right)^2 - p_1\frac{\lambda^2}{4p_1^2}\left(\frac{l_1}{\rho+\delta}\right)^2\right] + \frac{1}{\rho}\frac{l_1}{\rho+\delta}\lambda\frac{\lambda}{2p_1}\left(\frac{l_1}{\rho+\delta}\right) \tag{A7}$$

$$V_{F2}^* = \frac{l_2}{\rho+\delta}x_{F2} + \frac{1}{\rho}\left[b\frac{b}{c_1+c_r} - \frac{(c_1+c_r)}{2}\left(\frac{b}{c_1+c_r}\right)^2 - p_o\frac{\lambda^2}{4p_o^2}\left(\frac{l_2}{\rho+\delta}\right)^2\right] + \frac{1}{\rho}\frac{l_2}{\rho+\delta}\lambda\frac{\lambda}{2p_o}\left(\frac{l_2}{\rho+\delta}\right) \tag{A8}$$

Appendix B

Find the partial derivatives of $Q_{C1}(t)$ and $A_{C1}(t)$ with respect to (15), and find the partial derivatives of $Q_{C2}(t)$ and $A_{C2}(t)$ with respect to (16), and set them equal to zero, we can get:

$$Q_{C1}^*(t) = \frac{b}{c_1},\ A_{C1}^*(t) = \frac{\lambda^2}{4(p_1-p_o)^2}\left(\frac{\partial V_{C1}}{\partial x_{C1}}\right)^2 \tag{A9}$$

$$Q_{C2}^*(t) = \frac{b}{c_1},\ A_{C2}^*(t) = \frac{\lambda}{2p_o}\left(\frac{\partial V_{C2}}{\partial x_{C2}}\right) \tag{A10}$$

Substituting (A9) and (A10) into Equations (15) and (16), we get:

$$\begin{aligned} \rho V_{C1} = &\left[b\frac{b}{c_1} - \frac{c_1}{2}\left(\frac{b}{c_1}\right)^2 - (p_1-p_o)\frac{\lambda^2}{4(p_1-p_o)^2}\left(\frac{\partial V_{C1}}{\partial x_{C1}}\right)^2 - C_o + l_1 x_{C1}(t)\right] \\ &+ \frac{\partial V_{C1}}{\partial x_{C1}}\left[\lambda\frac{\lambda}{2(p_1-p_o)}\left(\frac{\partial V_{C1}}{\partial x_{C1}}\right) - \delta x_{C1}(t)\right] \end{aligned} \tag{A11}$$

$$\rho V_{C2} = \left[b\frac{b}{c_1} - \frac{c_1}{2}\left(\frac{b}{c_1}\right)^2 - p_o\frac{\lambda^2}{4(p_o)^2}\left(\frac{\partial V_{C2}}{\partial x_{C2}}\right)^2 - C_o + l_2 x_{C2}(t)\right] + \frac{\partial V_{C2}}{\partial x_{C2}}\left[\lambda\frac{\lambda}{2p_o}\left(\frac{\partial V_{C2}}{\partial x_{C2}}\right) - \delta x_{C2}(t)\right] \tag{A12}$$

Let $V_{C1}^* = k_5 x_{C1} + k_6$, $V_{C2}^* = k_7 x_{C2} + k_8$, where k_5, k_6, k_7, k_8 are all constants. The parameters of the optimal social welfare function can be obtained by calculation as follows:

$$\begin{cases} k_5 = \frac{l_1}{\rho+\delta} \\ k_6 = \frac{1}{\rho}\left[b\frac{b}{c_1} - \frac{c_1}{2}\left(\frac{b}{c_1}\right)^2 - (p_1-p_o)\frac{\lambda^2}{4(p_1-p_o)^2}\left(\frac{l_1}{\rho+\delta}\right)^2 - C_o\right] + \frac{1}{\rho}\lambda\frac{\lambda}{2(p_1-p_o)}\left(\frac{l_1}{\rho+\delta}\right)^2 \end{cases} \tag{A13}$$

$$\begin{cases} k_7 = \frac{l_2}{\rho+\delta} \\ k_8 = \frac{1}{\rho}\left[b\frac{b}{c_1} - \frac{c_1}{2}\left(\frac{b}{c_1}\right)^2 - p_o\frac{\lambda^2}{4(p_o)^2}\left(\frac{l_2}{\rho+\delta}\right)^2 - C_o\right] + \frac{l_2}{\rho+\delta}\frac{1}{\rho}\left[\lambda\frac{\lambda}{2p_o}\left(\frac{l_2}{\rho+\delta}\right)\right] \end{cases} \tag{A14}$$

Therefore, the optimal social welfare function of the two logistics enterprises with different scales is:

$$V_{C1}^{*}=\frac{l_1}{\rho+\delta}x_{C1}+\frac{1}{\rho}\left[b\frac{b}{c_1}-\frac{c_1}{2}\left(\frac{b}{c_1}\right)^2-(p_1-p_o)\frac{\lambda^2}{4(p_1-p_o)^2}\left(\frac{l_1}{\rho+\delta}\right)^2-C_o\right]+\frac{1}{\rho}\lambda\frac{\lambda}{2(p_1-p_o)}\left(\frac{l_1}{\rho+\delta}\right)^2 \quad \text{(A15)}$$

$$V_{C2}^{*}=\frac{l_2}{\rho+\delta}x_{C2}+\frac{1}{\rho}\left[b\frac{b}{c_1}-\frac{c_1}{2}\left(\frac{b}{c_1}\right)^2-p_o\frac{\lambda^2}{4(p_o)^2}\left(\frac{l_2}{\rho+\delta}\right)^2-C_o\right]+\frac{l_2}{\rho+\delta}\frac{1}{\rho}\left[\lambda\frac{\lambda}{2p_o}\left(\frac{l_2}{\rho+\delta}\right)\right] \quad \text{(A16)}$$

