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The Environmental Assessment on Chinese Logistics Enterprises Based on Non-Radial DEA

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Abstract: Under the new situation of economic development in China, the logistics industry is facing unbalanced development regarding economic and environmental performance. From the enterprise level, this study investigated the sustainability of Chinese logistics based on the environmental assessment data envelopment analysis (DEA) model, and measured the unified efficiency of a logistics company under two different production arrangement strategies. The empirical measurement provides several findings. First, logistics enterprises give higher priority to operational benefits than environmental performance. Second, under the operational priority of production arrangement, small and medium-sized enterprises' (SMEs) unified efficiency is better than a large enterprise, and private enterprises' unified efficiency is better than state-owned enterprises. Moreover, the empirical study has further proved that the sustainability development of Chinese logistics is still at the primary stage; when facing trade-offs in the sustainability context, logistics companies still prioritize operational performance first. Therefore, transforming corporate strategy into an environmental sustainable priority and realizing logistics sustainability still has a long way to go, which is the backbone of realizing balanced development of both the economy and environment.

Keywords: sustainability; green logistics; Chinese logistics; DEA

1. Introduction

As one of the biggest sources of global greenhouse gas (GHG) emissions, transportation comprises 23% of global energy-related emissions in 2018, and 92% of its energy demand depends on oil [1]. The contribution of freight transportation to total transport emissions is 39%, and is expected to be at least equivalent to passenger transport by 2050 [2]. According to Intergovernmental Panel on Climate Change (IPCC), driven by the rapidly growing economies in Asia, Africa, and Latin America, freight transport demand is predicted to increase three-fold by 2050. Environmental sustainability in freight transportation has drawn immense concern in both research and practice areas.

Freight transportation plays a key role in supply chain operation, and the environmental sustainability concern has sparked tremendous interest towards optimal supply chain networks that balance both economic and environmental influences. Under the framework of sustainable supply chain management (SSCM), logistics is a relatively small topic, with most researches focused on broader areas of the supply chain or focal supply chain members, which are usually manufactures [3]. The existing studies on environmentally sustainable logistics appear to focus on models for reducing emissions or the relationships between logistics activities and environmental impacts [4]. From the enterprise perspective, despite pressures or governmental regulations to reduce GHG emissions, companies may still plan to continue their original environmental strategies [5]. While in the long

run, to survive under this carbon-constrained business environment, companies have to adjust their business strategies to deal with various environmental constraints [6]. Additionally, transportation is one of the few GHG emissions sources that enterprises can efficiently influence [5]. Therefore, at the enterprise level, it is important, even fundamental, to figure out how logistics companies arrange their production resources to cope with environmental pressures, and how efficient their production strategy is under the environmental sustainability concern.

In 2018, the total expenses on Chinese logistics activities were up to 13.3 trillion yuan, which makes China the biggest freight transportation market around the world [7]. Driven by economic growth and the increasing consumption demand, logistics has become the backbone of the Chinese economy. Since the construction of ecological civilization became one of the key objectives of China's Thirteenth Five-Year Plan (2016–2020), the "Construction of Ecological Civilization" in the transportation sector has been stressed by the Ministry of Ecology and Environment and the Ministry of Transport of China. Environmental regulation on freight transportation and logistics from the government places high pressure on logistics companies to enhance their environmental performance.

Despite the tremendous concerns from macro regulations toward environmental performance in the logistics sector, the sustainable development of Chinese logistics is still in its infancy [8]. When first confronted with environmental regulations, enterprises resist change and give more preferences to commercial concerns in the trade-off between environmental protection and economic benefits [9]. It is essential to evaluate and analyze the environmental efficiency under the trade-off between environment and economic benefits during the operational process of logistics enterprises. Therefore, the main objective of this paper was to measure the environmental efficiency of Chinese logistics enterprises under different sustainable strategies, in order to fundamentally figure out the development stage of environmental sustainability and give implications to enterprises' business strategy arrangement and government environmental regulations.

Data envelopment analysis (DEA) has recently become one of the important tools for environmental assessment in the sustainability area. The DEA methodology was first proposed by professor A. Charnes and professor W.W. Cooper in 1978 [10]. Since then, DEA has become a major approach for performance assessment in various organizations. As an approximation approach, it could provide an empirical guideline for enterprises and policy makers. After the concept of undesirable output was proposed by Färe [11], the use of DEA for environmental assessment has drawn attention from researchers in the sustainability development area. Nowadays, environment sustainability has become the most popular application area of DEA [12].

Previous literature that uses DEA for environmental assessment operates on multiple levels. At the country level, Camarero, Castillo [13] used DEA to determine the eco-efficiency of a group of 22 The Organisation for Economic Co-operation and Development (OECD) countries, and a similar research was also conducted in European Union countries [14]. Cui and Li [15] evaluated transportation carbon efficiencies from 15 countries. Research at the country level is more focused on a comparison between macro economies [16], which could provide policy implications for global and national sustainability.

As to the regional level, China's environmental efficiency has been explored by several studies using different production factors [17–19]. Sueyoshi and Yuan [19] explored the regional sustainability development of China by incorporating particulate matter (PM) 2.5 and PM10 as undesirable outputs. Another research by Zhou and Chen [17] explored the environmental efficiency of 30 provinces in China based on a DEA environmental assessment radial model. The regional environmental efficiency displays the direction of government policy for environmental protection and economic development, and could give implications for industries' sustainable development.

At the industry level, the majority of studies are based on the energy sector, such as petroleum firms, solar thermal power stations, petroleum coal-fired power plants, and fossil fuel power generation [20–24]. Additionally, Li and Zhang [25] also investigated provincial differences in fossil fuel power plants in China. The energy industry is one of the most concerned sectors under sustainability circumstances, and efficiency measurement can give instructions for the arrangement of energy production in a certain

country. In the manufacture industry, Sueyoshi and Goto [26] applied DEA environmental assessment to Japanese industrial enterprises to explore the unified efficiency on differently prioritized resource arrangements (operational and environmental). Another research of Sueyoshi and Goto [27] explored the sustainability of Japanese enterprises, which included manufacturing firms and non-manufacturing firms, and found that manufacturing firms outperform non-manufacturing ones in operations. According to previous literatures, except for researches focused on energy production, studies that investigated environmental efficiency at the enterprise level are usually from multiple industry sectors.

