Investment decision-making research of oil tanker considering the reduce of oil spill risk

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Abstract: An oil spill accident at sea contributes to an economic loss for oil tanker companies, and the uncertainty of shipping price has a serious impact on the oil tanker investment decision. In view of this, this study establishes an optimal investment decision model, considering the cost of oil spill under uncertain freight conditions with the expectation of investment income as the main optimization target. First, on the basis of the principle of demand and supply function curve, the relation equation of the fluctuating freight rate is established according to the traffic volume, and the size of the freight rate is obtained by considering any alterations of the transportation scale. Second, based on the tanker freight demand uncertainty, a model considering the additional maintenance costs of the oil spill as well as the optimal investment timing and scale is established. Finally, an empirical analysis is undertaken to know the optimal investment timing and scale of the tanker. The results show that on one hand, with the increase in freight uncertainty, the waiting value and scale to reduce the risk from uncertainty increase, and the additional maintenance costs for preventing oil spill will reduce the probability of oil spills and the requirement for investment timing and scale.

1. Introduction

In order to maintain continuous operation, shipping companies have to add to their capacity by investing in building new ships, updating old ones, or leasing them temporarily. The investment decision is directly related to the development profit and survival of international shipping companies. Therefore, shipping investment decision making is always a hot topic in the shipping economy theory and practice. In recent years, the documentation on shipping investment around the world can be mainly divided in two categories:

(1) Traditional investment decision making of ships

Syriopoulos and Roumpis used the vector autoregressive model to study the price and volume dynamics in second-hand dry bulk and tanker shipping markets[1]. Alizade and Monika studied the investment strategy for oil tankers by using the co-integration analysis[2]. Celik applied the fuzzy quality functioned deployment model to integrate different types of tankers, and after analyzing his proposed investment decision project[3]. Tran figured out the characteristics of fleet expansion and container liner transport’s ship size growth by using multivariate autoregressive models[4]. Jeon compared the ship investment strategy of the world's major liner companies by using the fuzzy hierarchy analysis model[5].

(2) Ship investment based on real options analysis

With the development of the investment decision theory, a lot of literature analyzed the defects of traditional methods; at the same time, successful use of the real option theory in different investment...
fields, including shipping investment decision making, caught experts’ and scholars’ interests. Pires analyzed the investment decision-making scheme that took termination probability into consideration[6]. Acciaro discussed the optimal time for investment in LNG by using a real option model[7]. Gkochari set up the optimal investment-timing model for dry bulk ships by assuming demand follows geometric Brownian motion characteristic[8]. Ballauw used the real option theory and put forward a model to determine the optimal timing for entry and exit from the ship investment market under uncertain decision making[9]. Rau established the investment decision-making model of second-hand container ship considering endogenous price function, energy saving investment, endogenous delivery time, and price under the oligopoly market mode by applying the real option theory[10].

Although such literature has helped in making some progress in the ship investment optimization theory and model, there are still some inadequacies in the current theory and strategy mainly in the following two aspects: the first is that the hypothesis of freight rate is fixed. However, in the actual shipping market, since the shipping companies are in pursuit of scale economic benefit, freight will be adjusted according to the change of freight volume. The second aspect is that the ship investment strategy is often analyzed only from the perspective of the benefit-cost. This lacks the consideration of the environmental pollution caused by the ship especially the tanker oil spill accidents occurring in the process of operation. When such accidents occur, the companies need to spend a lot of time and money to deal with the environmental and ecological problems caused by the spillage of oil. Based on the analysis above, considering the cost of oil spill with the main optimization goal of maximizing the investment income expectations, and with the aid of the real option theory, this paper establishes an optimal investment decision model of an oil tanker dealing with the cost of maintenance of oil spill under the uncertainty of freight, in order to make up for the inadequacy of the existing tanker’s investment optimization theory and model.

