Regional Cooperation in Marine Plastic Waste Cleanup in the South China Sea Region

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Abstract: This paper uses countries in the South China Sea Region (SCSR) as examples to study the level of regional cooperation in the marine plastic waste cleanup initiative. We designed a cooperation model to investigate the “cleanup system” from the Ocean Cleanup initiative to reduce marine plastic pollution. The non-cooperative game theory was applied to regional cooperation. The simulation results indicate that the plastic waste cleanup cooperation in the SCSR is related to the plastic trade network structure, the influence parameters of the Experience-Weighted Attraction learning model, and the economic effects. The results suggest that regional cooperation in the cleanup system in the SCSR is feasible, and it could create a significantly larger investment in the cleanup project than the current project attracts. Therefore, countries in the SCSR should adjust their laws and policies to make a good cooperative environment and to maximize the contribution to the marine plastic waste cleanup.

Keywords: marine plastic; waste cleanup; regional cooperation; non-cooperative game; EWA learning model; Matlab simulation

1. Introduction

Marine plastic pollution has become an urgent worldwide problem. Marine plastic pollution, particularly the micro-plastic debris, can persist in the ocean for many decades [1], causing irreversible damage to marine ecosystems and impacting the health of human beings through the international food supply chain [2]. Its irreversibility and worldwide influence have raised significant concerns that it may become one of the major planetary boundary threats such as climate change [3,4]. More importantly, without proper waste management, the marine plastic waste generated from the land is predicted to increase by an order of magnitude by 2025 compared to the 12.7 million metric tons of plastic waste in 2010 [5]. Despite the global focus on this issue, such as the International Convention for the Prevention of Pollution from Ships (MARPOL) and the third session of the United Nations Environment Assembly [2,6], little effort has been made to mitigate this form of pollution from an international collaboration perspective [7].

The current two main themes of solving the marine plastic debris problem are reducing the source and increasing the cleanup. Many scholars argue that cutting the sources of marine garbage is the most efficient way to achieve a solution [8–10]. Willis et al. [10] posited that the problem with the current cleanup programs is their primary focus on areas where waste accumulates as sink. They suggest that collecting should be performed at the source, where the waste can be collected before it enters the coastal environment. If not, then the dirty beaches will need to be continuously cleaned.
Some researchers, however, also postulate that it is not only about the source; waste cleanups should be carried out throughout the system, from source to ocean, to reduce the already significant ecological impacts in the marine system [9]. There are many reasons why marine plastic needs to be cleaned up as soon as possible. First, the plastic debris can degrade into micro-plastic and nano-plastic [1], which is then ingested by marine organisms such as fish [11,12]. The micro-plastic also has a significant impact on the marine carbon cycle [13]. Moreover, once the micro-plastic particles are formed, it is nearly impossible to remove them from seawater [11]. The marine debris washed ashore could also lead to significant losses in tourism [14,15]. Finally, since most of the plastics are non-biodegradable [1], they will persist in the ocean for long periods, and the problems they cause will continue to harm the marine environment until they are collected.

Considering that the current existence of marine plastic is an enduring hazard, waste cleanup is an urgent task that must be addressed. In 2019, the United Nations Environment Assembly called upon member states and other actors at local, national, regional and international levels, and in the private sector, civil society, academia, and other stakeholders to address the problem of marine litter and microplastics prioritizing a whole life cycle approach and resource efficiency, building on appropriate existing initiatives and instruments, and supported by and grounded in science, international cooperation, and multi-stakeholder engagement.

This paper focuses on how marine plastic waste is removed from the oceans. From the literature, the current cleanup project is neither efficient enough nor large enough in scale to change the current marine plastic situation. Moreover, there is an important undeveloped region for the marine cleanup, the South China Sea Region (SCSR) which is responsible for more than 50% of the global plastic waste that finds its way from land into the ocean [5]. The SCSR plays a major role in ocean plastic pollution as a waste contributor, and it has a solid foundation on which to establish further cooperation, but the cleanup project network there is yet to be developed.

Therefore, this paper combines the complex network theory with game theory to design a cooperation model in the SCSR. The aim is to apply the new cleanup technology in the South China Sea on a large scale. From this model and its simulation results, the following questions can be answered: (i) What factors influence regional cooperation in marine plastic cleanups? (ii) How do these factors influence such regional cooperation? (iii) How can policy be formulated to promote this regional cooperation?

The remainder of this paper is organized as follows. The following part discusses the building of a marine plastic waste cooperative network in the SCSR, introduces the main assumptions of the EWA learning model, and presents an analysis of how the model works. Next, the simulation of 15 rounds of repeated games is performed and analyzed. The final part provides the conclusion and discussion.

2. Literature Review

This literature review focuses on the research on cleanup projects and tries to find out why current cleanup projects have failed to make a significant change to the increasing marine plastic pollution problem [16].

