A Decision-Making Model of Port Carbon Emission Reduction Investment under Uncertainty

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Abstract. Ports are big emitters of carbon emissions and often spend a lot of money and time on carbon emission reduction. Therefore, this paper constructs a port carbon emission reduction investment decision-making model under the uncertainty of carbon emission amount and carbon trading price, which taking the minimization of carbon emission reduction comprehensive cost as the optimization objective including some key factors such as the budget constraint of port carbon emission investment, carbon emission quota, and so on. At last, the case study of Shanghai port is carried out, and the optimization results show that Shanghai port should invest 3.10 Yi yuan in 2019 for carbon emission reduction. It is useful for the port carbon emission reduction managers and policy makers.

Keywords: Carbon Emission Reduction Investment, Carbon Trading, Decision-Making

1. Introduction

Ports are big emitters of carbon and are the main targets of carbon trading pilots. The energy consumption of port occupies a large proportion in the whole transportation industry. In recent years, a lot of China ports have been included in carbon emission trading pilot projects. In this pilot process, many ports actively strengthen carbon emission reduction investment and participate in the carbon emission rights market trading in their jurisdiction, and the carbon emission pilot has achieved positive results. However, some ports are faced with the problem of how much carbon emission reduction investment and how to maximize the effect of carbon emission reduction investment in practice, and the carbon emission reduction investment decision needs to be optimized and improved.

Many studies have shown that increasing investment helps to reduce carbon emissions (Vogt-Schilb, Meunier and Hallegatte (2018)[1], Ganda (2019)[2]). At present, the academic circle mainly focuses on the decision-making of carbon emission reduction investment in the supply chain, thermal power industry and other fields. Toptal, OEzlue and Konur (2014)[3] analyzed the joint strategies of inventory replenishment and carbon emission reduction investment under three carbon emission regulations: carbon quota, carbon tax and cap-and-trade. Li, Su and Lai(2019)[4] built single-layer and double-layer principal-agent principal-agent models including the supplier, and compared the abatement strategies of the manufacturer and designs the government's incentive contracts for the manufacturer of the supply
chain on reducing emissions. Zhang, Yang and Yu, et al(2018)[5] present a carbon-abatement investment-option game model for asymmetric generation companies. The results show that the investment behavior of generation companies is largely affected by the critical value of the electricity price after carbon-abatement investment. Zhang, Gan and Wang, et al(2020)[6] constructed real option models of the coal-fired power plants’ carbon emission reduction investment under the carbon price floor and revenue floor schemes, and discuss the investment optimal implementation duration of these two schemes. Mo, Schleich and Fan(2018)[7] developed a three-stage carbon capture and storage technology investment decision model under multiple uncertainties which allowed for investment and especially operating flexibilities.

However, the above relevant carbon emission reduction investment decision research theories and models are not necessarily applicable to the port carbon emission reduction investment scenario. At the same time, the research on port carbon is still relatively backward (Yang(2017)[8], Sim(2018)[9], Zhong, Hu and Yip(2019)[10]), and the core issues such as the investment decision on carbon emission reduction of the port need to be further studied. Therefore, this paper constructs a decision-making model of port carbon emission reduction investment under uncertainty, and to solve the optimization problem of port carbon emission reduction investment.

2. The Model

2.1 Problem Description

The carbon emission quota trading system is a cap-and-trade system, in which the government sets the total amount of quota and grants it to the emission control enterprises, allowing them to trade freely. In other words, certain subjects are given the legal right of carbon emission quota under the premise of the limited amount of quota, and this right is allowed to be bought and sold like commodities. The port will generally be included in the carbon emissions pilot scope every year. Each year, the government will determine the next year annual carbon emission quota of the port according to their historical carbon emission intensity base and annual business scale. The port performs settlement obligations mainly according to the annual carbon emission quota. If the quota is insufficient, it shall be made up through a carbon trading platform. Where the quota is in surplus, it may also be used for quota trading. In the process of carbon emission, the port generally make long-term strategic investment in accordance with the national carbon emission reduction target, and make corresponding investment in carbon emission reduction to ensure the realization of the corresponding target.

Therefore, the port needs to make optimal decision on the carbon emission reduction investment. Generally speaking, the port can take two measures to ensure that their carbon emission strategies meet the requirements. The first is to reduce carbon emissions through investment. The second is to buy or sell in the carbon trading market. If the current year's carbon emissions still exceed the quota in the case of reduction investment, then the corresponding balance needs to be purchased in the carbon market. If the current year's carbon emissions do not exceed the quota in the case of reduction investment, then the remaining quota can be sold in the carbon trading market, so as to obtain the carbon income. In this process, the port needs to make decisions on their carbon emissions to minimize their costs.