2. Model building and solving

2.1 Relationship between traffic volume and freight rate model
Due to some influencing factors, such as the complexity of the international shipping investment environment, the volatility of the international shipping market, the huge amount of investment in the international shipping vessels, and the long recovery period, the international shipping investment is uncertain.

In order to better reflect the uncertainty of the shipping market, the real options theory is applied in this paper. Assuming that the enterprise of crude oil transportation risk is neutral, \( \theta(t) \) is the freight rate under the condition that the enterprises do not have pricing authority. The law of movement is defined by Geometric Brownian \( d\theta(t) = \alpha\theta(t)dt + \sigma\theta(t)dw(t) \), where \( \alpha \) is the instantaneous expected growth rate of \( \theta(t) \), \( \sigma > 0 \) is the instantaneous volatility rate of \( \theta(t) \), and \( dw(t) \) is the standard Wiener’s incremental process. The value of \( \sigma \) represents the degree of uncertainty of freight rate, where the bigger the \( \sigma \), the greater the uncertainty.

When the traffic volume increases, companies will adjust the freight rate to obtain scale economic benefit. Thus, Assuming that the change of freight rate is \( \Delta p = \gamma\Delta q \), then the volatility of freight rate under scale change of transportation is:

\[
P(t) = \theta(t) - \gamma q(t)
\]  

(1)

Where \( P(t) \) is tanker freight rate under the change of traffic volume, \( q(t) \) is the added traffic volume of the company, and \( \gamma \) is the sensitivity of freight rate to added traffic volume.

2.2 Investment decision-making model
The real option theory can solve the problems of big risk and big uncertainty, which are the remarkable characteristics of an investment. Therefore, this article, with the help of the real option theory, adds the maintenance cost as the investment variable in order to prevent the oil spill and
maximize the expected investment return as the main optimization target to establish the optimal investment timing and the optimal investment scale model.

Knowing that the unit cost for managing oil spill is $\delta$, if tanker companies invest in the project of carrying capacity size $Q$ and unit investment cost $2\delta$, then the total investment cost would be $2\delta Q$.

After investment, the unit cost for the maintenance of tanker oil spill for one year is $3\delta$ and the oil spill accident probability for an oil tanker in its life cycle is $\lambda$. Thus, considering the cost of the oil spill, the return after the investment scale would be,

$$\pi(t) = P(t)q(t) = (\theta(t) - \gamma Q - \frac{C}{k})kQ$$

(2)

Where $k$ is carrier frequency for one year, $Q$ is the traffic volume for investment, and $C$ is unit operating costs for each year. So, $kQ$, $\frac{C}{k}$ and $\theta(t) - \gamma Q$ are, respectively, the volume for years, the unit operating costs for each voyage, and the unit freight rate after the carrying capacity is increased.

Above all, in oil tanker investment decision planning, the project investment problems of tanker companies can be expressed as a stochastic optimal stopping time problem as follows:

$$\max_{\tau \geq 0} kE[e^{-rt}(\int_{\tau}^{\infty} e^{-\sigma \tau}[(\theta(t) - \gamma Q - \frac{C}{k}Q - \frac{\delta}{k}Q|d\tau - \frac{\lambda\delta}{k}Q - \frac{\delta}{k}Q)]$$

(3)

Where $E$ is the profit expectation or project value after investment, $r$ is the discount rate, $T$ is the stopping time, that is, the time for investment, and $Q$ is the scale of investment.

2.3 Model solved
The solution of the optimal investment strategy can be divided into three steps.

First, for a given $Q$, one should find the optimal investment threshold $\theta^*(Q)$ to maximize the value of enterprise investment. If $\theta \geq \theta^*$, and the businesses are located in the stopping region, then the optimal investment strategy would be to invest immediately. Else, one would be advised to keep waiting since the freight is low. Though there is no cash flow generated, capital gains or losses brought by options changes still emerge. According to the standard real options analysis method of Dixit and Pindyck[11], the option value of enterprise is,

$$F(\theta) = k(L, \theta^\alpha + L, \theta^\beta)$$

(4)

Where $\beta_1 > 0$ and $\beta_2 < 0$ are the roots of equation (5),

$$L = \frac{1}{\alpha \beta^{-1}} + \alpha \beta - r = 0$$

(5)

Obviously, when $\theta = 0$, $F(\theta) = 0$. This is because $\beta_2 < 0$, $L_2 = 0$.

