Research on European Container Ports Based on Lotka-Volterra Model

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Abstract. Europe is one of the important regions with the global container shipping business. Studying competition among port container business helps to improve the overall containerized transportation efficiency in Europe and assist liners to make correct decisions under the new global shipping pattern. Therefore, this paper uses non-autonomous Lotka-Volterra model to quantitatively study the type and degree of competition among major European container ports. The result shows that the ports in the Mediterranean region tend to be predatory and competitive. Besides, this paper also predicts the future trend of competition and cooperation of European container ports under the scenarios of “Sulphur Restriction Order” by modifying the utility function.

1. Introduction
In the past 20 years, container transportation has been favoured by cargo owners, so competition among container ports has become increasingly fierce[1][2]. Since cooperation between ports must comply with specific market, environment and other conditions, and Europe is one of the important regions for the global container shipping industry, the importance of determining the best cooperation conditions and time for European ports has become increasingly prominent, which is not only conducive to improving the efficiency of container transportation in Europe, but also helps container lines to make correct choices under the new global shipping landscape.

2. Methodology

2.1. Model introduction
It is supposed that there are N main container ports in a certain space (that is, ports with a large market share), namely port 1, port 2...port N, denoted by $X_i(t)$ ($i=1,...,N$), the market share of container throughput of port i in this specific area at time t. The port Lotka-Volterra Model can be described as[3]:

$$\frac{dX_i(t)}{dt} = X_i(t)[g_i(t) - \sum_{j=1}^{N} g_{ij}(t)X_j(t)] \quad i=1,...,N \quad (1)$$

Assuming there are N container ports in a certain space, equation (1) describes the dynamic co-opetition relationship between port i and port j. The role of port i in the co-opetition relationship is judged by the sign of the integral function $g_i(t)$ (as shown in Table 1).
Table 1. Relationship between \( g_i(t) \) and the type of interaction between ports

| \( g_i(t) \) | \( g_j(t) \) | Relationship |
|-----------|-----------|-------------|
| >0        | >0        | Competition |
| >0        | =0        | Amensalism  |
| >0        | <0        | Predator (port j) and prey (port i) |
| <0        | >0        | Predator (port i) and prey (port j) |
| <0        | =0        | Commensalism |
| <0        | <0        | Mutualism   |
| =0        | =0        | Neutralism  |

Suppose the original function of \( g_i(t) \) is \( f_i(t) \), which can be described as [4][5][6]:

\[
f_i(t) = \ln X_i(t) - \ln X_0(t) \quad i=1, \ldots, N
\]  

\( X_0(t) \) is the market share of rest ports. After substituting the historical data of the container throughput market share into equation, a set of discrete utility function values is obtained and fitted into a smooth Fourier series curve (as shown in equation (3)).

\[
f_i^F(x) = a_0 + \sum_{n=1}^{\infty} \left( a_n \cos \frac{n\pi x}{L} + b_n \sin \frac{n\pi x}{L} \right) \quad i=1, \ldots, N
\]  

In equation (3), \( a_0, a_n, \) and \( b_n \) are all constants, which are undetermined coefficients of the fitted curve.

2.2. Model test

In order to test whether the model can accurately reflect the real market situation, this paper calculates the MSE and MAPE of the fitted value of the container throughput market share of each port [3].

\[
MSE = \frac{1}{N} \sum_{i=1}^{N} (h_i - p_i)^2
\]  

\[
MAPE = \frac{1}{N} \sum_{i=1}^{N} \left| \frac{h_i - p_i}{h_i} \right| \times 100\%
\]

\( h_i \) represents the actual utility function value calculated based on historical container throughput data, and \( p_i \) represents the port utility function value obtained by fitting the curve. The MAPE evaluation criteria are shown in Table 2.

| MAPE | Predictive Ability |
|------|-------------------|
| <10% | Precise           |
| 10%—20% | Good          |
| 20%—50% | Reasonable    |
| >50% | Inaccurate        |

2.3. Data collection

This paper takes 9 container ports in Europe along Mediterranean Sea as the research object and conducts an empirical study on the Lotka-Volterra model. Valencia (i=1), Algeciras (i=2), Barcelona (i=3), Piraeus (i=4), Marsaxlok (i=5), Genoa (i=6), Gioia Tauro (i=7), La Spezia (i=8), Marseille (i= 9) and all other European container ports are taken as the research objects.