Despite its importance, the current global marine cleanup project is still in the early stages and there are many issues with it. First, current cleanup methods are not efficient enough to mitigate marine plastic pollution. The litter collected from manual removal accounts for most of the overall collected waste, and since the amount of waste in the ocean continues to grow, there is an urgent need to find a more efficient way to cleanup [16]. Another problem with the cleanup method is that the current cleanup projects are not uniform, and their costs vary with different types of litter, the cleanup methods, and the locations of the waste cleanup [14]. Therefore, it is hard to estimate the scale of cleanup required for the significant mitigation of marine plastic pollution.

There is a uniform and effective cleanup system provided by a non-profit organization called the Ocean Cleanup [17]. This system has a passive design, which means that it relies
on natural forces such as the wind, the waves, and the current without using non-renewable energy. Therefore, it is more sustainable than normal cleanup projects. It has been proved that, on a small scale, this cleanup project is economically feasible [18], and the Ocean Cleanup claims that it will remove 90% of the ocean plastic by 2040, on the conditions of effective source reduction and that every ocean is covered with fleets of their cleanup systems [17].

There are, however, some doubts about the effectiveness of the Ocean Cleanup’s current cleanup project in the Great Pacific Garbage Patch. The first issue is the relatively small scale of the Ocean Cleanup’s project—that is, the volume of the collected waste is too little compared to the existing plastic waste in the ocean. Cordier and Uehara [19] used a dynamic model to simulate how much investment is needed to achieve a 25% reduction in the 2010 level of plastic debris in the ocean by 2030. They found that 1924 cleanup projects similar to the current Ocean Cleanup project are required. The current investment in cleanup projects is far from enough to change marine plastic pollution, so there is a need to study how this cleanup project can be applied at a much larger scale.

The second problem is the location of the Ocean Cleanup’s project. Sherman and Sebille [9] developed a model to prove that, compared to the North Pacific garbage patch, where the cleanup project is operating, the area close to the shore is more suitable to be targeted by these plastic collectors. Based on their simulation results, the coast of China and the Indonesian Archipelago are the two best places for effective removal. Another study also revealed that around 80% of the marine plastic debris is dumped from the land; of this, 50% comes from five countries in the South China Sea Region (SCSR)—China, Indonesia, the Philippines, Vietnam, and Thailand [5]. Therefore, compared to the Great Pacific area, a more suitable location for the cleanup could be within the SCSR. However, how to utilize the cleanup system in this area is yet to be established, so there is a need to research how countries in this region can cooperate in the marine cleanup.

The third problem of Ocean Cleanup is their plastic recycling business model. According to their website, with a donation of USD 50, the consumer can purchase a recycled plastic product made from the collected ocean waste, and the revenue will be reinvested into the cleanup system [17]. However, this is a high cost for a plastic product which is not a business approach, so there is a need for an improvement in their recycling process—which is another reason for regional cooperation—from which plastic waste can be collected and recycled efficiently along a mature recycling supply chain.

To date, many agreements have been reached on maritime cooperation in the SCSR. For example, China held bilateral agreements with Malaysia, The Philippines, Indonesia, and Thailand, in which they agreed to cooperate on fisheries, marine environmental protection, and ocean sciences [20]. Therefore, there is a good environment of cooperation and bonding among the countries in the SCSR. Most of the above cooperation was agreed on during diplomatic visits, science seminars, or bilateral consultations. For example, in 1997, China and the Philippines agreed to organize a bilateral consultation on fishery cooperation, marine environmental protection, and mutual confidence-building measures in the South China Sea [20]. From this, it can be seen that countries’ cooperation relationships vary in relation to factors such as trading connections, culture communication, and technology, among others, and countries that have not participated in those activities or connections may lack a solid foundation for cooperation.

Since the connections between the countries are different, a relationship network must exist to determine which two countries can collaborate most effectively on marine plastic waste, so the connection network needs to be concluded in the SCSR regional cooperation on marine plastic debris. Previous network studies include the research by Wang et al on the plastic waste trade network [21]. One of their conclusions is that policies such as the plastic waste input ban by China had a significant impact on the characteristics of the network; therefore, the relationship network may also experience a sudden change with such a policy.
In conclusion, there are flaws in the current cleanup projects, and an ideal place for large-scale cleanup could be the SCSR. The countries in the SCSR play an essential role in marine plastic debris cleanup and they have a solid basis in marine cooperation. Their cooperative relationship varies in their connections, which may be dynamic in that they change with policies such as the import ban.

3. Materials and Methods

3.1. Cooperation Network

3.1.1. The Reason for Using Plastic Waste Trading Data

First, the cleanup activity needs the recycling of marine plastic waste as its financial support. With the plastic waste trading relationship, the countries in cooperation can easily trade what they collect and then recycle effectively. According to Article 7 of the “Circular Economy Law” of China, the state encourages international cooperation in the development of the circular economy. Second, according to scholars’ analysis of the plastic waste trade for the global coordination of plastic pollution, the volume of the plastic waste trade has an essential impact on the cooperation in marine plastic waste cleanups [22]. Therefore, the plastic waste trade data is a good sign of whether countries have cooperation opportunities in relation to marine plastic waste cleanup and recycling. This paper used the changes in the plastic waste trade connections to simulate the changes in the marine plastic cleanup cooperation partnership.