When it comes to logistics and freight transportation, few studies have adopted the DEA method to explore environmental efficiency in the transport sector. Yang and Taudes [28] used DEA to measure the efficiency of 20 freight villages in Europe but did not consider any environmental outputs. Haralambides and Gujar [29] applied DEA to evaluate dry port efficiency in India while taking into account the undesirable environmental output. Another study focused on public transportation in Iran, and developed a DEA-based target-setting methods to set targets for 24 bus companies under green supply chain management requirements [30]. In China, Li and Meng [31] investigated the sustainability performance of the transportation industry under environmental regulations by using provincial data in China. Different with those traditional manufacture enterprises, such as the automobile industry or paper-making industry, the production network of logistics enterprises has a higher degree of regional crossover, which may bias the regional level of sustainability efficiency. Yet, there has not been any literature that explores the environmental efficiency of freight transportation from the enterprise perspective.

According to those previous studies, though DEA assessment has been employed in port and public transport companies in other countries, environmental efficiency in the logistics and freight transport sector should be investigated more comprehensively. Studies on environmental efficiency assessment using the DEA method in Chinese freight transport companies is still blank. Therefore, the aim of this study was to fill the aforementioned gap in the Chinese logistics sector under the environmental sustainability consideration. This paper intended to investigate the environmental efficiency of logistics enterprises in China by using the DEA model under different operational priorities.

The rest of this paper is organized as follows. Section 2 describes the two disposability concepts and the methodology of DEA environmental assessment by a non-radial model. In Section 3, the environmental assessment of Chinese logistics enterprises is illustrated, and the unified efficiencies under natural and managerial disposability are calculated. Subsequently, statistical tests are employed to explore the differences between groups classified by enterprise size and ownership. Section 4 presents the conclusions and implications of this study.

2. The Methodology of Non-Radial DEA

This study applied non-radial DEA models for environmental assessment, as proposed by Sueyoshi and Goto [24]. The DEA model for environmental assessment needs to fully utilize all kinds of production factors (the inputs, desirable outputs, and undesirable outputs), and this requirement needs all dual variables in the model to be positive or zero. In this circumstance, the non-radial model could be the one that satisfies the requirements. Moreover, given the output factors, such as the net income of a certain enterprise could be negative, the property of the translation invariance of the non-radial model makes it possible to evaluate the efficiency of DMUs (decision-making units) whose inputs or outputs contain zero/or negative values [32]. Therefore, the non-radial DEA model was adopted to measure the efficiency of logistics enterprises under environmental regulation in China.

2.1. Nomenclatures Used in the DEA Model

The nomenclatures used in the non-radial DEA models are summarized as follows:

Notations of production factors that are observed from the data set:

x_{ij} : i -th input of the j -th DMU ($i = 1, \dots, m$ and $j = 1, \dots, n$);

g_{rj} : r -th desirable output of the j -th DMU ($r = 1, \dots, s$ and $j = 1, \dots, n$); and

b_{fj} : f -th undesirable output of the j -th DMU ($f = 1, \dots, h$ and $j = 1, \dots, n$).

Notations of other unknown variables that need to be measured:

d_i^x : A slack variable of the i -th input ($i = 1, \dots, m$);

d_r^s : A slack variable of the r -th desirable output ($r = 1, \dots, s$);

d_f^b : A slack variable of the f -th undesirable output ($f = 1, \dots, h$);

R_i^x : The range for the i -th input ($i = 1, \dots, m$) which makes it for full utilization;

R_r^s : The range for the r -th desirable output ($r = 1, \dots, s$) which makes it for full utilization;

R_f^b : The range for the f -th undesirable output ($f = 1, \dots, h$) which makes it for full utilization; and

λ_j : An unknown variable of the j -th intensity variable ($j = 1, \dots, n$) to connect production factors.

2.2. Disposability Concepts

In this non-radial DEA applied to environmental assessment, two important disposability concepts are the basis of the environmental assessment DEA framework: The “natural disposability” and “managerial disposability”, where the concept of disposability implies the elimination of inefficiency [33].

Natural disposability: Natural disposability indicates that a decision-making unit (DMU) decreases the undesirable outputs by reducing the inputs. Considering the decreasing inputs, the DMU is dedicated to increasing the desirable outputs as much as possible. Natural disposability implies that the operational performance of DMU is the first criterion, and companies reduce their inputs in order to reduce the undesirable outputs. In another words, enterprises under natural disposability would use a negative way, such as reducing the operation scale, to deal with environmental regulation while in the meantime, they try to maximize their desirable outputs.

Managerial disposability: Managerial disposability indicates that a DMU decreases the undesirable outputs by increasing the inputs. On the basis of the increasing inputs, the DMU is dedicated to increasing the desirable outputs as much as possible. Managerial disposability implies that the environmental performance of the DMU is the first criterion, and companies increase their inputs in order to reduce the undesirable outputs. Enterprises under managerial disposability take environmental regulation as an opportunity to enhance their unified efficiency by using environmental technologies or new management. This is a positive way to deal with environmental regulation, and it gives the same propriety to both economic and environmental performance.

The axiomatic expressions of the disposability are as follows:

It considers $X \in R_+^m$ as the vector for inputs with m components, $G \in R_+^s$ as the vector for desirable outputs with s components, and $B \in R_+^h$ as the vector for undesirable outputs with h components. The j stands for the j -th DMU. Those three kinds of vectors are production factors. The unified production and environmental emissions possibility set to express natural and managerial disposability are as follows:

$$P_v^N(X) = \left\{ (G, B) : G \leq \sum_{j=1}^n G_j \lambda_j, B \geq \sum_{j=1}^n B_j \lambda_j, X \geq \sum_{j=1}^n X_j \lambda_j, \sum_{j=1}^n \lambda_j = 1 \ \& \ \lambda_j \geq 0 (j = 1, \dots, n) \right\}, \quad (1)$$

$$P_v^M(X) = \left\{ (G, B) : G \leq \sum_{j=1}^n G_j \lambda_j, B \geq \sum_{j=1}^n B_j \lambda_j, X \leq \sum_{j=1}^n X_j \lambda_j, \sum_{j=1}^n \lambda_j = 1 \ \& \ \lambda_j \geq 0 (j = 1, \dots, n) \right\}, \quad (2)$$

where $P_v^N(X)$ stands for a possibility set under natural disposability, and $P_v^M(X)$ stands for a possibility set under managerial disposability. v stands for variable RTS (returns to scale) or DTS (damages to scale) since the constraint ($\sum_{j=1}^n \lambda_j = 1$) is in those two axiomatic expressions. In the axiomatic expressions, the two concepts both have $G \leq \sum_{j=1}^n G_j \lambda_j, B \geq \sum_{j=1}^n B_j \lambda_j$, which indicates that an efficiency frontier for all desirable outputs should be located above or on observations, and all undesirable outputs should be located below or on observations. Meanwhile, the difference between the two disposability

concepts is that $P_v^N(X)$ has $X \geq \sum_{j=1}^n X_j \lambda_j$, implying that a company can attain the efficiency frontier by reducing a directional vector of inputs while $P_v^M(X)$ has $X \leq \sum_{j=1}^n X_j \lambda_j$, implying that a company can attain the efficiency frontier by increasing a directional vector of inputs.

