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From Pollution Control Cooperation of Lancang-Mekong River to "Two Mountains Theory"

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Abstract: "Lucid waters and lush mountains are invaluable assets " (referred to as the "Two Mountains Theory") plays an important role in the process of controlling environmental pollution. This article introduces this practice with an example of pollution control in the Lancang-Mekong River Basin (LMRB). The research considers that the upstream and downstream countries can carry out water pollution control by imposing fines on enterprises that cause ecological damage and investing in pollution control resources. Firstly, the differential game model of pollution control by individual countries and international cooperation is established. Then, a differential game model of joint pollution control with compensation mechanism is established under the cooperation framework. Finally, the feedback Nash equilibrium of each state is obtained. The study shows that in the process of industrial pollution control by countries in the LMRB alone, due to the one-way externality of water pollution control, the more downstream countries are, the more resources will be invested in pollution control and the fewer fines will be imposed on enterprises that cause ecological damage. At the beginning stage of management, if more pollution control resources are input, fewer countries will participate in cooperation, and the fines for polluting enterprise would be less. When the amount of fines for enterprises is relatively small, the establishment of a river pollution compensation mechanism is not conducive to the input of pollution control resources. On the contrary, it is beneficial for the state to invest in pollution control resources. The coordinated development of economic development and ecological civilization construction is the core purpose of the "Two Mountains Theory". Therefore, the case of the LMRB fully illustrates the feasibility of the "Two Mountains Theory" based on cooperation.

Keywords: upstream and downstream countries; ecological environment; differential game; transnational rivers

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1. Introduction

Nowadays, many countries in the world are implementing the strictest ecological and environmental protection system. All of these are practices of green and sustainable development concept under the top-level design of "Lucid waters and lush mountains are invaluable assets" (referred to as the "Two Mountains Theory"). This theory interprets the dialectical and unified relationship between economic development and environmental protection. The "Two Mountains Theory" has played an important role in the naturalization of various habitats. Under the guidance of the "Two Mountains Theory", habitats of various species in many countries have been revitalized [1,2]. In recent years, internationalized water resources pollution has become more and more serious [3–5]. The pollution of transnational rivers affects several countries upstream and downstream.

The Lancang-Mekong River is the ninth largest river in the world and the fifth largest in Asia. It originates in the Tanggula mountains in the south of Qinghai province of China. The LMRB is an ecosystem with many unique functions. It provides a lot of water, raw materials and food for human beings. In addition, it plays an important role in maintaining ecological balance and biodiversity as well as water conservation, flood storage and drought prevention, degradation of pollution, climate regulation, groundwater replenishment and soil erosion control. Industrial pollution and other human impacts in the LMRB are becoming more and more serious with the continuous accumulation of pollutants and the weakening of the basin's purification capacity, as well as the increasingly serious destruction of forest, grassland and other vegetation caused by human activities [6–8]. The ecology of the LMRB is no longer able to repair itself. It must rely on countries to recreate, guide or accelerate the natural evolution of the basin. In the basin outside China, although the Lancang-Mekong River continues are constantly polluted by organics and heavy metals [8], it still cannot attract enough attention from downstream countries [9]. It not only pollutes people's drinking water [10], but also leads to low efficiency of aquaculture in the basin [11]. Countries should take early measures to reduce ecological destruction on the Lancang-Mekong River. In the LMRB, special spatial location factors exist, and ecological destruction generated by upstream countries is shared by themselves and downstream countries. As a result, industrial enterprises in upstream countries have increased their emission in order to obtain greater benefits, which is obviously not conducive to the implementation of the responsibility system for pollution control. It does not accord with the basic principle of environmental protection of "who pollutes, who controls". Therefore, it is particularly important to implement the compensation mechanism for environmental governance so that the pollution responsible parties can effectively take charge of pollution control [12]. Enhanced cooperation between regions provides an important reference for effective control of river pollution [13]. It is not easy to reach cooperation in pollution control because of differences in justice, internal affairs and cognition [14]. The Lancang-Mekong cooperation is conducive to upstream and downstream countries enjoying rights and responsibilities towards each other in the face of ecological destruction and realizing the ecological resilience [15].