2.2 Hypothesis

We sets \((F, \{F_t\}, \mathcal{Q})\) as the probability measure space with field flow \(\{F_t\}\), where \(F\) is the generated \(\sigma\) field, \(\mathcal{Q}\) is the risk neutral measure, and \(\{F_t\}\) is the field flow generated by the involved random process. In order to simplify the problem, the optimization model of carbon emission reduction investment decision of the port is assumed, mainly including:

**Hypothesis 1**: according to the carbon emission pilot program, the annual carbon emission quota \(A\) allocated to port at the beginning of the year at time \(t=0\).

**Hypothesis 2**: the port's annual carbon emission amount \(C\), obeys the following random process (Tian, Pan and Du, et al(2017) [11]):
Among them, the drift rate and volatility of the port annual carbon emission amount are respectively represented by the $\mu_C$ and $\sigma_C$.

**Hypothesis 3:** the carbon trading price $S_t$ is also subject to the following random process (Tian, Pan and Du, et al(2017) [11]):

$$\frac{dS_t}{S_t} = \mu_S dt + \sigma_S dW_{2t}$$

Where, $\mu_S$ and $\sigma_S$ respectively represent the drift rate and volatility of the carbon trading price $S_t$. $W_{2t}$ is a standard Brownian motion, and $W_t$ correlation coefficient for $\rho$ under $Q$ measure.

**Hypothesis 4:** according to the comparison between the actual carbon emission amount and the quota, the port will go to the carbon trading market to buy or sell at $t=1$. We assume that the carbon trading market is active and can be traded instantaneously. In addition, transaction fees, costs and taxes are not considered.

**Hypothesis 5:** the budget constraint of the port’s carbon emission reduction investment in that year is $T$. Where, carbon emission reduction investment $K$ is the decision variable, and the relationship between $K$ and emission reduction amount $\Delta C_t$ satisfies the following formula (Yang, Zhang and Ji (2017) [12]):

$$\Delta C_t = \alpha K^\gamma$$

Where, $\alpha$ is the marginal coefficient of the port carbon emission reduction.

**Hypothesis 6:** The government gives corresponding subsidies to the port according to its actual carbon emission reduction amount in that year, assuming that the following relationship is satisfied:

$$G = \beta \Delta C_t = \alpha \beta K^\gamma$$

Among them, $\beta$ is the subsidy coefficient of carbon emission reduction. Here, the decision variable $K$ in that year must satisfy:

$$T \geq K - G = K - \alpha \beta K^\gamma \geq 0$$

### 2.3 The Optimization Model

The port in a certain period of their carbon emissions below or beyond the quota two scenarios are likely to occur, that is, there is either remaining carbon emission quota, or carbon emission quota is insufficient. According to the above problem description and hypothesis, we consider the port’s carbon emission reduction investment optimization strategy under the two measures of carbon emission reduction investment and carbon trading. The model is set up as follows:

**Scenario 1:** if carbon emission reduction investment is considered and the quota has surplus, the port needs to sell surplus quota in the carbon trading market. In this scenario, the port’s comprehensive cost $O_1 = [(A - (C_t - \Delta C_t))S_t + G - K]$.

**Scenario 2:** if carbon emission reduction investment is considered, and there is still a gap of the quotas, the port needs to buy quota balance in the carbon trading market. In this scenario, the port’s comprehensive cost $O_2 = [(A - (C_t - \Delta C_t))S_t + G - K]$.

Therefore, in order to reach port's goal of minimizing the carbon emission reduction comprehensive cost with investment budget constraint $T$, we merge two scenarios, and get comprehensive cost decision objective function expressions under the probability $\text{Prob}[(A - (C_t - \Delta C_t))S_t + G - K - T \leq 0]$ as follows:
In fact, if \( \mathrm{Prob}\{(A-(C_t-\Delta C_t))S_t+G-K-T>0\}\) , it means the port carbon emission comprehensive cost excess investment budget constraint \(T\), this case will not be considered. Correspondingly, the optimization model of carbon emission reduction investment decision of the port is obtained by formulas (7):

\[
\begin{align*}
\min & \quad O = \{(A-(C_t-\Delta C_t))S_t+G-K-T,0\} \\
\text{s.t.} & \quad T \geq K-G = K-\alpha\beta K^\dagger \geq 0
\end{align*}
\]

Formulas (7) are the port investment decision under the uncertain environment of the carbon trading price \(S_t\) and carbon emission amount \(C_t\).