Compared to traditional DEA, which usually assumes a capacity limit on the production system, the DEA environmental assessment is dedicated to discussing how to balance economic benefit and environmental protection. In other words, the production cost is determined according to the marginal cost (variable RTS and DTS), rather than the total cost in traditional DEA evaluation [18,33]. The natural disposability and managerial disposability are linked to the operational difficulty and eco-technology innovation on undesirable outputs, such as CO₂ emissions. Therefore, the measurement of efficiency is in the context of sustainability, which can provide a more comprehensively environmental assessment result.

2.3. Non-Radial Approach for Unified Efficiency Measures

The unified efficiency of DMU in this non-radial model separates the slack variables of the i -th input into positive and negative parts (d_i^{x+} and d_i^{x-}) to illustrate the two kinds of disposability. The unified efficiency (UE_v^{NR}) for the k -th DMU can be reformulated under natural and managerial disposability. The NR stands for the non-radial measure, and v refers to variable RTS and DTS. The magnitude of UE_v^{NR} is measured by the following model:

$$\begin{aligned} & \text{Maximize } \sum_{i=1}^m R_i^x (d_i^{x+} + d_i^{x-}) + \sum_{r=1}^s R_r^g d_r^g + \sum_{f=1}^h R_f^b d_f^b \\ \text{s.t. } & \sum_{j=1}^n x_{ij} \lambda_j - d_i^{x+} + d_i^{x-} = x_{ik} \quad (i = 1, \dots, m), \\ & \sum_{j=1}^n g_{rj} \lambda_j - d_r^g = g_{rk} \quad (r = 1, \dots, s), \\ & \sum_{j=1}^n b_{fj} \lambda_j + d_f^b = b_{fk} \quad (f = 1, \dots, h), \\ & \sum_{j=1}^n \lambda_j = 1, \\ & \lambda \geq 0, d_i^{x+} \geq 0 \text{ for all } i, d_i^{x-} \geq 0 \text{ for all } i, \\ & d_r^g \geq 0 \text{ for all } r, d_f^b \geq 0 \text{ for all } f. \end{aligned} \quad (3)$$

In the proposed Equation (3), the production factors are adjusted by the data ranges. This study uses the following three types of data ranges according to the upper and lower bounds on each production factor. The data range adjustment can be used to control the magnitude of the unified efficiency measure between full efficiency and inefficiency [33]:

$$\begin{aligned} R_i^x &= (m + s + h)^{-1} \left(\max\{x_{ij} | j = 1, \dots, n\} - \min\{x_{ij} | j = 1, \dots, n\} \right)^{-1}, \\ R_r^g &= (m + s + h)^{-1} \left(\max\{g_{rj} | j = 1, \dots, n\} - \min\{g_{rj} | j = 1, \dots, n\} \right)^{-1}, \\ R_f^b &= (m + s + h)^{-1} \left(\max\{b_{fj} | j = 1, \dots, n\} - \min\{b_{fj} | j = 1, \dots, n\} \right)^{-1}. \end{aligned} \quad (4)$$

Based on the optimal solution from Equation (3), the UE_v^{NR} score on optimality is as follows:

$$UE_v^{NR} = 1 - \left(\sum_{i=1}^m R_i^x (d_i^{x+*} + d_i^{x-*}) + \sum_{r=1}^s R_r^g d_r^{g*} + \sum_{f=1}^h R_f^b d_f^{b*} \right). \quad (5)$$

In this non-radial approach, the vector $\lambda = (\lambda_1, \dots, \lambda_n)^{Tr}$ in Equation (3), as the intensity or the structural vector, is used for connecting the production factors by a convex combination. The production and pollution possibility set for Equation (3) is structured under variable RTS and DTS. The slack variables represent the level of inefficiency, and the level of inefficiency is determined on the optimality of Equation (3) by the total amount of slacks. Therefore, Equation (5) expresses the level of unified efficiency.

2.4. Unified Efficiency under Natural Disposability

The non-radial model under natural disposability (N) is used to measure the unified efficiency of the k -th DMU, and is formulated by the following model:

$$\begin{aligned}
 & \text{Maximize } \sum_{i=1}^m R_i^x d_i^{x-} + \sum_{r=1}^s R_r^g d_r^g + \sum_{f=1}^h R_f^b d_f^b \\
 & \text{s.t. } \sum_{j=1}^n x_{ij} \lambda_j + d_i^{x-} = x_{ik} \quad (i = 1, \dots, m), \\
 & \quad \sum_{j=1}^n g_{rj} \lambda_j - d_r^g = g_{rk} \quad (r = 1, \dots, s), \\
 & \quad \sum_{j=1}^n b_{fj} \lambda_j + d_f^b = b_{fk} \quad (f = 1, \dots, h), \\
 & \quad \sum_{j=1}^n \lambda_j = 1, \\
 & \lambda \geq 0, d_i^{x-} \geq 0 \text{ for all } i, d_r^g \geq 0 \text{ for all } r, d_f^b \geq 0 \text{ for all } f.
 \end{aligned} \tag{6}$$

In order to attain the strategy under natural disposability, Equation (6) only considers the slack variable, d_i^{x-} , related to the inputs. The unified efficiency under natural disposability (UEN) is measured by Equation (7), where all slack variables are obtained from the optimality of Equation (6). The equation within the parentheses expresses the level of inefficiency under natural disposability, and the unified efficiency formulated in Equation (7) is obtained by subtracting the score of the inefficiency from the unity:

$$UEN_v^{NR} = 1 - \left(\sum_{i=1}^m R_i^x d_i^{x-*} + \sum_{r=1}^s R_r^g d_r^{g*} + \sum_{f=1}^h R_f^b d_f^{b*} \right). \tag{7}$$