3.1.2. The Data and Relation Matrix of the SCSR

This paper used the data in the SCSR to simulate the non-cooperative game in relation to the marine plastic cleanup. The SCSR includes states and regions with borders at sea: China, the Philippines, Malaysia, Brunei, Indonesia, Thailand, Singapore, and Vietnam—eight countries in total [23]. In this article, whether there was a plastic waste trade relationship between any two countries was determined by establishing whether the plastic waste trade volume between the two countries was high enough to effectively implement recycling processes after the waste cleanup.

The data on the plastic waste trade in various countries can be obtained from the United Nations Commodity Trade Database (http://comtrade.un.org/, accessed on 16 August 2021). We took every two countries’ bilateral trade value in plastic waste. Similar to the method from Wang et al. [21], this paper included the re-export and re-import (Re-imports are goods imported in the same country as previously exported and are already included in the country imports, whereas re-exports are exports of foreign goods to the same country from which the goods were previously imported, and they are to be included in the country exports [21]) in the export and import data. In terms of the phenomenon of bilateral asymmetries—that is, the difference between the reported exports from country “i” to country “-i” and the reported imports from country “-i” to country “i”—this study chose the higher value as the true value. This was based on the assumption that exporters and importers are more likely to report less than the actual trade volume [21].

Our method of simulating the marine plastic cleanup cooperation partnership is as below. If there was a significant trade volume between two countries, it was assumed that there was a cooperative relationship between the two countries; otherwise, there would be no cooperation between them.

3.2. Game Assumption

3.2.1. Background

The Ocean Cleanup already has a matured passive system to collect the trash in the sea. The Ocean Cleanup has used this system to catch plastic in the Great Pacific Garbage Patch and even transformed the collected plastic into useful recycled products [17]. However, the current partners in the Ocean Cleanup are mainly commercial companies such as Deloitte and Microsoft, while only the Dutch government has a partnership with the Ocean Cleanup, allowing it to run its prototype test off the Dutch coast [17]. If coastal countries
join as partners or invest in this cleanup system in their sea area, the process of garbage cleanup can be developed on a significantly larger scale. Therefore, the cooperation that this study proposes in this paper uses the cleanup system provided by the Ocean Cleanup as an example and as the unit of investment in the marine cleanup cooperation.

3.2.2. Hypotheses for the Cooperation Revenue Matrix

**Hypothesis 1 (H1).** The cooperation in the SCSR is designed to be a bilateral cooperation between any two countries that have a partnership in marine plastic waste. In any bilateral cooperation, two partners will need to co-invest in a certain amount of the cleanup system in a common sea area of the SCSR at every period.

The first reason for selecting bilateral cooperation but not multilateral cooperation was that previous international cooperation or agreement on marine plastic waste management has tended to fail [22]. Dauvergne [22] found that the global governance of marine plastic pollution is failing because of factors such as weak international institutions, uneven regulations, and uncoordinated policies. Therefore, this paper assumed that it is more feasible to start cooperation in two countries, as it is easier to coordinate between two partnered countries.

Second, in a multilateral cooperation, it is hard to decide where the co-invested cleanup system should be located, since every country would like to have the cleanup system in the sea area which is connected to their interests. For example, every country would like to implement the cleanup project near their fishery area to have better fishery resources. Conversely, in bilateral cooperation, it is easier for two countries to discuss where the fairest region is, for instance, in their adjacent sea area.

Last, in the SCSR, there is a history of bilateral cooperation in relation to fisheries and environment protection. For example, China had bilateral agreements with Malaysia, the Philippines, Indonesia, and Thailand [20]. Therefore, bilateral cooperation in the marine cleanup in the SCSR should be feasible and a foundation for future multilateral cooperation.

**Hypothesis 2 (H2).** Each node country has two strategic choices of cooperation and non-cooperation; that is, whether to participate in marine plastic waste cooperation. \( m_i = \{0,1\} \) represents the strategy set of node \( i \), \( i \in S \) is the strategy of node \( i \), \( j = 1 \) represents the cooperative strategy, and \( j = 0 \) represents the non-cooperative strategy. \( S_{ij} \) is the strategy of node \( i \)’s cooperation partner \( -i \), \( -i \in N_i \), where \( N_i \) is the marine plastic waste cooperation network neighbors of the country \( "i" \). The definition of neighbor in this paper is not the geographical neighbor but the neighbor in the cooperation matrix shown in Table 1; these countries are neighbors when their cooperation relationship is 1 in the matrix.

**Hypothesis 3 (H3).** Since the cleanup system relies on natural forces, which means that both plastic and the cleanup system will be freely moving around this common area, the two countries should share the benefit of cleaning this sea area. Assume the target amount of systems invested for each country is \( w \)—that is, they invest in \( 2w \) of cleanup systems in total into their common plastic sea area—and the cost per system is \( c \). Assume the maintenance and recycling fee for the cleanup system is low enough that the value from recycling the collected litter could cover this, and there is no cost afterward. The cleanup system’s cost should be low since the system depends mainly on nature’s forces [17] and, according to Magnier et al. [24], the consumer shows a great willingness to pay a price premium for recycled ocean plastic. Therefore, recycling ocean plastic could also be profitable.