The ecological restoration of LMRB should focus on the self-organization and self-regulation ability of the ecosystem itself. In addition, the external artificial regulation ability should be supplemented [16]. If the ecological restoration can only be achieved by artificial control, the ecological environmental control of the Lancang-Mekong River will consume a large number of human, material and financial resources. In this case, the pollution control work on the Lancang-Mekong River is a failure. The Lancang-Mekong River has strong dynamic resilience. Its own dynamic recovery ability can gradually restore and realize the various functions of the ecosystem [17]. However, human production and living activities have increased in the past few years. This has resulted in significant damage to the dynamic resilience of the Lancang-Mekong River. The pollution control mode selected by countries in the LMRB can correctly create favorable conditions and promote the ecological restoration of countries in the LMRB. Once the ecological environment of the Lancang-Mekong River is restored to a large extent, all countries need to reduce the disturbance to the ecosystem.

With deepening research on river pollution by domestic and foreign scholars, a large number of achievements have emerged in the study of pollution control by using inductive method, multi-parameter analysis method, data analysis method, statistical method, decision-making systems and engineering technologies. For example, Surasinghe et al. sum up the problem of water pollution in the Kelani River basin [18]. Cooray et al. use a multi-parameter analysis to study water pollution in Sri Lanka [19]. Li et al. use data analysis to study water pollution in Shanghai [20]. Einax et al. use the multivariate analysis method for evaluation and interpretation of the river pollution data [21]. Nasiri et al. build expert system to calculate the water pollution index [22]. Zheng et al. use chemistry to study the causes of eutrophication in Hongfeng Lake [23]. Among them, game theory, which is used to analyze human social conflicts and cooperation, provides a good analytical tool for river pollution. Conventional games include bargaining games, static games and evolutionary game. Yuan built the bankruptcy and bargaining games to solve the problem of water resource allocation [24], the static game model between enterprise pollution emission control and government regulation [25]. Evolutionary game, including the evolutionary game model of government and sewage management in the process of Huai River water pollution control [26], the use of evolutionary game to control complex and changeable water pollution problems [27] and the use of evolutionary game to deal with the time consistency of downstream water pollution control [28]. The above literature analysis basically covers traditional game methods, evolutionary game and other emerging game theories. However, based on the above game theory literature on water pollution control, the assumption about time is simultaneous or time is discrete. The problem of time continuity in the decision-making interaction between upstream and downstream countries in the process of pollution control has not been considered.

Differential game refers to a time continuous game played by multiple players in a time continuous system. It has the goal of optimizing the independence and conflict of each player, and can finally obtain the strategy of each player evolving over time and reach the Nash equilibrium. The theory of differential game originated from research on the pursuit of flight by both sides in the military confrontation carried out by the US Air Force in the 1950s. It is a combination of optimal control and game theory. At present, it is mainly applied in the fields of pricing strategy [29], traffic network equilibrium problem [30], advertising decision [31,32] and information security [33,34]. In the field of environmental governance, Huang established a differential game model to deal with the dynamic governance of cross-border pollution in two regions [35]. Yeung used the cooperative differential game model to analyze cross-border ecological destruction [36]. Kossioris used the differential game model to study pollution control of lakes [37]. The above study on ecological destruction by using differential game has no spatial and geographical constraints and considers the compensation mechanism of pollution control.

Due to the upstream and downstream relationship between countries in the LMRB, this paper referred to the "Two Mountains Theory" and was based on Huang's differential game model of trans-boundary pollution [35]. How to construct international cooperative pollution control mechanisms under different governance modes on the basis of considering the spatial position relationship between the upper and lower reaches of the LMRB?

2. Methodology

In order to effectively protect the ecological environment, habitat and natural landscape of transnational river basins, the following three ecological environment governance modes are mainly adopted by countries in river basins:

(1) Individual management model. In the absence of effective international management mechanisms, each watershed country protects its own ecological environment, habitat and natural landscape. At this point, the ecological governance of upstream countries will produce positive externalities to downstream countries. However, the destruction of ecological environment, habitat and natural landscape by the upstream countries will have negative externalities to the downstream countries. That is, emissions by upstream countries can harm the interests of downstream countries. In addition, the upstream countries can protect the interests of the downstream countries by controlling pollution. On the contrary, the destruction of the ecological environment, habitat and natural landscape by the downstream countries will only have an impact on the domestic countries, not the upstream countries [38].

(2) Joint management model. If the damage to the ecological environment, habitat and natural landscape in the upstream countries is not effectively addressed, it will seriously affect the international reputation of the upstream countries. Therefore, it is necessary for upstream and downstream countries to carry out information and intelligence exchange on river pollution, and establish cooperation mechanism to deal

with river pollution emergencies. Therefore, cooperation among countries along the LMRB to protect the ecological environment, habitat and natural landscape will help reduce conflicts among countries [11].