The data of container throughput of each port comes from Lloyd’s Daily, and the data of regional total container throughput comes from Eurostat. The container throughput market share of each port equals the container throughput of the port divided by total container throughput of the area where the
Port is located. According to the collected container throughput data, the container throughput market share \( X_i(t) \) of Mediterranean ports from 2011 to 2018 and the \( X_0(t) \) value of the region are calculated.

### 3. Model results

Port market share \( X_i(t) \) and area’s \( X_0(t) \) value are substituted into equation (2). Then, annual utility function value \( f_i(t) \) of each port is calculated. Matlab’s curve fitting toolbox is used to fit this set of discrete utility values with Fourier curve according to equation (3), so 9 Fourier series curves are obtained, representing 9 European container ports respectively. The discrete data and fitting results are shown in Figure 1.

![Figure 1. Curve fitting of utility function of container ports along Mediterranean Sea (2011-2025)](image-url)

MSE and MAPE values of each port are calculated by substituting the function value \( p_i \) and the actual utility value \( h_i \). The test results of the fitting error value are shown in Table 3, which proves that the port utility fitting in this paper is effective.

| Port            | MSE          | MAPE       | Predictive ability |
|-----------------|--------------|------------|--------------------|
| Valencia        | 0.04796100   | 19.14%     | Good               |
| Algeciras       | 0.03179089   | 15.00%     | Good               |
| Piraeus         | 0.01623076   | 12.04%     | Good               |
| Malthus Locke   | 0.04524129   | 33.79%     | Reasonable         |
| Barcelona       | 0.03837681   | 32.02%     | Reasonable         |
| Genoa           | 0.05040025   | 32.31%     | Reasonable         |
| Gioia Tauro     | 0.04571044   | 23.62%     | Reasonable         |
| La Spezia       | 0.07311616   | 44.83%     | Reasonable         |
| Marseille       | 0.04464769   | 17.82%     | Good               |

Derivative function \( g_i(t) \) is obtained after derivating the utility function \( f_i(t) \) of each port, and then the co-opetition coefficient of those ports in the North Sea-English Channel region and Mediterranean region are obtained, shown in Figure 2.
However, the total utility value of a container port will change with changes in the economic conditions of the region, social environment and other factors. Therefore, utility function has to be modified to predict the competition and cooperation relationship of container ports in the future.

$$f'_i(t) = f_i(t) + \tau_i(t)$$  \hspace{1cm} (6)

With the implementation of the “sulphur limit order”, shipping lines' fuel costs will rise sharply in the short term. In order to reduce fuel costs, most shipping lines will shorten the voyage as much as possible due to rising oil prices. Therefore, for cargo shipped by sea to the European region, the attractiveness of calling at the Mediterranean transhipment port will increase unprecedentedly. It can be seen that the implementation of the global “sulphur limit order” in 2020 will increase the probability of shipping lines choosing to call ports in the Mediterranean region, which means that the utility of Mediterranean ports will be greatly improved in the short term, and the increase is closely related to the port's transhipment rate. Let

$$\tau_i(t) = \varphi \arctan\left(\frac{t-T_0}{T-T_0}\right)$$  \hspace{1cm} (7)

$T_0=2019$, $T=2025$, $t \in [2019, 2025]$, and $\varphi$ represents the transhipment rate. Since the implementation of the global “sulphur limit order” has a close relationship with the effectiveness of Mediterranean ports and its cargo transhipment rate, only the utility functions of ports with a high transhipment rate (greater than 50%) in the Mediterranean region are revised, such as Gioia Tauro, Marsaxlokk, Algeciras, Piraeus and Valencia, $i=1,2,4,5,7$. The adjusted relationship of the obtained co-opetition coefficient is shown in Figure 3.
4. Conclusion
Based on the market share of major European container ports from 2011 to 2018, this paper calculates the co-opetition coefficient and finds that since 2014, the container ports in the Mediterranean region began to gradually develop a purely competitive relationship. In addition, this paper also uses scenario analysis to predict the future port competition and cooperation relationship. The implementation of the “sulphur limit order” will also make the ports in the Mediterranean region more competitive and predatory in the short term. But over time, the relationship between competition and predation will gradually weaken.

From the perspective of enterprises, investment by shipping lines in ports with different container handling facilities will facilitate the creation of mutually beneficial and symbiotic relationships between ports. From a government perspective, the transnational port cooperation project will make up for the shortcomings of insufficient investment in port infrastructure due to the inability of local governments to obtain all the relevant benefits of investment infrastructure, in order to cope with local port competition in the short term caused by a certain country or global policy changes.

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