2.5. Unified Efficiency under Managerial Disposability

Compared with the UEN, the unified efficiency under managerial disposability (M) puts the environmental performance of DMU as the first priority. The non-radial model under managerial disposability to measure the unified efficiency of the k -th DMU is formulated by the following model:

$$\begin{aligned}
 & \text{Maximize } \sum_{i=1}^m R_i^x d_i^{x+} + \sum_{r=1}^s R_r^g d_r^g + \sum_{f=1}^h R_f^b d_f^b \\
 & \text{s.t. } \sum_{j=1}^n x_{ij} \lambda_j - d_i^{x+} = x_{ik} \quad (i = 1, \dots, m), \\
 & \quad \sum_{j=1}^n g_{rj} \lambda_j - d_r^g = g_{rk} \quad (r = 1, \dots, s), \\
 & \quad \sum_{j=1}^n b_{fj} \lambda_j + d_f^b = b_{fk} \quad (f = 1, \dots, h), \\
 & \quad \sum_{j=1}^n \lambda_j = 1, \\
 & \lambda \geq 0, d_i^{x+} \geq 0 \text{ for all } i, d_r^g \geq 0 \text{ for all } r, d_f^b \geq 0 \text{ for all } f.
 \end{aligned} \tag{8}$$

In order to attain the strategy under managerial disposability, Equation (8) only considers the slack variable, d_i^{x+} , related to the inputs. The unified efficiency under managerial disposability (UEM) is measured by Equation (9), where all slack variables are obtained from the optimality of Equation (8). The equation within the parentheses expresses the level of inefficiency under managerial disposability, and the unified efficiency formulated in Equation (9) is obtained by subtracting the score of inefficiency from unity:

$$UEM_v^{NR} = 1 - \left(\sum_{i=1}^m R_i^x d_i^{x+*} + \sum_{r=1}^s R_r^g d_r^{g*} + \sum_{f=1}^h R_f^b d_f^{b*} \right). \tag{9}$$

3. The Environmental Assessment of Chinese Logistics Enterprises

3.1. Variables and Data

This study chose four input variables, two desirable output variables, and one undesirable output variables. The four inputs were as follows: (a) Total assets, it refers to the total amount of assets owned by each company, and it is the sum of all current and noncurrent assets; (b) total operating expenses, operating expenses are the total expenses in a company's day-to-day regular operations, such as sale

and management expenses; (c) employee, this is the total number of each company's employees; and (d) energy consumption, this is the total amount of fossil fuel and electricity consumption in each company's operation. The two desirable outputs were revenue and net income. Revenue refers to the total income generated from the sale of goods or services before any expenses are deducted. Net income is the total revenue minus all expenses in an accounting period. The undesirable output was CO₂ emissions, and the CO₂ emissions is from scope 1 and scope 2. According to the GHG Protocol Corporate Accounting and Reporting Standard [34], scope 1 emissions are direct emissions from a company's controlled sources; scope 2 emissions are indirect emissions, such as electricity purchased and used by a company; and scope 3 emissions are all other indirect emissions, which were not included in our data collection.

One of the major challenges in environmental assessment at the enterprise level is environmental data collection and standardization, especially in the freight transportation area. According to the review of Ellram and Murfield [5], there are very few comprehensive data sets on transportation emissions (such as by source, time horizon, or freight and passenger). Using empirical data to establish a baseline for environmental transportation performance is critical to understand the impact of freight transportation on sustainability. Considering this, the study collected environmental secondary data from enterprises' corporate sustainability report (CSR) disclosures. All samples were collected from China's listed freight transportation companies. The emissions and energy consumption data were collected from the database of Hong Kong Exchanges and Clearing Limited (SEHK), which contains environmental sustainable disclosures of listed companies. The other inputs and outputs were collected from the Wind Economic Database, which is the most comprehensive database on China's economy and industries.

Due to the data availability, 32 out of 58 enterprises in the industrial transportation sector were selected. The total income of the collected enterprises accounts for around 80% of the whole freight transportation sector in SEHK. Considering the environmental information of a listed company changed to mandatory disclosure in 2016, both financial and environmental data were collected from the last three years (2016–2018). Descriptive statistics of the data are shown in Table 1.

Table 1. Descriptive statistical data.

Variables	Unit	Mean	Min.	Max.
Total assets	million USD	5070.51	11.50	33,241.61
Operating expense	million USD	1809.88	6.47	17,142.98
Employee	person	6843.00	41.00	40,300
Energy consumption	tce	443,000	42.52	7,630,000
Revenue	million USD	1933.36	2.08	17,549.22
Net income	million USD	152.39	−33.05	924.94
CO ₂ emissions	tons	1,030,000	185.40	16,000,000

3.2. Results and Discussions

3.2.1. Unified Efficiency of Enterprises

In the selected data set, the occurrence of negative values is observed in net income since enterprises may encounter losses in a certain financial year. Considering the property of translation invariance of the non-radial model, the two desirable output variables were shifted towards the positive direction to eliminate the negative values while the efficiency measure was not influenced [35].

Given the service types provided by the collected logistics companies, the 32 companies were divided into 3 different service modes: Logistics service provider (LSP), port, and ocean carrier. The statistical character of the input and output factors indicates different service features of the three modes. Among those three enterprise groups, the average energy consumption of ocean carriers is the highest while the average employee of LSP is the highest. The UEN was calculated by Equation (7), and the UEM was calculated by Equation (9). Tables A1–A3 in the Appendix A present the unified

efficiency of each company from the LSP, port, and ocean carrier separately. Each table presents the UEN and UEM scores of the listed company from 2016 to 2018.

The companies in the LSP group mainly supply integrated logistics services, such as transportation, warehouse, supply chain solutions, express delivery, and any other customized services in supply chain operation, and the process of operation could contain multiple transportation modes. The UEN and UEM of each company and average scores all indicate high levels of efficiency under both natural and managerial disposability while the UEN is higher than the UEM score on each LSP enterprise.

The companies belonging to the port group mainly provide comprehensive port services, such as port management and operation, dock service, container handling, and any other related business. The average score of UEN is 0.979 and the average score of UEM is 0.729.

The companies in the ocean carrier group mainly focus on shipping transportation, especially on international shipping operation, maritime service, and ship chartering, and most of the enterprises have their own cargo ship. Similarly, the UEN is higher than the UEM score on each ocean carrier enterprise. The average score of UEN is 0.989 and the average score of UEM is 0.616.

Comparing the UEN of all enterprises, the UENs range between 0.9 and 1. The average efficiency under natural disposability of LSP is 0.993, higher than the port and ocean carrier, while the average value of UEN in ocean carriers is the lowest. The scores of UEM are between 0.3 and 1. The UEM of each enterprise is lower than its UEN. The average UEM in LSPs is 0.729, the average UEM of the port is 0.709, and the average UEM of the ocean carrier is 0.678. Apparently, the LSPs have a higher unified efficiency under both natural and managerial disposability.