(3) Joint management model based on compensation. As for the national responsibility caused by the damage to the ecological environment, habitat and natural landscape of transnational rivers, especially the compensation problem, there are great differences among the basin countries. Different from the second cooperation mechanism, in this compensation-based cooperation mechanism, compensation needs to be made according to the amount of pollution discharged, and the compensation can be used to control pollution.

The economic development of the LMRB requires the production and processing of products, but needs to discharge waste water, waste gas and waste residue. Thus, it causes certain damage to the ecological environment, habitat and natural landscape. The investment of pollution control resources (such as sewage pipes, push flow aerators and other pollution control equipment, hiring personnel for pollution control, ammonia nitrogen remover, limestone and other raw materials for water purification) can play a role in the ecological environment of the LMRB. How to make decisions on the amount of sewage discharge (or product production) and pollution control of each country has become an important issue studied in this paper. Therefore, this paper first sets up the relevant assumptions and parameters and then establishes the relevant model.

2.1. Assumptions

A river has a certain bearing capacity [11]. The upper and lower reaches of sewage beyond its bearing capacity will cause losses [39]. Due to the upstream and downstream relationship between countries along LMRB, pollutants from upstream countries can flow into downstream countries, thus adversely affecting downstream countries, while ecological destruction from downstream countries can hardly affect upstream countries. This paper makes the following assumptions about the analysis objects.

A1: This paper assumes that six countries in the LMRB (China, Myanmar, Laos, Thailand, Cambodia and Vietnam) make pollution control decisions in a continuous time and unlimited planning cycle [6]. The first upstream country is country 1, and the second upstream country is country 2, . . . , and the most downstream country is country 6.

A2: The ecological protection decision-making of each country is in a state of continuous and dynamic change.

Both upstream and downstream countries of transnational rivers can control the amount of pollution discharge and treatment to achieve the purpose of protecting the ecological environment, habitat and natural landscape. Under the separate treatment mode, the upstream countries of transnational rivers make use of their own geographical and spatial advantages, and their ecological destruction and restoration can affect the downstream countries; the downstream countries cannot influence the downstream countries. In order to restrict the upstream countries and achieve the purpose of jointly protecting the ecological environment of the upstream and downstream countries of transnational rivers, the countries in the LMRB can establish a common ecological protection model and a compensation-based common ecological protection model. Taking the common pollution control model as an example, under which the downstream countries can obtain certain economic compensation based on the net emission of the upstream countries, so that the upstream countries have to determine their emission according to the ecological compensation, and the net emission determined by the upstream countries further affects the ecological destruction level suffered by the downstream countries. Therefore, the ecological protection decisions of various countries are in continuous dynamic changes.

A3: Each country has only one major pollutant for the LMRB.

All countries in the LMRB are developing countries. In addition to China, which has a complete industry, other countries mainly focus on low-end industries. For example, although Vietnam has many companies in the LMRB, its main damage in the LMRB comes from its own sand mining industry. Perennial sand mining in Vietnam has caused serious soil erosion in the LMRB [40]. In addition, Cambodia's fishing industry has destroyed the food chain and ecological balance in the LMRB [41]. For convenience, this article assumes that each country has only one major pollutant for the LMRB.

A4: Every unit of product produced will result in a unit of river pollution in the LMRB.

The destruction of ecological environment in the LMRB is affected by many aspects. On the one hand, the production of the same product can produce a variety of pollutants, and the damage of different pollutants to the ecological environment, habitat and natural landscape is different. On the other hand, the self-regulation capacity of the LMRB at different times also affects the degree of damage. The LMRB is divided into dry season and rainy season. Compared with the dry season, rivers can effectively dilute pollutants in the rainy season, thus accelerating the decay of acid, alkali, oxidant, copper, cadmium, mercury and other heavy metal pollutants. In addition, rainwater, groundwater, snow and ice melt water supply in upstream and downstream basins are different, which will also affect the restoration rate of ecological environment, habitat and natural landscape. Some scholars have also made the same assumption. For example, although the production of many products can cause carbon dioxide emissions, Bertinelli et al. also assumed that only one product was produced when conducting carbon emission research [42]. For convenience, this paper assumes that unit product produces unit pollutant.

2.2. Parameter Setting

In the face of river pollution, habitat destruction and natural landscape damage in several countries along the LMRB [8], cooperation between governments is necessary for governance. Chen et al. studied the necessity of government cooperation [43], and Qi et al. studied the impact of China-South Korea cooperation on pollution emission [44]. Although these scholars studied the impact of pollution control cooperation on the effect of pollution control, they did not study the specific form of cooperation.