Under the condition that enterprises have no certain autonomy of price, the freight rate fluctuation obeys the geometric Brownian motion. Thus, by solving the differential equation $d\theta(t) = \alpha \theta(t)dt + \sigma \theta(t)d\omega(t)$, the optimal investment strategy becomes:

$$\max_{\tau \geq 0} kE[e^{-\sigma \tau}(\frac{\theta}{r} - \frac{\gamma}{r}Q^2 - \frac{C}{kr}Q - \frac{\delta_1}{kr}Q - \frac{\lambda \delta_1}{k}Q - \frac{\delta_2}{k}Q)]$$

(6)

Thus, when $\theta < \theta^*$, the enterprise decides to wait; the options value would be

$$F(\theta, Q) = kL, \theta^\alpha$$

(7)

When $\theta > \theta^*$, the waiting time $T = 0$ and $e^{-\sigma T} = 1$. The enterprise invests immediately and its options value would be:

$$F(\theta, Q) = k(\frac{\theta}{r} - \frac{\gamma}{r}Q^2 - \frac{C}{kr}Q - \frac{\delta_1}{kr}Q - \frac{\lambda \delta_1}{k}Q - \frac{\delta_2}{k}Q)$$

(8)

From formulae (7) and (8), the optimal investment threshold $\theta^*$ satisfies the continuity and smooth conditions as follows.
\[
L_i \theta^\beta_i = \frac{\theta}{r - \alpha} Q - \frac{\gamma}{r} Q^2 - \frac{C}{k r} Q - \frac{\delta_2}{k} Q - \frac{\lambda \delta_1}{k} Q - \frac{\delta}{k} Q \\
\beta_i L_i \theta^{\beta_i - 1} = \frac{Q}{r - \alpha}
\]

(9)

After solving the nonlinear systems of (9), one has

\[
\theta^* (Q) = \frac{\beta_i (r - \alpha)}{k (\beta_i - 1)} \left( \frac{\gamma Q}{r} + \frac{C}{r k} + \frac{\delta_2}{r} + \lambda \delta_1 + \delta \right) \\
L_i = \frac{\theta^{\gamma - \beta_i}}{r - \alpha}
\]

(10)

Second, for reaching the largest option value of \( F(\theta_0) = L_i \theta^\beta_i \), an optimal production scale \( Q^* \) that meets the first-order differential condition should be solved through

\[
\frac{\partial F(\theta, Q)}{\partial Q} = \frac{\partial L_i \theta^\beta_i}{\beta_i} \cdot \frac{Q}{r - \alpha} \theta^\beta_i = 0
\]

(12)

Formulae (10) to (12) can be considered to get the optimal production scale:

\[
Q^* = \frac{r (\lambda \delta_1 + \delta_2) + C + \delta_1}{k (\beta_i - 2) \gamma}
\]

(13)

Third, the optimal investment threshold is found out by plugging formula (13) into formula (10)

\[
\theta^* = \frac{\beta_i (r - \alpha) (r \lambda \delta_1 + r \delta_2 + C + \delta_1)}{kr (\beta_i - 2)}
\]

(14)

By now, the optimal investment scale and timing of optimal investment strategy have been calculated. Based on the above results, problem (3) can be solved under two conditions as follows.