Figure 1 displays the average UEN scores of each logistics enterprise. The color indicates the different service modes, and the company name is shown as the company's stock symbol (the links of the stock symbol and company name are displayed in Table A4 in the Appendix A). The performance of LSP under natural disposability is better than the other two service types: Only 2 out of 10 LSPs do not have the unit score, which means the production arrangement under natural disposability achieved full efficiency. Meanwhile, the majority of the efficiency scores in the port and ocean carrier groups does not reach the efficiency frontier, and the minimum UEN is in the port company.

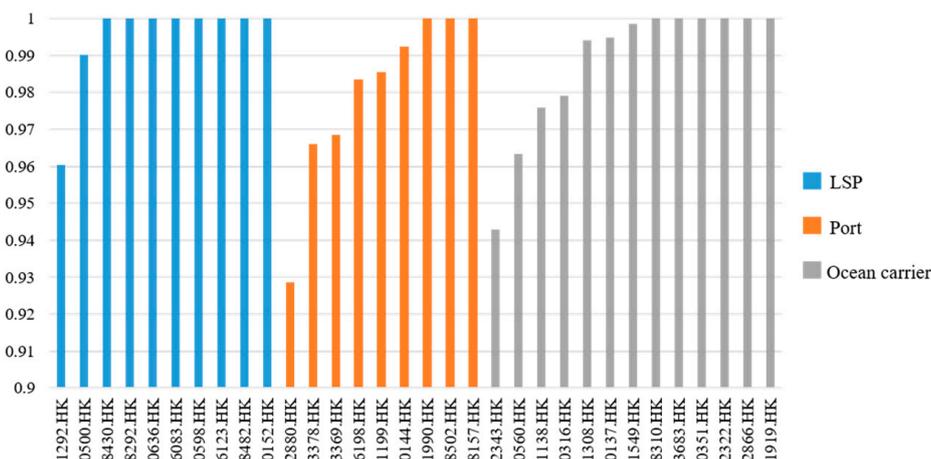


Figure 1. The average UEN of logistics enterprises.

Figure 2 shows the average UEM scores of each logistics enterprise, with the meaning of the color and company name the same as in Figure 1. It is obvious that the efficiency under managerial disposability varies more significantly. The unified efficiency of LSPs is still the highest compared to port and ocean carriers. Four out of seven DMUs with UEM values higher than 0.9 are LSP companies. While the efficiency of ocean carriers contains more low scores, most DMUs with UEM values under 0.5 are ocean carriers. The lower efficiency under managerial disposability of ocean carriers could be due to the high energy consumption in the maritime compared with other freight transportation modes [7].

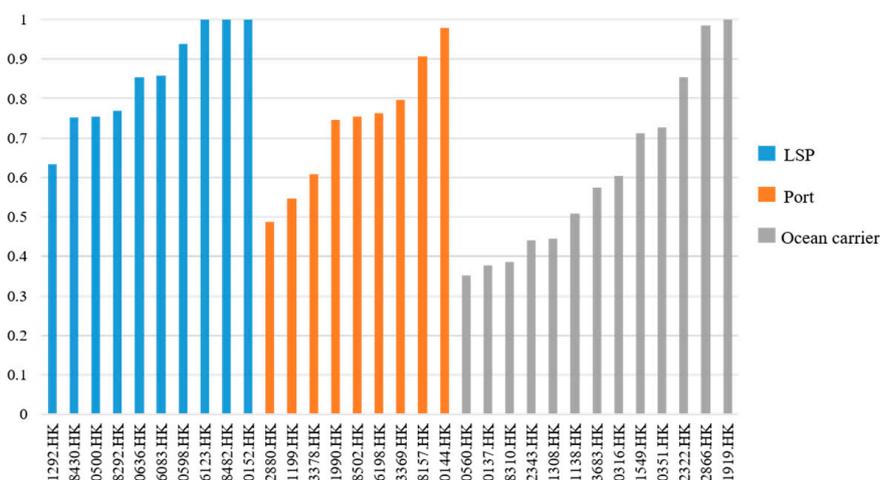


Figure 2. The average UEM of logistics enterprises.

Based on the aforementioned results from each company, the high average UEN and the relatively lower average UEM of logistics enterprises indicate that the business strategies of Chinese logistics companies still put economic benefits at a high priority when facing environmentally sustainable pressure. According to Jeswani and Wehrmeyer [9], when first confronted with environmental constraints, companies may resist change and use negative strategies. Therefore, these results are consistent with the primary development stage of sustainability in China’s logistics industry. Additionally, under the new situation of economic transition in China, the key point of the industry structure has shifted to internet-based industry, such as e-commerce. Additionally, this transition would promote freight transportation and logistics to move into a bigger market, which also means increased CO₂ emissions and more severe environmental constraints [36]. Therefore, under the sustainability business circumstance, Chinese logistics companies should consider not only the operational performance but also more proactive actions towards emissions reduction and environmental protection, such as using clean technology and improvement of management efficiency.

3.2.2. Unified Efficiency Grouped by Enterprise Size and Ownership

To further explore the environmental performance under the two disposability scenarios, this study classified the logistics enterprises into different groups by enterprise size and ownership separately.

1. Grouped by enterprise size. The data set was divided into two groups by enterprise size: Small and medium enterprises (SMEs) and large enterprises. The classification of enterprise size was adopted from the standard of National Bureau of Statistics in China [37]. The standard defines large enterprises in the transportation sector as employing more than 1000 people with a revenue of more than 300 million RMB while enterprises with less than 1000 employees and less than 300 million RMB revenue are defined as SMEs.

2. Grouped by ownership. The logistics companies were classified into two categories according to their ownership: (a) State-owned enterprises, state-owned enterprises are under the supervision of the national or local government, and the government has significant control through full, majority, or significant minority ownership; and (b) private enterprises, which refer to companies that operate under independent firms or individuals, and are free from government intervention.

Figure 3 is the treemap of the 32 enterprises classified by ownership and enterprise size. Obviously, all state-owned enterprises belong to the large enterprise group while the private enterprises have different company sizes, from large corporations to micro enterprises employing a handful of people. The classifications of each company by sample size and ownership are displayed in Table A4 in the Appendix A.