The profits from the production of goods in a region shall be enjoyed by that region alone. However, the pollution to the ecological environment has a certain spread. That is, the ecological destruction of one area will affect other areas. As a result, the ecological environment, natural habitat and landscape of other areas are also damaged. This results in inequality of ecological destruction and benefits in different areas. Therefore, some scholars have studied the form of cooperation based on compensation. For example, Rosemary's study concluded that compensation for victims can make the ecological destruction mechanism fairer [45], and Cui et al. studied the impact of air ecological destruction compensation on pollution emission [46]. Although these scholars studied the specific form of cooperation (ecological destruction compensation), they did not compare and analyze the abstract ecological cooperation with the cooperation based on ecological compensation. In order to make up for the shortcomings of the above research, this paper constructed three differential game models of pollution control by the upstream and downstream countries of the Lancang-Mekong River alone, cooperative pollution control and compensation-based cooperative pollution control, and then compared the balanced production and control quantity of the upstream and downstream countries under each pollution control mode.

In this paper, three pollution control modes are considered: individual ecological control, cooperative ecological control and compensation-based cooperative ecological control. The main variables and parameter definitions set in this paper are shown in Table 1.

Table 1. Definition of major variables and parameters.

Variables and Parameters	Specific Meaning
$A_i(t)$	The ecological governance resources invested by country i at time t, namely, the amount of pollution control, $A_i(t) \geq 0$
$q_i(t)$	The amount of damage to the ecological environment caused by products produced by country i at time t, $q_i(t) \geq 0$
$G_i(t)$	The penalty imposed on enterprises in country i at time t per unit of ecological damage, $G_i(t) \geq 0$
$x_i(t)$	Long-term impact of pollution, habitat destruction and other human activities on country i at time t, $x_i(t) \geq 0$
ρ	The discount rate that occurs over time. That is the discount factor, $0 < \rho < 1$
δ	Decay rate of ecological damage. That is, the restoration rate of ecological environment, habitat and natural landscape, $0 < \delta < 1$
π	The positive impact of unit pollution control, $\pi \geq 0$
b	Parameters in a requirement function. It is the vertical intercept of the price demand curve, and it is the price when demand exceeds supply, $b \geq 0$
$V_i(t)$	The benefit function of state i's pollution control at time t

Next, this article explains the parameters and variables in Table 1. Every country in the LMRB has some industrial enterprises. In the process of production and management, enterprises are prone to unreasonable use of water resources, excessive deforestation, overload mining of mineral resources and other behaviors. The resulting destruction of the ecological environment, habitat and natural landscape. The damage to ecological environment, habitat and natural landscape caused by products produced by country i at time t is $q_i(t)$. Of course, countries in the LMRB will take measures to protect the environment after discovering that their ecological environment, habitat and natural landscape are damaged. Specific measures include: (1) Water pollution control. For example: put sewage pipes, push flow aerator and other pollution treatment equipment, hire personnel to carry out pollution treatment, put ammonia nitrogen remover, limestone and other raw materials to purify water; (2) Reduce biodiversity loss and expand the connectivity of natural habitats in the LMRB; and (3) Invest manpower and material resources to restore the natural landscape of the LMRB. At this point, the ecological governance resource invested by country i at time t is $A_i(t)$. Different measures are adopted to regulate the ecological environment, habitat and natural landscape. For convenience, this paper sets the positive impact of unit pollution control as π. Although the countries in the LMRB invest pollution control resources to control the environment, it can play a certain role in the restoration of the ecological environment, habitat and natural landscape, but it cannot prevent the behavior of destroying the ecological environment from the source. Each country may also impose penalties on its own enterprises that damage the ecological environment, habitat and natural landscape if the expected results cannot be achieved by using pollution control resources. The penalty imposed on enterprises in country i by unit ecological damage at time t is $G_i(t)$. Human production and operation activities will have a long-term impact on the ecosystem of transnational rivers. Take migratory fish as an example, which require different environments for the main phases of their life cycle, which are reproduction, production of juveniles, growth and sexual maturation. The life cycle of diadromous species takes place partly in fresh water and partly in sea water. The reproduction of anadromous species takes place in fresh water, whereas catadromous species migrate to the sea for breeding purposes and back to fresh water for trophic purposes. Once the cross-border rivers are polluted, it will have an important impact on the reproduction, larval production, growth and sexual maturity of migratory fish, resulting in long-term damage to the migratory specie. The migration of dolphins will also change with their own environment. If cross-border rivers are damaged, the migration route of dolphins will be changed, and they will become an alien species, resulting in damage to the ecological environment and natural habitat. In this paper, $x_i(t)$ is defined as long-term impact of pollution, habitat destruction and other human activities on country i at time t.