(1) Without considering the additional maintenance costs (\( \delta_1 = 0 \)):

\[
Q^*_1 = \frac{r (\lambda \delta_1 + \delta_2) + C}{k (\beta_i - 2) \gamma} \\
\theta^*_1 = \frac{\beta_i (r - \alpha) (r \lambda \delta_1 + r \delta_2 + C)}{kr (\beta_i - 2)}
\]

(15)

(2) Considering the additional maintenance costs:

\[
Q^*_2 = \frac{r (\lambda \delta_1 + \delta_2) + C + \delta_1}{k (\beta_i - 2) \gamma} \\
\theta^*_2 = \frac{\beta_i (r - \alpha) (r \lambda \delta_1 + r \delta_2 + C + \delta_1)}{kr (\beta_i - 2)}
\]

(16)

3. Model calculation

3.1 Data sources and processing

(1) Selecting tanker operation parameters

Based on the the Clarkson website, several operating parameters of VLCC running from West Africa to Dalian are selected as shown in Table 1.

| Working days (days) | 345 |
|---------------------|-----|
| Tonnage (thousand tons) | 26 |
| Shipbuilding cost ($) | 78000000 |
| Voyage number (time) | 4.93 |
| Total operating costs ($) | 11027800 |
| Total number of days for round trip | 70 |

(2) Selecting Baltic Exchange Dirty Tanker Index

The statistics of the Baltic Exchange Dirty Tanker Index (BDTI) as reported by the Baltic Stock
Exchange are viewed as an important index because the BDTI reflects the freight information of the target market as well as the performance of the shipping company. BDTI data spanning seven years (January 2010 to December 2016) for West Africa to China released by the Clarkson website[12] are shown in Figure 1.

![BDTI index of West Africa to China from 2010 to 2016.](image)

Figure 1. BDTI index of West Africa to China from 2010 to 2016.

(3) In order to facilitate comparison and analysis, three assumptions are listed.

1. Suppose that the tanker’s operating life is infinite, additional oil spill maintenance costs for a year are $10000, and in the operation time of a ship life, the oil spill probability is 0 if it has maintenance costs.

2. Hypothesis is put forward that the probability of an oil spill accident for each year is 0.00106 if it has no maintenance costs. This data is calculated by the International Tanker Owners Pollution Federation (ITOPF) from 2010 to 2016[13].

3. Assume that the oil pollution treatment cost is $31605 per ton, which is obtained by the rules of the Clean Water Act.

The parameters are standardized to obtain the corresponding price of per unit volume for one year, as shown in Table 2.

| $\delta_1$ | $\delta_2$ | $\delta_3$ | $C$ | $k$ | $r$ | $\lambda_1$ | $\lambda_2$ |
|----------|-----------|-----------|-----|-----|-----|------------|------------|
| 31605    | 300       | 0.0385    | 41.41 | 4.93 | 0.05 | 0.00106    | 0          |

3.2 Determining the variation coefficient of freight rate and volume

In order to quantify the relationship between freight rate and volume change, a parameter is introduced to represent the ratio between them. Since the operating conditions of different oil tanker companies have different relation between freight rate and traffic volume, suppose that the actual freight index is lower than the reference when the tanker enterprises increases 1 VLCC. Therefore, a ratio parameter can be calculated by:

$$\gamma = \frac{\Delta p}{\Delta Q} = \frac{1}{260000} = 3.85 \times 10^{-6}$$

(17)

3.3 Determining geometric Brownian motion equation coefficient

In this paper, the method of maximizing likelihood estimation is used to determine the coefficient of the geometric Brownian motion equation. As paper[14], the value of parameters $\alpha$ and $\sigma$ of the geometric Brownian motion is calculated.

| $\hat{\alpha}$ | $-0.0043$ |
| $\hat{\sigma}$  | $0.1433$   |

4. Results

(1) The optimal investment timing and scale by considering and not considering the maintenance cost of oil spill
By substituting the parameters of Tables 2, 3 into formulae 15, 16, the optimal investment timing and scale of oil tankers, are calculated and obtained as shown in Table 4.