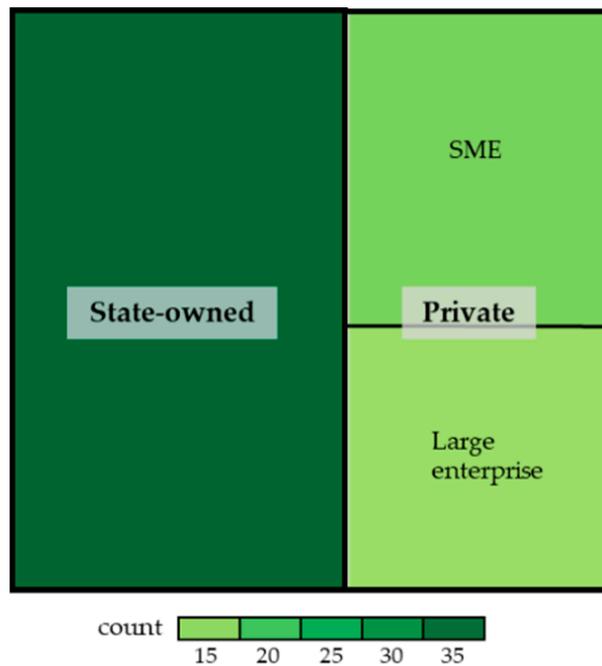


Figure 3. The amount of enterprises classified by ownership and enterprise size.

Table 2 presents the unified efficiency of groups divided by enterprise ownership and size. According to the efficiency of companies grouped by enterprise size, the UEN average of SMEs is 1, and the UEN average of large enterprises is 0.982, lower than SMEs. Similarly, the UEM average of SMEs (0.780) is higher than the large enterprises (0.685). Meanwhile, the standard deviations of SMEs are smaller than large enterprises from both UEN and UEM. Apparently, the unified efficiency of SMEs shows a better performance under both natural and managerial disposability.

Table 2. Unified efficiency grouped by enterprise size and ownership.

Groups	Statistics	UEN	UEM
Enterprise Size			
SME	Average	1.000	0.780
	Max.	1.000	1.000
	Min.	0.999	0.574
	S.D.	0.001	0.108
Large enterprise	Average	0.982	0.685
	Max.	1.000	1.000
	Min.	0.928	0.300
	S.D.	0.023	0.228
Ownership			
State-owned	Average	0.982	0.717
	Max.	1.000	1.000
	Min.	0.928	0.300
	S.D.	0.025	0.235
Private	Average	0.991	0.701
	Max.	1.000	1.000
	Min.	0.937	0.376
	S.D.	0.018	0.185

Given this comparison of enterprise size, the differences between the two groups are intriguing. The differences between large enterprises and SMEs indicate that the production factors are better arranged in SMEs from operational priorities. The higher score of UEN in SMEs is in line with the survey of Lin and Ho [38] based on Chinese logistics companies. Due to the limited resources, SMEs tend to give priority to the improvement of core business activities rather than improving environmental performance. According to Kudla and Klaas-Wissing [39], the size of logistics companies may have an impact on their attitudes towards green initiatives. Considering that environmental sustainability in the Chinese logistics sector is still at the primary stage, SMEs usually provide less service categories with a smaller scale of transportation instruments than large enterprises, which could make the operational adjustment more agile when facing environmental regulations. Given the greater organizational structure and higher management cost in large logistics enterprises, it may take a more complex arrangement and longer time to adjust the sustainable business context. Moreover, in order to achieve better competition advantages, SMEs also face higher pressure from downstream supply chain partners in environmental sustainability. Therefore, the UEM in SMEs could be higher than large logistics companies at this early stage of environmental sustainability in the logistics industry.

As to the comparison of efficiency from state-owned and private enterprises, the UEN average of the state-owned enterprises is 0.98, lower than the private enterprises, which is 0.994. On the contrary, the UEM average of the state-owned enterprises (0.712) is higher than private enterprises (0.704). However, the standard deviations of state-owned enterprises are bigger than private enterprises from both UEN and UEM.

State-owned enterprises under government management can enjoy monopolies of strategic industries and get public capital support more easily, such as subsidies, preferential loans, and lower rates of taxation. However, state-owned enterprises also face stricter control and intervention by the government, and the Chinese government has already given high priority to environmental sustainability, regulations, and policies that firstly target state-owned enterprises. Furthermore, the study of Quan and Wu [40] based on Chinese listed firms showed that only state-owned companies can achieve economic performance enhancement to be environmentally sustainable. Therefore, at the early stage of sustainable development for logistics companies, state-owned enterprises would face more severe pressures and driving force from the government on environmental issues. They will dedicate more resources towards satisfying the policy requirements and being environmentally sustainability. Considering this, the UEM of state-owned enterprises would be higher than private enterprises. This result is also consistent with the finding of Fryxell and Lo [41], which indicated that managers in Chinese state-owned enterprises appeared to embrace stronger environmental ethical values over the private sector.

In contrast, private enterprises have decision-making autonomy on enterprise operations, and are often viewed as more dynamic and market-orientated than state-owned enterprises. Private logistics enterprises in China now account for a significant proportion of freight transportation activity. When facing environmental protection pressures, private enterprises may still make decisions that rely on commercial consideration to achieve maximum economic benefit using minimum inputs. Therefore, the UEN of private enterprises may be higher than state-owned enterprises.

3.2.3. Statistical Test

To further test whether statistical differences existed between the means of the groups divided by enterprise size and enterprise ownership on the unified efficiency under natural and managerial disposability, the Welch's ANOVA test and Welch's t-test were conducted [42]. The Welch's ANOVA method is appropriate for a situation when data has unequal variance, and it has lowest type 1 error compared to nonparametric methods [43]. Additionally, according to the simulation of Moder [43], the ANOVA test is not sensitive to situations when the data has an abnormal distribution. Therefore, this study chose Welch's ANOVA test to compare the differences across enterprise types. Furthermore, the

Welch's t-test, which also does not require the assumption of equal variance, was used for a robust test. The statistical results are displayed in Tables 3 and 4.

Table 3 reports the test results of the comparison between large enterprises and SMEs. According to Welch's ANOVA test, the UEN scores on SMEs and large enterprises are significantly different at the $p < 0.05$ level. The Welch's t-test also shows that the mean score of UEN in SMEs is significantly higher than the mean score of UEN in large enterprises ($t = -3.880$, $p = 0.000$). The two tests on UEN both indicate that the difference between SMEs and large enterprise is statistically significant. On the test of UEM in different enterprise sizes, Welch's ANOVA test ($p = 0.208$) and Welch's t-test ($p = 0.058$) both indicate that the difference between SMEs and large enterprises on UEM is not large enough to be statistically significant.

Table 3. Comparison between SMEs and large enterprises.