The value range of the decay rate of ecological damage δ is (0,1). Nature has a special property that it can self-balance and self-repair. Like the immune system of all living things, nature is a self-repairing, circular, endless environmental system. The resilience is δ. The discounted factor ρ is different from the decay rate δ of ecological damage. The discount factor means that earnings have a time value. That is, because of factors such as inflation, even if the absolute amount of the return is the same, the return now will be different from the return some time later. Among them, the governance capacity of a country is the state variable, and the pollution control input and fines of a country are the control variables.

Enterprises tend to pursue the maximization of economic benefits. Therefore, enterprises that cause ecological damage do not consider the damage and loss of ecological environment, natural habitat and landscape into their own costs. Therefore, the cost of enterprises that cause ecological damage includes the production cost of products and fines imposed on enterprises that cause ecological damage, but it does not include the cost of the pollution, habitat destruction and other human impacts. For convenience of analysis, referring to the simple form of the convex return function proposed by Breton et al. [47]. The net income generated by all enterprises that cause ecological damage in country i is:

$$\varphi_i(t) = bq_i(t) - \frac{1}{2}q_i^2(t) - G_i(t)q_i(t) \tag{1}$$

In Equation (1), $bq_i(t)$ represents the operating income generated by all industrial enterprises in country i selling products of $q_i(t)$ units (product backlog is not considered in this paper). $\frac{1}{2}q_i^2(t)$ represents the cost of production for all industrial enterprises in country i. $G_i(t)q_i(t)$ represents the fines paid by all industrial enterprises in country i for damaging the ecological environment of the Lancang-Mekong River.

The total profits of all enterprises that cause ecological damage in country i within a production cycle T are as follows:

$$\max_{q_i} \int_0^T \left[bq_i(t) - \frac{1}{2}q_i^2(t) - G_i(t)q_i(t) \right] e^{-\rho t} dt \tag{2}$$

In Equation (2), $e^{-\rho t}$ represents the discount rate, which is the ratio of future returns to present values.

By solving Equation (2), the optimal output of enterprises in country i can be obtained as follows:

$$q_i^*(t) = b - G_i(t) \tag{3}$$

It can also be seen from Equation (3) that the output of commodities of country i is not directly related to the degree of damage to the ecological environment, natural habitat and ecological landscape, but is related to fines.

It is very difficult for country i to fully restore the ecological environment, habitat and natural landscape of the LMRB. Therefore, the degree of damage to the ecological environment is greater than the degree of repair. It can be expressed as: $q_i^*(t) \geq A_i^*(t)$, $b - G_i(t) \geq A_i(t)$.

Since the goodwill of an enterprise is affected by the advertisements made by itself and other enterprises [48], this paper considers that the effect of national pollution control is related to national pollution control capacity and that of other countries. In addition, according to the formula of demand price in economics, this paper obtains the income of country i for producing goods. With the continuous increase in pollution control, the input of pollution-related production factors is increasing, which is easy to cause the shortage of production factors, and eventually lead to the increase in the price of production factors. Therefore, the pollution control effect obtained by the state is as follows:

$$e_i(t) = \begin{cases} \left[\sum\limits_{h=1}^{i} q_h(t) - \sum\limits_{h=1}^{i-1} A_h(t)\right] A_i(t) & 2 \le i \le 6 \\ q_1(t) A_1(t) & i = 1 \end{cases} \tag{4}$$

In Equation (4), when i = 1, there is no upstream country in country 1. $q_1A_1(t)$ represents the effect achieved by country 1 in pollutant control of the Lancang-Mekong River. When $2 \le i \le 6$, $\sum\limits_{h=1}^{i} q_h(t)$ represents the industrial pollutants generated by country i and upstream country to the Lancang-Mekong River. $\left[\sum\limits_{h=1}^{i} q_h(t) - \sum\limits_{h=1}^{i-1} A_h(t)\right]$ indicates the pollution, habitat destruction and other human impacts status of the Lancang-Mekong River in country i.

The long-term impact of the pollution, habitat destruction and other human activities of LMRB on country i is $x_i(t)$ ($1 \le i \le 6$). Its change at time t can be expressed as:

$$x_i^{\&}(t) = \alpha\left(\sum_{h=1}^{i} q_h(t) - \sum_{h=1}^{i} A_h(t)\right) - \delta x_i(t) \tag{5}$$

In Equation (5), α represents the influence coefficient of net damage to the ecosystem, and it is a negative number. $\sum\limits_{h=1}^{i} q_h(t) - \sum\limits_{h=1}^{i} A_h(t)$ represents the extent of net ecological damage in the Lancang-Mekong River in country i over the long term. $\delta x_i(t)$ refers to the degree to which an ecosystem recovers itself over time in the Lancang-Mekong River in country i.