**Hypothesis 4 (H4).** Assume that there is a public fund \( F \), funded by an external organization, which is responsible for implementing the punishment and reward policy. This fund is necessary because there may be some unbearable economic costs of marine plastic waste management for some countries [2]; thus, the international fund can provide initial capital inputs for some countries, and so promote cross-border coordination. Borrelle et al. [2] examined how such funding could be
achieved; they suggested building a global fund for cross-border waste management, similar to the climate fund of the United Nations Framework Convention on Climate Change (UNFCCC).

The cost of the system will be compensated by this fund $F$, with a reward of $r$ per system. If two neighboring countries invest in 2w systems and locate them in their adjacent sea area, they obtain the reward of $2rw$, so their average profit from investing is then $2w(r-c)$. If one country betrays and chooses not to invest in the system during this period, the other country still needs to invest in w. In this case, it is assumed that F would reward them $w$ in total since the added systems work in their common area. Therefore, there is a “free rider” problem, where the betrayer is still rewarded $wr/2$.

This assumption of the “free rider” problem is because of the shared nature of plastic pollution. Plastic pollution is similar to a common marine resource such as a fishery; it is an issue shared by all countries in a certain region. No matter how many countries are participating in the cleanup activity, the resulting marine environment is still shared by all countries in the SCGR. For example, if the ocean is cleaned by half of the countries in the SCGR, the other half still benefits from the clean ocean. Therefore, this regional cooperation in the marine cleanup is designed so that all countries in one cooperation should share their expected benefits.

On the other hand, to discourage the betrayal, all participants should agree to pay a fine “$f$” to the public fund if they choose to give up cooperation.

**Hypothesis 5 (H5).** To encourage the cooperative strategy, the countries agree to give tariff rewards to their partner if their partner chooses the cooperation strategy (investing in the cleanup system in their common area). That is, in the cooperation of country “$i$” and country “$-i$”, as long as country “$i$” chooses the cooperation strategy, it will obtain the tariff reduction for its plastic waste export with the country “$-i$”, and the reduction amount is $Q_{i,-i}T$. The tariff is designed to the country “$-i$”’s import tariff; that is, the tariff that country “$i$” needs to pay when exporting plastic waste to country “$-i$”. Therefore, $Q_{i,-i}$ refers to the volume of plastic waste exported from country “$i$” to country “$-i$”.

Based on the above assumptions, the cooperation game between the two countries follows the single-income payment matrix in the table below.

<table>
<thead>
<tr>
<th>$i$’s strategy</th>
<th>“$-i$’s Strategy</th>
<th>Cooperate</th>
<th>Betray</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperate</td>
<td>$rw-cw + Q_{i,-i}T$, $rw-cw + Q_{i,i}T$</td>
<td>$rw/2-cw + Q_{i,i}T$, $rw/2-f$</td>
<td></td>
</tr>
<tr>
<td>Betray</td>
<td>$rw/2-f$, $rw/2-cw + Q_{i,i}T$</td>
<td>0, 0</td>
<td></td>
</tr>
</tbody>
</table>

**3.3. The Learning Model**

The members of the Ocean Plastic Waste Cooperative Network are countries. Their strategic choices in each round of the game are related to their experience and psychological expectations. Therefore, the strategy choices of each round change with the update of the past strategy history. For example, if, in the last round of the game, neighboring countries choose to betray and do not participate in the treatment of marine plastic waste, this results in damage to the country’s last round of interests or failure to meet targets. Then the country’s strategy in this round will change, and the probability of choosing to continue cooperation will be reduced. This is a learning reinforcement process, so the construction of the cooperative game model requires the introduction of a learning game model. This paper used the experience weighted attraction (EWA) learning model, which is a generalization of reinforcement and belief learning [25]. This model predicts well in a small strategy space [26], which is suitable for this cleanup cooperation since the two by two ($2 \times 2$) game was applied in this article. It has also been proved that the EWA model
is better at predicting the rate of switching than its choice reinforcement and belief-based special cases, and also forecasts better than reinforcement models.

The EWA model was created by Camerer and Ho [27]. In the EWA model, the probability that node “i” chooses strategy j in the t + 1 round of games depends on the attractiveness of node “i” in the t-round game \( A_i(t) \), while the attractiveness of this round of games depends on the historical game revenue \( \pi [S^t_i, S_j(t)] \). Here, this study assumed that the result of the opponent’s historical strategy selection is known to the country; that is, in the marine plastic waste cooperation game, whether the partner country “-i” involved in the t-round cooperation will be discovered by the country “i” in the t + 1 round of cooperation.

According to the model created by Camerer and Ho [27], the attractive equation of the EWA model and the experience weight equations are:

\[
A_i(t) = \varphi M(t-1) \times A_i(t-1) + \left[ \delta + (1 - \delta) \times I(s_i^{t}, s_j(t)) \right] \times \Pi_i(s_i^{t}, s_{-i}(t)) / M(t)
\]

(1)

\[
M(t) = \varphi(1-k)M(t-1) + 1
\]

(2)

\( M(t) \) is the weight of past experience in the attractive equation, it has an initial value \( N(0) \), and is updated according to the rule in Equation (2). The definition of the indicator function \( I(s_i^{t}, s_j(t)) \) is that, for \( s_i^{t} = s_j(t) \), its value is 1; otherwise, it is 0.