Appendix C

Find the partial derivatives of $Q_{B1}(t)$ and $A_{B1}(t)$ with respect to (17), and find the partial derivatives of $Q_{B2}(t)$ and $A_{B2}(t)$ with respect to (18), and set them equal to zero, we can get:

$$Q_{B1}^{*}(t)=\frac{b}{c_1}-h,\ A_{B1}^{*}(t)=\frac{\lambda^2}{4(p_1-p_o)^2}\left(\frac{\partial V_{B1}}{\partial x_{B1}}\right)^2 \quad \text{(A17)}$$

$$Q_{B2}^{*}(t)=\frac{b}{c_1+c_r},\ A_{B2}^{*}(t)=\frac{\lambda}{2p_o}\left(\frac{\partial V_{B2}}{\partial x_{B2}}\right) \quad \text{(A18)}$$

Substituting (A17) and (A18) into Equations (17) and (18), we get:

$$\rho V_{B1}=\max_{Q_{B1}(t),A_{B1}(t)}\left\{\left[b(Q_{B1}(t)+h)-\frac{c_1}{2}(Q_{B1}(t)+h)^2-(p_1-p_o)A_{B1}(t)-c_Bh+l_1x_{B1}(t)\right]+\frac{\partial V_{B1}}{\partial x_{B1}}\left[\lambda\left(A_{B1}(t)\right)^{\frac{1}{2}}-\delta x_{B1}(t)\right]\right\} \quad \text{(A19)}$$

$$\rho V_{B2}=\max_{Q_{B2}(t),A_{B2}(t)}\left\{\left[bQ_{B2}(t)-\frac{(c_1+c_r)}{2}Q_{B2}^2(t)-p_oA_{B2}^2(t)+c_Bh+l_2x_{B2}(t)\right]+\frac{\partial V_{B2}}{\partial x_{B2}}[\lambda A_{B2}(t)-\delta x_{B2}(t)]\right\} \quad \text{(A20)}$$

Let $V_{B1}^{*}=k_9x_{B1}+k_{10}$, $V_{B2}^{*}=k_{11}x_{B2}+k_{12}$, where $k_9, k_{10}, k_{11}, k_{12}$ are all constants. The parameters of the optimal social welfare function can be obtained by calculation as follows:

$$\begin{cases} k_9=\frac{l_1}{\rho+\delta} \\ k_{10}=\frac{1}{\rho}\left[b\left(\frac{b}{c_1}\right)-\frac{c_1}{2}\left(\frac{b}{c_1}\right)^2-(p_1-p_o)\frac{\lambda^2}{4(p_1-p_o)^2}\left(\frac{l_1}{\rho+\delta}\right)^2-c_Bh\right]+\frac{1}{\rho}\frac{l_1}{\rho+\delta}\lambda\frac{\lambda}{2(p_1-p_o)}\left(\frac{l_1}{\rho+\delta}\right) \end{cases} \quad \text{(A21)}$$

$$\begin{cases} k_{11}=\frac{l_2}{\rho+\delta} \\ k_{12}=\frac{1}{\rho}\left[b\frac{b}{c_1+c_r}-\frac{(c_1+c_r)}{2}\left(\frac{b}{c_1+c_r}\right)^2-p_o\left(\frac{\lambda}{2p_o}\right)^2\left(\frac{l_2}{\rho+\delta}\right)^2+c_Bh\right]+\frac{l_2}{\rho+\delta}\frac{1}{\rho}\lambda\frac{\lambda}{2p_o}\left(\frac{l_2}{\rho+\delta}\right) \end{cases} \quad \text{(A22)}$$

Therefore, the optimal social welfare function of the two logistics enterprises with different scales is:

$$V_{B1}^{*}=\frac{l_1}{\rho+\delta}x_{B1}+\frac{1}{\rho}\left[b\left(\frac{b}{c_1}\right)-\frac{c_1}{2}\left(\frac{b}{c_1}\right)^2-(p_1-p_o)\frac{\lambda^2}{4(p_1-p_o)^2}\left(\frac{l_1}{\rho+\delta}\right)^2-c_Bh\right]+\frac{1}{\rho}\frac{l_1}{\rho+\delta}\lambda\frac{\lambda}{2(p_1-p_o)}\left(\frac{l_1}{\rho+\delta}\right) \quad \text{(A23)}$$

$$V_{B2}^{*}=\frac{l_2}{\rho+\delta}x_{B2}+\frac{1}{\rho}\left[b\frac{b}{c_1+c_r}-\frac{(c_1+c_r)}{2}\left(\frac{b}{c_1+c_r}\right)^2-p_o\left(\frac{\lambda}{2p_o}\right)^2\left(\frac{l_2}{\rho+\delta}\right)^2+c_Bh\right]+\frac{l_2}{\rho+\delta}\frac{1}{\rho}\lambda\frac{\lambda}{2p_o}\left(\frac{l_2}{\rho+\delta}\right) \quad \text{(A24)}$$

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