2.3. Different Pollution Control Modes

2.3.1. Individual Management

In the process of industrial pollution control by each country alone, each country can not only invest in pollution control resources to restore ecosystems, habitats and natural landscapes, but also impose fines for domestic enterprises that cause ecological damage to affect their pollutant discharge, in order to maximize the benefits of pollution control.

In the separate process of ecological environment management of transnational rivers, ecological governance of upstream countries will have positive externalities to downstream countries. The destruction and management of ecological environment, natural habitat and natural landscape in the upstream countries will not only affect the country, but also affect the downstream countries. On the contrary, the destruction and management of ecological environment, natural habitat and natural landscape in upstream countries will only affect the country, not the upstream countries.

The social welfare function of the upstream and downstream countries consists of income from production, ecological restoration costs, fines imposed on enterprises that cause ecological damage, and losses caused by ecological environment damage. Based on the previous statement, the total net benefit V_i (i = 1 and $2 \le i \le$ N, respectively) of country i through pollution control in one cycle can be expressed as:

$$V_i = \begin{cases} \max\limits_{A_i,G_i} \int_0^T e^{-\rho t}\left(\pi\left[\sum\limits_{h=1}^{i} q_h - \sum\limits_{h=1}^{i-1} A_h(t)\right] A_i(t) + G_i(t) q_i(t) - \frac{1}{2}A_i^2(t) - x_i(t)\right) dt & 2 \le i \le 6 \\ \max\limits_{A_i,G_i} \int_0^T e^{-\rho t}\left(\pi q_1 A_1(t) + G_1(t) q_1(t) - \frac{1}{2}A_1^2(t) - x_1(t)\right) dt & i = 1 \end{cases} \tag{6}$$

In Equation (6), $\pi\left[\sum\limits_{h=1}^{i} q_h - \sum\limits_{h=1}^{i-1} A_h(t)\right] A_i(t)$ represent the gains made by China and the countries on the lower reaches of the Lancang-Mekong River in the process of pollution control at time t. $G_i(t)q_i(t)$ represents the revenue from fines for enterprises that cause ecological damage. $\frac{1}{2}A_i^2(t)$ represents the cost of water pollution control. Since the inequality $\sum\limits_{h=1}^{i} q_h - \sum\limits_{h=1}^{i-1} A_h > 0$ is also true, it can be seen that with the increase in pollution control capacity of country i, the benefit of pollution control of country i also increases at a certain point.

According to the solution of feedback Nash equilibrium, in order to maximize the benefit of Equation (6), it must satisfy (refer to Definition 1 and 2 in the Appendix A for the specific solving process):

$$G_i^*(t) = -\frac{\pi}{2}A_i(t) - \frac{\alpha}{2}e^{\rho t}V_x(t,x) + \frac{b}{2}1 \leq i \leq 6 \tag{7}$$

$$A_i^*(t) = \begin{cases} \pi \sum\limits_{h=1}^{i}[b - G_i(t)] - \pi \sum\limits_{h=1}^{i-1} A_h(t) - \alpha e^{\rho t}V_x(t,x) & 2 \leq i \leq 6 \\ \pi(b - G_i(t)) - \alpha e^{\rho t}V_x(t,x) & i = 1 \end{cases} \tag{8}$$

In Equations (7) and (8), $V_x(t,x)$ is the partial derivative of V with respect to x. $Vx(t,x)$ is less than zero because the more ecological damage there is, the less utility a country gets. In Equation (8), the equation $A_1^*(t) \leq A_2^*(t) \leq \cdots \leq A_6^*(t)$ is satisfied because $b - G_i(t) \geq A_i(t)$. According to the relation between $G_i^*(t)$ and $A_i(t)$ in Equation (7), it can be obtained that $G_1^*(t) \geq G_2^*(t) \geq \cdots \geq G_N^*(t)$.

After analysis, it can be concluded that in the process of pollution control by countries in the LMRB alone, the optimal fine $G_i(t)$ imposed by country i on domestic enterprises that cause ecological damage is inversely proportional to the resource input $A_i(t)$ of country i on pollution control. Compared with upstream countries, downstream countries invest more in pollution control resources and impose fewer penalties on enterprises.