\( \varphi, \delta, \) and \( k \) are the parameters used to control the learning speed. \( \varphi \) represents the attenuation of attractiveness with the change of environment and time, \( \delta \) represents the learning ability, and \( k \) represents the growth of attractiveness of different models to the strategy of game learning process influences.

The probability of strategy choice determined by attractiveness is defined as an exponential model [27]:

\[
P_i^j(t + 1) = e^{\lambda A_i^j(t)} / \sum_{k=0}^{1} e^{\lambda A_i^k(t)}
\]

(3)

In the formula, \( \lambda \) represents the sensitivity of participants to the value of the strategy, which is affected by factors such as the motivation and psychological perception of participants.

3.4. Method of Model Analysis

According to the above assumption, the total return of node country “i” in t-th games depends on both country i’s strategy and country -i’s strategy. Assuming that the strategy choice probabilities of the two countries are independent of each other, in the t-th game of “i” country, the total game gains obtained by choosing two different strategies are as follows:

\[
U_i^t = \begin{cases} 
\sum_{i \in N_i, j \in [0,1]} \pi_{ij} (s_i^j, s_{-i}) \times P_{ij}(t) & s_i^j = 1 \\
\sum_{i \in N_i, j \in [0,1]} \pi_{ij} (s_i^0, s_{-i}) \times P_{ij}(t) & s_i^j = 0 
\end{cases}
\]

(4)

Among them, \( P “-i” j (t) \) is the probability of the “-i” node when making strategy selection in the t-period, which is estimated by the probability calculated by the EWA model. In more detail, the expected total return of the country “i” in the round t game can be expressed as the following:

\[
U_i^t = \begin{cases} 
N_i^c (r \times w - c \times w + Q_{i,-i}T)P_{ij}(t) + (N_i - N_i^c)(r \times w - c \times w + Q_{i,-i}T) \times [1 - P_{ij}(t)] & s_i^j = 1 \\
N_i^c (r \times w / 2 - f)P_{ij}(t) & s_i^j = 0 
\end{cases}
\]

(5)

where \( N_i \) represents the total number of partner countries of “i” in the SCSR; that is, the number of countries with possible cooperative relations with “i”. \( N_i^c \) represents the number of countries “-i” that choose the cooperation strategy.
If node “i” chooses a cooperation strategy in the t-th game, under the assumption of rational expectations, it should satisfy the outcome that the expected total return of cooperation is greater than the expected total return of the non-cooperation strategy, as shown below:

\[
N_{it} (r * w - c * w + Q_{i-i}T)P_{1-i}(t)
+ (N - N_{it}) (r * w/2 - c * w + Q_{i-i}T) [1 - P_{1-i}(t)] 
\geq N_{it} (r * w/2 - f)P_{1-i}(t)
\]

which is:

\[
\pi_i = N_{it} (r * w - c * w + Q_{i-i}T)P_{1-i}(t)
+ (N - N_{it}) (r * w/2 - c * w + Q_{i-i}T) [1 - P_{1-i}(t)]
\]

If \(\pi_i > 0\)—i.e., country “i” chooses a cooperation strategy \(-C_{it} = 1\), otherwise \(C_{it} = 0\), then the Annual Amount of System (AAS) invested in the SCSR would increase by \(w*N_{it}\), since country “i” invests \(w\) units of system in each cooperation with its partners.

\[
AAS_t = \sum_{i=1}^{N} w * N_{it} * C_{it}
\]

\[
TAS = \sum_{i=1}^{P} AAS_t
\]

TAS is the total amount of cleanup systems that countries in the SCSR would contribute to the ocean in all cooperation periods. Assume that the number of periods is \(P\). In this article, TAS represents the contribution of the cooperation project. Therefore, in the following part, the game simulation was carried out to find how TAS could be maximized. The purpose of using TAS was because it captures the value of the degree centrality of any node “i”. For example, China may have had many cooperators in the plastic trade before the plastic import ban, so its degree of centrality is high in the cooperation. Therefore, China plays a vital role in those networks. If China chooses not to cooperate, the number of systems invested would be reduced significantly.

### 3.5. Model Simulation

We followed the steps in Figure 1 to carry out the simulation. According to the empirical estimation of the parameters of the EWA model in the general model, this study obtained: the weight given by the participating players to the return of the unselected strategy \(\delta = 0.5\); the coefficient of the decline ratio of the previous attractiveness \(\varphi \in (0.8, 1)\), \(\lambda = 0.1\), and the growth rate of the attractiveness of the strategy \(k \in (0, \varphi)\) [25,26]. The following used the Matlab simulation to study how those factors in the cooperation (Reward, Cost, Goal, Fine, Tariff reduction rate, the attenuation of attractiveness, and the growth of attractiveness in the EWA model, and also the partnership network) impacted the cooperation results. This simulation set the number of the rounds of games to 15; that is, \(t = 15\). The purpose of this project was to cover the whole SCSR with the cleanup system from Ocean Cleanup in 15 years. Therefore, the goal of this cooperation is to achieve the maximum number of systems invested in SCSR.
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Figure 1. Simulation flow chart.