Welch's ANOVA Test			
	F-Value	p-Value	Adj R-Squared
UEN	6.730	0.014 *	0.156
UEM	1.650	0.208	0.021
Welch's t-test			
	t-Value	p-Value	Welch's Degrees of Freedom
UEN	-3.880	0.000 *	21.050
UEM	-1.612	0.058	31.690

Note: * indicates the significance level at $p < 0.05$

Table 4. Comparison between state-owned and private enterprises.

Welch's ANOVA Test			
Statistics	F-Value	p-Value	Adj R-Squared
UEN	6.140	0.019 *	0.142
UEM	0.180	0.678	-0.027
Welch's t-Test			
Statistics	t-Value	p-Value	Welch's Degrees of Freedom
UEN	2.418	0.011 *	25.500
UEM	0.412	0.341	28.300

Note: * indicates the significance level at $p < 0.05$

This statistical difference of UEN between large enterprises and SMEs further backs up the aforementioned discussion on the operational character of logistics enterprises of different sizes. At the early stage of sustainability development, logistics companies with a smaller market scale could be more agile in their operations to arrange production factors in order to achieve maximum desirable outputs without worsening the environment. Furthermore, all SMEs are also private enterprises, which face less government intervention on environmental protection, which could further motivate SMEs' business strategy toward operational priority; in other words, improve their efficiency under natural disposability.

Table 4 reports the test results of the comparison between state-owned and private enterprises. According to Welch's ANOVA test, the UEN scores on state-owned and private enterprises are significantly different at the $p < 0.05$ level. Welch's t-test also shows that the mean score of UEN in private enterprises is significantly higher than the mean score of UEN in state-owned enterprises ($t = 2.418$, $p = 0.011$). The two tests on UEN both indicate that the difference between private and

state-owned enterprises is statistically significant. On the test of UEM in different enterprise ownerships, Welch's ANOVA test ($p = 0.678$) and Welch's t-test ($p = 0.341$) both indicate the difference between private and state-owned enterprises on UEM is not large enough to be statistically significant.

Given the rapid growth rate of the private logistics market in China, it would take a lot of effort to transfer the market-orientated strategy to a sustainable-orientated strategy in private enterprises with less government regulations. Therefore, under natural disposability, it is not surprising that the difference between state-owned and private enterprises on UEN is statistically significant; in other words, the UEN of private logistics companies is significantly higher than state-owned enterprises.

It is worth noting that neither the enterprise size nor enterprise ownership shows statistical differences on UEM. That is to say, the differences of UEM are not big enough among those enterprise groups. Given the primary stage of logistics' sustainable construction, enterprises need more time to proactively change their business strategy to be in accordance with environmental sustainability. As the sustainable business environment becomes healthier in the logistics and freight transportation industry in China, the UEM would be enhanced significantly. Additionally, large and state-owned enterprises tend to maintain higher levels of research and development (R&D) investment than private enterprise [44]. State-owned enterprises, which have preferential treatment from the government, would have a greater advantage to reach the efficiency frontier under managerial disposability [31].

4. Conclusions

This paper explored the environmental sustainability development in Chinese logistics enterprises by using environmental assessment DEA methods. Given that the environmental efficiency of logistics in China has not been measured at the enterprise level, this paper attempted to fill the gap in the existing literature to employ environmental assessment into logistics' environmental sustainability. The environmental assessment of logistics enterprises would help logistics managers and policy makers understand the integrated state of environmental performance based on a real production arrangement, which would be a significant contribution to environmental sustainability in the Chinese freight transportation sector.

Based on the inputs and outputs data from listed logistics companies from 2016 to 2018, this study firstly calculated the unified efficiency of each DMU under natural and managerial disposability, then gave multiple comparisons on UEN and UEM by enterprise groups classified by enterprise size and ownership. Due to the unbalanced development of economic performance and environmental sustainability in the Chinese logistics industry, the UEN is higher than UEM for every logistics enterprise in the empirical results. The better performance of efficiency under natural disposability in SMEs and private enterprises was proven to be statistically significant while the efficiency comparison under managerial disposability all had no statistical differences. The empirical results further proved that the development of environmental sustainability in the Chinese freight transportation sector is still at its primary stage. When encountering environmental regulation from the outside, logistics companies, especially private logistics enterprises, may still put commercial consideration at first priority to achieve maximum economic benefit using minimum inputs.

Furthermore, the environmental assessment DEA was proven to be an efficient tool to figure out whether a company is resisting change or has begun taking proactive actions towards environmental protection. For future researches, firstly, though restricted by the availability of environmental data, this study chose CO₂ emissions as the undesirable output. With the improving quality of data disclosure in the transportation sector, future study could consider using multiple environmental data for further investigation. Secondly, as an important member of the supply chain, the activities of logistics are within the whole network of supply chain operation. Therefore, the environmental efficiency of logistics could be further explored under the green supply chain management framework, which can be evaluated by network DEA according to Mirhedayatian and Azadi [45]. Moreover, the comparative analysis of the environmental efficiency in different regions, such as Chinese enterprises

and cross-country enterprises, should be investigated due to the unique environmental and economic background in China.

Despite an increasing awareness of the harmful effects of freight transportation on the environment, efficiency assessment under economic and environmental operational priorities could provide an integrated picture of logistics' environmental development under sustainable business circumstances. There is still a long way to go on transforming logistics firms' operational strategy from an economic priority to an environmentally sustainable priority, which is the backbone of improving environmental performance from the enterprise perspective in the long run. Additionally, this study also provides significant insights for a comparative evaluation on environmental sustainability development in enterprises from other industries or regions.

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Appendix A

Tables A1–A3 present the unified efficiency of LSP, port, and ocean carrier enterprises separately. Each table presents the UEN and UEM scores of listed company from 2016 to 2018.

Table A1. Unified efficiency of LSP.

Year	Stock Symbol	Company Name	UEN	UEM
2017	8430.HK	C&N Holdings	1.000	0.753
2018	8430.HK	C&N Holdings	1.000	0.753
2017	6083.HK	World-Link Logistics (Asia)	1.000	0.858
2017	0636.HK	Kerry Logistics	1.000	0.708
2018	0636.HK	Kerry Logistics	1.000	1.000
2017	0152.HK	Shenzhen International	1.000	1.000
2017	8292.HK	Worldgate Global Logistics	1.000	0.769
2018	8292.HK	Worldgate Global Logistics	1.000	0.769
2018	8482.HK	WAN Leader International	1.000	1.000
2017	0500.HK	Frontier Services Group	0.991	0.754
2018	0500.HK	Frontier Services Group	0.990	0.756
2017	6123.HK	YTO Express	1.000	1.000
2016	1292.HK	Changan Minsheng Logistics	0.964	0.801
2017	1292.HK	Changan Minsheng Logistics	0.961	0.531
2018	1292.HK	Changan Minsheng Logistics	0.957	0.571
2016	0598.HK	Sinotrans	1.000	0.814
2017	0598.HK	Sinotrans	1.000	1.000
2018	0598.HK	Sinotrans	1.000	1.000
		Average	0.992	0.824
	Statistics	Max.	1.000	1.000
		Min.	0.957	0.531

Table A2. Unified efficiency of port.