In the process of controlling the ecological environment independently, countries in the LMRB must constantly impose fines and invest ecological resources to achieve certain effects. In addition, under this model, the downstream countries are in a very disadvantageous position. This model is not conducive to the restoration of ecological environment, habitat and natural landscape in the LMRB, nor to the promotion of the "Two Mountains Theory". Therefore, this paper discusses the cooperative ecological governance model.

2.3.2. Joint Management

Although the water resources of transnational rivers are shared by upstream and downstream countries, the upstream countries are often the first to take advantage of transnational rivers by virtue of their favorable topography, thus causing losses to the interests of the downstream countries. The LMRB is an organic whole, and the restoration of ecological environment, natural habitat and ecological landscape is not dependent on a single country to achieve the overall goal of upstream and downstream countries. For example, the reproduction and growth of migratory species and the successful migration of dolphins need the cooperation of upstream and downstream countries. Upstream and downstream countries should establish a strong organization to coordinate their relations. They are working together to improve the ecological environment, natural habitat and ecological landscape along the LMRB. This can realize the coordination of multiple interests and make the links between upstream and downstream countries closer.

It is very important for many regions to cooperate in ecological environment management. For example, since many places (especially rural areas) have a large water supply burden, it is necessary to develop and utilize water resources rationally [49]. Under the condition of pollution control by each country alone, the more upstream the country is, the smaller the pollution control input will be. Therefore, the downstream country must cooperate with the upstream country to manage the ecological environment, habitat and natural landscape in its own basin. In the process of jointly controlling the ecological environment, a community of interests will be formed. When countries 1 and 2 jointly control the ecological environment, their fines for industrial enterprises are set as $G_2(t)$. The invested pollution control resources are set as $A_2(t)$. When country 1, country 2 and country 3 jointly control the ecological environment, the fines for industrial enterprises are set as $G_3(t)$, and the pollution control resources invested are set as $A_3(t)$. Similarly, when country 1, country 2... country i jointly control the ecological environment, the fines imposed on industrial enterprises are set as $G_i(t)$, and the pollution control resources invested are set as $A_i(t)$.

As the problem of the pollution, habitat destruction and other human impacts in LMRB becomes more and more serious, cooperation between countries to control the ecological environment has become an irresistible trend. When country i ($2 \le i \le 6$) is cooperating with upstream countries for pollution control, the sum of its revenue function with upstream countries can be expressed as:

$$W_i = \max_{A_2 \cdots A_i, G_2 \cdots G_i} \int_0^T \sum_{k=2}^{i} \left(\pi \left[\sum_{h=1}^{k} q_h(t) - \sum_{h=1}^{k-1} A_h(t) \right] A_k(t) + G_k(t) q_k(t) - \frac{1}{2} A_k^2(t) - x_k(t) \right) e^{-\rho t} dt \tag{9}$$

According to the solution of feedback Nash equilibrium, in order to maximize the benefit of Equation (9), it must satisfy (refer to Definition 3 in the Appendix A for the specific solving process):

$$G_i^*(t) = \frac{b}{2} - \frac{\sum_{k=2}^{i} k}{2(i-1)} \pi A_i(t) - \frac{\sum_{k=2}^{i} k}{2(i-1)} \alpha e^{\rho t} W_x(t,x) \tag{10}$$

$$A_i^*(t) = \frac{\pi \sum_{k=2}^{i} k \left(b - G_i(t) \right) - \sum_{k=2}^{i} k \alpha e^{\rho t} W_x(t,x)}{\left[\pi \sum_{k=2}^{i} 2(k-1) \right] + i - 1} \tag{11}$$

In Equations (10) and (11), $W_x(t,x)$ is the partial derivative of W with respect to x. $W_x(t,x)$ is less than zero because the more damaged the ecological environment is, the less utility the country gains. The resources invested in pollution control of LMRB $A_i > 0$. It can be concluded from this paper that if the input pollution control resources are fixed, when $-\alpha e^{\rho t} W_x(t,x)/\pi$ is greater than a certain value, $G_2^*(t) < G_3^*(t) < G_4^*(t) < \cdots\cdots < G_N^*(t)$ will set up. In addition, when $-\alpha e^{\rho t} W_x(t,x)/\pi$ is less than that, $G_2^*(t) > G_3^*(t) > G_4^*(t) > \cdots\cdots > G_N^*(t)$ will set up. If the fine to domestic enterprises that cause ecological damage is fixed, when the profit that every unit pollution control brings is small, $A_2^*(t) < A_3^*(t) < A_4^*(t) < \cdots\cdots < A_N^*(t)$ will set up. When the profit that every unit pollution control brings is small, $A_2^*(t) > A_3^*(t) > A_4^*(t) > \cdots\cdots > A_N^*(t)$ will set up.