4. Game Simulation Result

4.1. Regular Variables Other than the Partnership Network

First, to study the influence of a single variable and to avoid the impact of changes in the network structure, it was assumed that the network relationship would not change every year. Then this study used the plastic waste trade relationship of the latest year (2019) as the data to determine the marine plastic waste cooperation partnership and assumed it would not change in 15 years to find out how one single variable would influence the cooperation result when other factors were stable. The threshold for determining the cooperation relationship was set to USD 1,000,000; that is, if the plastic waste trade data of the two countries exceeded this value, the two countries were considered to have a marine plastic waste cooperative partnership. It was assumed to be the same between countries since the same cleanup system is used in this cooperation. The one million dollars threshold was set by observing the overall magnitude of the data as is mentioned in the end of Section 3.1.2. This threshold was not specifically calculated for below reasons. First, it was only used to mimic one kind of cooperation relationship network, this network in reality is impossible to simulate since it depends on how countries negotiate with each other. Second, it would be interesting to see how the result changed with this threshold; however, that was not the focus of this study. Instead, this paper focused on how the result changed with the cooperation factor and network stabilization. Additionally, the cooperation relationship network was allowed to be dynamic in Section 4.2 from which it could also be seen how the level of cooperation would change with different networks. Then, this study constructed the cooperation relationship network (Figure 2).

The following are the results of how the adjustment of the game parameters can change the TAS, which reveals the impact of these parameters on the 15-year total investment in the cleanup system. Notice that, in this simulation, the unit of reward, cost and fine is USD 5.91 million. This is to simplify the value of the variables and to make the change of variables obvious. The value of USD 5.91 million was calculated from the cost of sponsoring an ocean cleanup system. According to the Ocean Cleanup website, the system is not available...
for purchase, but the cost of sponsoring one’s cleanup system is EUR five million (USD 5.91 million) [28].

4.1.1. The Relationship between the Reward and the TAS

As can be seen from Figure 3, when the other variables were set as \( c = 1; w = 2; f = 1.0; T = 0.04; \varphi = 0.85; \delta = 0.5; k = 0.5; \lambda = 0.1 \), for \( r \in (1.05, 2) \) the larger the reward, and the greater the total number of cleanup systems invested by countries in the SCSR. Limited by the total number of connections in the region and the marginal benefit of the system, after the number of cleanup systems reaches 832, even if the return on the income of the countries in the SCSR continues to increase, the countries in the region cannot increase investment.

4.1.2. The Relationship between the Cost and TAS

It can be seen from Figure 4 that when the other variables took the values: \( r = 1.44; w = 2; f = 1.0; T = 0.05; \varphi = 0.85; \delta = 0.5; k = 0.5; \lambda = 0.1 \), for \( c \in (0.9, 1.2) \) there was a negative relationship between the cost and the TAS. The higher the cost of input, the smaller the number of cleanup systems invested by countries in the South China Sea. When the cost reaches 1.2, the countries in the South China Sea will no longer invest in any cleanup systems. It can be seen that the use of technological innovation to invent a low-cost cleanup system is one of the key ways to solve marine plastic waste.

4.1.3. The Relationship between the Fine and TAS

It can be seen from Figure 5 that when the other variables were set as \( c = 1; r = 1.44; w = 2; T = 0.05; \varphi = 0.85; \delta = 0.5; k = 0.5; \lambda = 0.1 \), for \( f \in (0.3, 1.3) \) the greater the punishment the countries in the region will suffer, and the more inclined the country will be to adopt cooperative strategies; after the punishment reaches a certain value—1.3, the number of cooperative investments will reach the maximum, then increasing penalties will not
increase the number of systems invested in the cleanup cooperation. It can be seen that appropriate punishment is necessary for the governance of marine plastic waste.

![Figure 4](image1.png)  
**Figure 4.** The relationship between the Cost and TAS.

4.1.4. The Relationship between the Tariff Reduction Rate and TAS

It can be seen from Figure 6 that when the other variables were set as $c = 1; r = 1.44; f = 1.0; w = 2; \varphi = 0.85; \delta = 0.5; k = 0.5; \lambda = 0.1$, for $T \in [0, 0.03]$ the higher the tariff reduction rate for plastics trade, and the greater the number of cleanup systems invested by countries in the region. When the reduction or exemption reaches a certain threshold, the amount of cleanup system input will no longer change significantly with the change in the tariff reduction rate. This shows that tariff reductions and exemptions have a certain positive effect on the treatment of plastic waste in the South China Sea, but this effect has limitations and is only effective within a certain range.

![Figure 5](image2.png)  
**Figure 5.** The relationship between the Fine and TAS.