### Table 4. Investment scale and timing of tankers.

| $\beta$  | $g^*$ | $g^*$ | $\theta^*$ | $\theta^*$ |
|---------|-------|-------|------------|------------|
| 3.0251  | 11.4821 | 11.1586 | 37.7271 | 36.6642 |

Where $g^*$ is the number of VLCC that should be invested and $g^* = \frac{Q}{260000}$.

From this table, several interesting phenomena have been revealed based on the results of the algorithms. The optimal investment scale when considering oil spill maintenance is reduced by 2.8% compared to non-consideration of oil spill maintenance. Taking into account the building cost of a VLCC, that is, about $78 million, the investment cost is reduced by nearly $2184000, which allows investment companies to have more investment options and more flexible capital flows. The optimal investment or the freight index is also reduced by 2.8% when considering oil spill maintenance, that is, the investment companies are able to achieve the best returns for a shorter waiting time.

First, through this comparison, it is obvious that due to the lower probability of an oil spill, even if the enterprise had paid a small part of maintenance costs, such as $10000 a year, it can also make a relatively larger investment income with a lower investment scale and a lower freight restriction. It shows that reducing the risk of oil spill is not only beneficial to the maintenance of marine environment but is also conducive to reduce the amount of ship investment and to cut the waiting time.

Second, from the BDTI of West Africa to China in Table 2, one can see that the minimum BDTI value is 34.59 in April 2013, while the highest is 103.51 in January 2010 and the average is 55.55. However, the optimal investment timings of freight index are 37.7271 and 36.6642, respectively, according to these two algorithms, which are almost the lowest levels from 2010 to 2016. This means that it is not difficult to reach the requirement of ship investment opportunity. Therefore, even when the shipping market at present is not very good because of the influence of the world economic crisis, shipping companies still need to grasp favorable opportunities to invest in large ships like VLCC.

2) The optimal investment timing and scale by considering the uncertainty and the risk of oil spill comprehensively

Based on the model, considering the uncertainty and the risk of oil spill comprehensively, we can see from Figures 2 and 3 that, on one hand, with the increase in uncertainty and oil spill risk, the scale and timing of investment get bigger. On the other hand, under the same uncertainty and oil spill risk level, an additional consideration of the cost of oil spill maintenance would be able to save investment scale and shorten the waiting time. Finally, the impact of input oil spill maintenance on investment scale is more pronounced than the investment timing.

![Figure 2. Investment scale.](image1)

To conclude, this algorithm has certain feasibility and practical meaning. First, uncertainty and oil
spill probability increases the amount of waiting value for the investment companies. Enterprises will delay the investment and ultimately invest a larger amount in order to meet the needs of the future market demand. Second, due to a lower oil spill probability, even if the companies pay a small annual maintenance cost, larger investment returns can be expected with a relatively low investment scale and low freight rates restriction.

5. Conclusion
This paper used the real option theory with the main optimization goal of maximizing the investment income expectations to study the topic of optimal investment timing and scale. The analysis considered the cost of oil spill and reduced oil spill risk, and compared the results by studying the effects of not considering the cost of oil spill and increased oil spill risk under the condition of market demand uncertainty. Through the empirical analysis, we found that the uncertainty of tanker freight rate and the increase in the oil spill probability raised the waiting value of the enterprise. When the uncertainty of freight rate and large oil spill probability was increased, in order to meet the needs of future market growth and reduce the investment risk, enterprises will delay the time of investment and ultimately invest a higher amount. In addition, our analysis shows that due to the reduction in oil spill probability, if the companies pay a maintenance cost, they can get larger investment returns at a relatively lower investment scale and lower rate limitation. In this paper, the combining of oil spill risk and ship investment will effectively reduce the loss of oil spill accidents, as well as promote the maintenance of the marine environment, which can provide some guidance for the decision maker to put forward a reasonable scheme for investment.

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