Year	Stock Symbol	Company Name	UEN	UEM
2017	2880.HK	DaLian Port (PDA)	0.930	0.495
2018	2880.HK	DaLian Port (PDA)	0.928	0.480
2017	3369.HK	Qinhuangdao Port	1.000	0.801
2018	3369.HK	Qinhuangdao Port	0.937	0.795
2016	6198.HK	Qingdao Port International	0.966	0.712
2017	6198.HK	Qingdao Port International	0.985	0.772
2018	6198.HK	Qingdao Port International	1.000	0.805
2016	3378.HK	XiaMen Port	0.963	0.616
2017	3378.HK	XiaMen Port	0.970	0.613
2018	3378.HK	XiaMen Port	0.966	0.598
2017	8157.HK	XIANGXING International	1.000	1.000
2018	8157.HK	XIANGXING International	1.000	0.813
2017	1990.HK	Xinghua Port	1.000	0.745
2018	8502.HK	Ocean Line Port Development	1.000	0.754
2016	0144.HK	China Merchants Port	1.000	0.936
2017	0144.HK	China Merchants Port	0.978	1.000
2018	0144.HK	China Merchants Port	1.000	1.000
2016	1199.HK	COSCO SHIPPING Ports	0.957	0.478
2017	1199.HK	COSCO SHIPPING Ports	1.000	0.627
2018	1199.HK	COSCO SHIPPING Ports	1.000	0.535
		Average	0.979	0.729
Statistics		Max.	1.000	1.000
		Min.	0.928	0.478

Table A3. Unified efficiency of ocean carrier.

Year	Stock Symbol	Company Name	UEN	UEM
2017	8310.HK	Dafeng Port Heshun Technology	1.000	0.387
2018	8310.HK	Dafeng Port Heshun Technology	1.000	0.384
2017	0316.HK	Orient Overseas	0.958	0.600
2018	0316.HK	Orient Overseas	1.000	0.607
2016	1308.HK	SITC International	0.982	0.432
2017	1308.HK	SITC International	1.000	0.450
2018	1308.HK	SITC International	1.000	0.454
2017	0137.HK	JINHUI Holdings Company	0.990	0.376
2018	0137.HK	JINHUI Holdings Company	1.000	0.379
2018	2322.HK	Hong Kong ChaoShang Group	1.000	0.855
2018	3683.HK	Great Harvest Maeta Group	1.000	0.574
2017	2343.HK	Pacific Basin Shipping	0.937	0.432
2018	2343.HK	Pacific Basin Shipping	0.949	0.451
2017	0351.HK	Asia Energy Logistics	1.000	0.748
2018	0351.HK	Asia Energy Logistics	1.000	0.706
2016	1549.HK	Ever Harvest Group	0.999	0.709
2017	1549.HK	Ever Harvest Group	0.999	0.714
2018	1549.HK	Ever Harvest Group	0.999	0.712
2016	2866.HK	COSCO Shipping Development	1.000	1.000
2017	2866.HK	COSCO Shipping Development	1.000	1.000
2018	2866.HK	COSCO Shipping Development	1.000	0.958
2017	1919.HK	COSCO SHIPPING Holdings	1.000	1.000
2018	1919.HK	COSCO SHIPPING Holdings	1.000	1.000
2016	1138.HK	COSCO Shipping Energy	1.000	0.508
2017	1138.HK	COSCO Shipping Energy	0.952	0.510
2016	0560.HK	Chu Kong Shipping	0.988	0.403
2017	0560.HK	Chu Kong Shipping	0.939	0.300
		Average	0.989	0.616
Statistics		Max.	1.000	1.000
		Min.	0.937	0.300

Table A4 displays the categories of each company which classified by ownership and enterprise size.

Table A4. Classification of each company.

Stock Symbol	Company Name	Ownership	Size
0137.HK	JINHUI Holdings Company	Private	Large enterprise
0144.HK	China Merchants Port	State-owned	Large enterprise
0152.HK	Shenzhen International	State-owned	Large enterprise
0316.HK	Orient Overseas	State-owned	Large enterprise
0351.HK	Asia Energy Logistics	Private	SME
0500.HK	Frontier Services Group	Private	Large enterprise
0560.HK	Chu Kong Shipping	State-owned	Large enterprise
0598.HK	Sinotrans	State-owned	Large enterprise
0636.HK	Kerry Logistics	Private	Large enterprise
1138.HK	COSCO Shipping Energy	State-owned	Large enterprise
1199.HK	COSCO SHIPPING Ports	State-owned	Large enterprise
1292.HK	Changan Minsheng Logistics	State-owned	Large enterprise
1308.HK	SITC International	Private	Large enterprise
1549.HK	Ever Harvest Group	Private	SME
1919.HK	COSCO SHIPPING Holdings	State-owned	Large enterprise
1990.HK	Xinghua Port	Private	Large enterprise
2322.HK	Hong Kong ChaoShang Group	Private	SME
2343.HK	Pacific Basin Shipping	Private	Large enterprise
2866.HK	COSCO Shipping Development	State-owned	Large enterprise
2880.HK	DaLian Port (PDA)	State-owned	Large enterprise
3369.HK	Qinhuangdao Port	State-owned	Large enterprise
3378.HK	XiaMen Port	State-owned	Large enterprise
3683.HK	Great Harvest Maeta Group	Private	SME
6083.HK	World-Link Logistics (Asia)	Private	SME
6123.HK	YTO Express	Private	Large enterprise
6198.HK	Qingdao Port International	State-owned	Large enterprise
8157.HK	XIANGXING International	Private	SME
8292.HK	Worldgate Global Logistics	Private	SME
8310.HK	Dafeng Port	State-owned	Large enterprise
8430.HK	C&N Holdings	Private	SME
8482.HK	WAN Leader International	Private	SME
8502.HK	Ocean Line Port Development	Private	SME

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