4.1.5. The Relationship between the Annual Goal of System Invested and the TAS

It can be seen from Figure 7 that when the other variables were set as $c = 1; r = 1.44; f = 1.0; T = 0.05; \varphi = 0.85; \delta = 0.5; k = 0.5; \lambda = 0.1$, for $w \in [0.124, 1.598]$, the higher the number of systems required for each country to invest in each cooperation, and fewer cleanup systems will be invested in the South China Sea in 15 years. However, for $w \in [1.598, 3.34]$, the TAS would decrease if $w$ increases. It can be seen that the goal of systems invested per game should not be too high, otherwise, countries may think it is too risky and would no longer be willing to invest.

![Figure 6](image3.png)  
**Figure 6.** The relationship between the Tariff Reduction Rate and TAS.
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by the previous strategy, and the greater the investment in cooperation among countries in
the region was negative. The faster the attractiveness declines, the fewer the num-
ber of cleanup systems invested by countries in the South China Sea.

Figure 7. The relationship between the Annual Goal of System Invested and the TAS.

4.1.6. The Relationship between the Attenuation of Attractiveness and TAS

In Figure 8, when the other variables were set as: c = 1; r = 1.44; f = 1.0; w = 2; T = 0.02;
δ = 0.5; k = 0.5; λ = 0.1, for φ ∈ [0.8, 1] [23,25], the relationship between the attractiveness
decline index of the previous period and the number of cleanup systems invested by
countries in the region was negative. The faster the attractiveness declines, the fewer the
number of cleanup systems invested by countries in the South China Sea.

Figure 8. The relationship between the Attenuation of Attractiveness and TAS.

4.1.7. The Relationship between the Growth of Attractiveness and TAS

In Figure 9, when the other variables were set as: c = 1; r = 1.44; f = 1.0; w = 2; T = 0.02;
δ = 0.5; φ = 0.85; λ = 0.1, keep k ∈ [0, φ] [23,25], the greater the growth index attracted by
the previous strategy, and the greater the investment in cooperation among countries in
the SCSR.

Figure 9. The relationship between the Growth of Attractiveness and TAS.

4.2. The Partnership Network

4.2.1. The Number of Systems Invested in per Year in 15 Years When the Network
Structure Is Stable

Assuming that the structure of the partnership network does not change within
15 years of the simulation, the latest year (2019) of the plastic waste trade network was
used as the partnership network, and the game variable parameters were set according
to the simulation results in the previous section (i.e., when other variables are set as c = 1;
r = 1.44; f = 1.0; w = 2; T = 0.02; δ = 0.5; f = 0.85; λ = 0.1, k = 0.5) so that each country is
willing to participate in the cooperation. The relationship between the input system and
time is as shown in Figure 10. It can be seen that if the network structure does not change significantly, a slight fluctuation may come from unstable psychological variables. Once the cooperation environment is stable, the number of marine plastic garbage cleanup systems invested in by the partners each year will also stabilize around a value.

![Figure 10](image1.png)

**Figure 10.** The number of systems invested in per year in 15 years when the network structure is stable.

4.2.2. The Annual Number of Systems Invested in 15 Years When the Plastic Waste Trade Network Is Dynamic

Setting the same game parameters as in Section 4.2.1, using the data of the plastic waste trade in the past 15 years to simulate the 15 years of changes in national cooperation relations, the changes in the number of cleanup systems invested each year in 15 years are as in Figure 11. It can be seen that the bilateral plastic trade volume of countries in the South China Sea is changing every year, and the structure of the relationship network constructed by trade relations is also altering. The changes in the network structure have also changed the game structure of the marine plastic waste cleanup, which in turn altered the cooperative relationship. In Figure 11, the total number of cleanup systems invested in by countries in the region fluctuates as the structure of the plastic trade network changes. In 2018, China implemented a ban on the import of plastic waste and since then the structure of trade relations among countries in the SCSR has changed dramatically. The bilateral trade of some countries has approached zero, the density of the trade network has declined, and the structure has become sparse. This sudden policy shock led to a sharp drop in the number of cleanup systems invested in by countries in the region during the simulation process. It can be seen that the structure of the plastic trade network is one of the important factors affecting cooperation in the marine plastic waste cleanup.

![Figure 11](image2.png)

**Figure 11.** The annual number of systems invested in 15 years when the plastic waste trade network is dynamic.

5. Conclusions and Discussion

5.1. Discussion

The SCSR is an area of conflict and there are ongoing discussions about maritime claims [29]. At the same time, the SCSR also plays a vital role in the marine plastic waste issue [14]. There is a need for a cooperative effort, but it would be hard for any regional cooperation to exist in the SCSR. However, this paper concludes there is economic feasibility in the marine plastic cleanup cooperation in this area. This paradox may come from the fact that marine plastic pollution is a worldwide problem that needs a global effort. This "public
bad” problem cannot be solved in the absence of international cooperation. Therefore, the conclusion of this study raises the urgent need for a regional agreement to resolve the South China Sea conflict and environmental cooperation.