Due to the complexity of this model, we use numerical simulation method to solve the optimal solution.

3. Case Study

Shanghai port is the largest port in the world, and its carbon emission reduction work has typical demonstration significance in Chinese ports. As early as 2012, Shanghai port was included in the Shanghai government's first batch of carbon emission trading pilot units. For this reason, this paper makes a case study on the carbon emission reduction investment decision of Shanghai port in 2019.

3.1. Data and Parameters

According to the consumption of diesel oil, fuel oil and electricity in the sustainable development report of Shanghai port from 2008 to 2018, multiply the corresponding carbon emission conversion coefficient to get the annual carbon emissions. The daily carbon trading price of on Shanghai carbon emission exchange was collected, and the time span was 2013/12/19-2018/12/28. By using the historical carbon emission data of Shanghai port and Shanghai carbon trading price (annualized), the parameters were obtained, i.e., \(\mu_C=1.9843\%\), \(\sigma_C^2=1.5186\%\), \(\mu_S=2.6673\%\), \(\sigma_S^2=37.0734\%\), \(\rho=-0.6560\).

In 2018, carbon emission amount from Shanghai port was \(C_0=43.12\) Wan tons, and Shanghai carbon trading price \(S_0=35.88\) yuan/ton. Meanwhile, it is assumed that in 2019, the carbon emission settlement quota granted to Shanghai port by the Shanghai government is \(A=45\) Wan tons, and the subsidy coefficient is \(\beta=0.1500\) Yi yuan/Wan ton. The Shanghai port's investment budget constraint \(T=4\) Yi yuan. The marginal coefficient of carbon emission reduction investment \(\alpha=4.1742\).

3.2. The Optimal Solution

According to formulas (7), the optimal solution of the optimal carbon emission reduction investment decision variable \(K\) for Shanghai port in 2019 is solved. According to equation (7.2), the range of carbon emission reduction investment \(K\) can be obtained [1.29, 3.10]. Then, according to the objective function (7.1), the change of the Shanghai port's carbon emission reduction investment decision variable \(K\) and comprehensive cost \(O\) can be obtained, as shown in Figure.1. The relationship between carbon emission reduction investment \(K\) and comprehensive cost \(O\) is concave and monotonously decreasing. As the decision-making variable \(K\) gradually increases, the comprehensive cost \(O\) of carbon emission of Shanghai port gradually decreases. When the investment amount reaches the upper limit, the comprehensive cost \(O\) reaches the minimum value. Therefore, according to the calculation results of this model, the Shanghai port optimal emission reduction investment is 3.10 Yi yuan in 2019, which can ensure the minimization of its own comprehensive cost.

From the perspective of the entire investment decision-making process, the only important parameter that Shanghai port can control is the carbon emission reduction investment budget constraint \(T\). Other parameters are external factors, which mean that some or all of these factors are beyond the control of Shanghai port. In other words, it is unlikely for Shanghai port to exert influence on other parameters.
through various measures. Therefore, we do not carry out sensitivity analysis on other parameters, and only analyzes budget constraint $T$. The result is shown in Figure 2.

![Figure 1](image1.png)

**Figure 1.** The trend relationship between carbon emission reduction investment $K$ and comprehensive cost $O_t$.

![Figure 2](image2.png)

**Figure 2.** The sensitivity surface of budget constraint $T$ to comprehensive cost $O_t$.

As can be seen from the $T$-axis dimension in Figure 2, with the Shanghai port’s budget constraint $T$ increasing gradually, the comprehensive cost $O_t$ has little change. From the $K$-axis dimension, the influence is obvious. With the increase of $K$, its comprehensive cost $O_t$ decreases correspondingly. This shows that if Shanghai port increases its carbon emission reduction investment, it can get a significant return. Therefore, Shanghai port should step up efforts to build a green port, and further take relevant measures to reduce carbon emission.

4. Conclusion
Ports are big emitters of carbon emissions, and those are also the main participants in the carbon trading market. For this reason, this paper constructs a port carbon emission reduction investment decision model in uncertain environment, and makes a deeper study on investment decision strategy. This model includes several key factors such as carbon emission investment budget constraint, carbon emission quota, carbon emission amount, carbon trading price and so on, making the decision-making scenario as close to reality as possible. At the same time, with the optimization goal of minimizing the carbon emission reduction comprehensive cost under influence of carbon trading price and carbon emission amount, the investment optimal strategy is obtained. Finally, the case of Shanghai port is analyzed by using this model, and the carbon emission reduction investment strategy in 2019 is simulated.

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