Marine plastic waste cleanup is a long-term process, and its cooperation requires both long-term strategic policies and short-term cooperation measures. From the above conclusion, this paper provides the following policy advice for the optimization of the cleanup cooperation in the SCSR.

(1) Short-Term Policy

a. To build this cleanup cooperation system, countries in the SCSR should first establish a regional cleanup organization for marine plastic waste cleanup cooperation based on existing international organizations, through which they can guide the cleanup of marine plastic waste for countries in the region. At the same time, a special financial service platform should be established to provide sufficient rewards and punishments for the cooperation.

b. Second, a policy communication mechanism should be established to achieve a tariff reduction plan for the plastic waste trade, which would provide a reduction in export tariffs to countries that actively invest in the marine plastic waste cleanup. Corresponding tariff reductions and exemptions should be based on the country’s investment in marine plastic waste treatment.

(2) Long-Term Policy

a. In the long term, countries in the region should carry out the following cooperation: the first is to provide commercial support for the market operation of the collected plastic waste. The manufacturers of the plastics industry should strengthen corporate social responsibility (CSR) and cooperate along the supply chain of plastic waste to improve the plastic waste recycling system. In so doing, the cost of investing in the cleanup system could be further compensated.

b. Second, the regional cleanup organization should make use of the existing regional economic cooperation mechanisms such as the China–ASEAN Free Trade Area, to adjust the structure of the plastic trade network to strengthen the relationship between the plastic trade and the marine plastic waste trade of the countries in the region, thus optimizing the structure of the plastic trade network.

Furthermore, countries and non-profit organizations should continue to innovate in marine plastic waste cleanup technologies to reduce the cost of marine plastic waste treatment.

5.2. Conclusions

Overall, the plastic waste cleanup cooperation in the South China Sea is related to the plastic trade network structure, the influence parameters of the EWA learning model, and the economic effects and policies of the marine plastic waste cleanup.

(1) The greater the density of the plastic trade network, that is, the more balanced the degree of the node countries, the more favorable it is for cooperation in the marine plastic cleanup. At the same time, the plastic waste trade policies of countries in the region have a shocking impact on cooperation. In 2018, China introduced a plastic waste import ban, which reduced the plastic trade ties between countries in the SCSR. Subsequently, their cooperation network structure was weakened which has harmed cooperation in the cleanup of marine plastic waste in the short term. Our findings are similar to Wang et al. [19] who claimed that the import ban has brought about a major change in the international collaboration network.

(2) The learning ability of countries in the SCSR in marine plastic waste cooperation has a positive effect on cooperation. The stronger the ability to learn from previous governance experience, the more attractive and effective strategies that can be adopted to promote cooperation. Failure to learn and the decrease in the attractiveness of previous experiences will reduce cooperation.
(3) Marine plastic waste treatment measures directly affect the cooperative behavior of regional countries. The greater the reward for cooperative behavior, the stronger the retaliation for non-cooperative behavior is, and the greater the reduction in tariffs on plastic trade are, all of which can lead to better cooperation. Conversely, the higher the cost of the cleanup system, the more unfavorable the cooperation is.

Based on the above results, the following cleanup cooperation framework can be derived in Figure 12:

![Figure 12. Theoretical model diagram of the marine plastic waste cleanup cooperation.](image)

5.3. Contributions and Limitations

The main contributions of this study are: First, this paper brings the concept of regional cooperation to the marine cleanup project. It has built a cooperation model and applied the EWA learning model to countries’ strategy behaviors. This cooperation could change the current status of the cleanup project and increase the scale of the cleanup project significantly. Second, this paper points out how factors such as the cost of systems could affect the cleanup of marine plastic waste, and it provides policy advice to adjust these factors for maximized cooperation results. Third, it reveals that the structure of the relationship network formed by countries in the SCSR has an impact on the cleanup cooperation of relevant countries. The relationship structure is a kind of social capital, which has a direct impact on the outcome of economic games. Last, the simulation results of the EWA model show that the learning ability of countries in the South China Sea has a direct impact on the treatment of marine plastic waste, which theoretically explains the influence of psychological factors such as social psychology and mental models on a country’s social and economic governance. It provides a new theoretical perspective for the governance of joint international issues such as the marine plastic cleanup.

There are also some limitations to this study. First, the assumed cooperation in the marine cleanup is a two-player game, while in reality, some countries could be involved in multilateral cooperation, such as the cooperation among three correlated countries. If this assumption is changed to allow multilateral cooperation, the first possible result would be that there could be larger payments from cooperation, thus more investment in the marine cleanup. This possibility is coming from the fact that marine plastic pollution is a public bad problem; it impacts all countries near the polluted area and thus needs efforts from all the parties. However, there may also be the chance that the cooperation becomes unstable during the 15 years because of the complexity of the strategies of multi-players. The “free-rider” problem may become more severe if there are more conflicts in relation to the payment and the tariff reward, which would mean that the “free-rider” problem may become more serious. Second, establishing a cooperation partnership network is based on trade links, which simplifies the condition for countries’ cooperation on public issues. In
reality, whether two countries have a partnership in the marine cleanup should depend on their diplomatic relations, distance, and economic connections, among other factors.

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