In the process of joint pollution control of LMRB, when the impact of the pollution, habitat destruction and other human activities is greater than the benefit of pollution control, the more countries involved in industrial pollution control, the more fines will be imposed on enterprises that cause ecological damage. On the other hand, the more countries involved in industrial pollution control, the fewer fines will be imposed on enterprises that cause ecological damage. When the benefits from pollution control are relatively large, the more countries involved in industrial pollution control, the less pollution control resources each country will invest. On the contrary, the more countries involved in industrial pollution control, the more pollution control resources each country will invest.

Countries must intervene if the ecological environment, habitat and natural landscape of the LMRB are damaged to a large extent and the lives of local residents are greatly affected. However, with the gradual progress of ecological governance, the ecological environment, habitat and natural landscape in the LMRB have been greatly restored. At this time, countries should gradually withdraw from the intervention of the basin, and focus on the self-repair of the basin.

2.3.3. Joint Management with Compensation Mechanism

According to the conclusion drawn in Section 3, under certain circumstances, the state may impose more fines for enterprises that cause ecological damage and invest fewer resources in the treatment. While this provides financially challenged countries with a viable means of controlling the pollution, habitat destruction and other human impacts in LMRB, it is clearly detrimental to the sustainable development of LMRB. If we implement the responsibility system for pollution control, we must establish a compensation mechanism for pollution control and implement the basic principle of "who pollutes, who controls". All fines imposed by country i on domestic industrial enterprises are used to invest resources in pollution control. The function expression is $A_i(t) = G_i(t)$. In this paper, pollution control resources invested by country i, output of enterprises and the long-term effects of the pollution, habitat destruction and other human impacts on country i are respectively set as $\widehat{A}_i(t)$, $\widehat{q}_i(t)$ and $\widehat{x}_i(t)$.

$$\widehat{W}_i = \max_{A_2 \cdots A_i} \int_0^T \sum_{k=2}^{i} \left(\pi \left[\sum_{h=1}^{k} \widehat{q}_h - \sum_{h=1}^{k-1} \widehat{A}_h(t) \right] \widehat{A}_k(t) + \widehat{A}_k(t) \widehat{q}_k(t) - \frac{1}{2} \widehat{A}_k^2(t) - \widehat{x}_k(t) \right) e^{-\rho t} dt \tag{12}$$

According to the solution of feedback Nash equilibrium, in order to maximize the benefit of Equation (13), it must satisfy (refer to Definition 4 in the Appendix A for the specific solving process):

$$\widehat{A}_i^*(t) = \frac{\left(\frac{i^2}{2} + \frac{i}{2} - 1\right)\pi b + (i-1)b}{(2i^2-2)\pi + 3(i-1)} - \frac{(i^2+i-2)\alpha e^{\rho t} W_x(t,x)}{(2i^2-2)\pi + 3(i-1)} \tag{13}$$

When $-\alpha e^{\rho t} W_x(t,x) b\pi$ is greater than a certain value, $\widehat{A}_2^*(t) > \widehat{A}_3^*(t) > \widehat{A}_4^*(t) > \cdots\cdots > \widehat{A}_N^*(t)$ will set up. In addition, when $-\alpha e^{\rho t} W_x(t,x) b\pi$ is less than that, $\widehat{A}_2^*(t) < \widehat{A}_3^*(t) < \widehat{A}_4^*(t) < \cdots\cdots < \widehat{A}_N^*(t)$ will set up.

In the process of joint pollution control of the Lancang-Mekong River, the establishment of compensation mechanism for pollution control of the Lancang-Mekong River is not conducive to the increase in investment in pollution control resources when the pollution, habitat destruction and other human activities have a great impact. The establishment of compensation mechanism for industrial pollution control of the Lancang-Mekong River is conducive to the increase in investment in pollution control resources when the pollution, habitat destruction and other human impacts have a small impact.

The compensation mechanism of ecological damage has a very positive effect on the restoration of ecological environment. If the ecological environment, habitat and landscape are restored to a certain extent, this mechanism is not conducive to the self-repair of the ecological environment. At this point, countries in the LMRB should gradually withdraw from the compensation mechanism for ecological damage.

2.4. International Cooperation Control Concept

2.4.1. From Pollution Control to "Two Mountains Theory"

The main purpose of "Two Mountains Theory" is to solve the problems of ecological sustainable development and ecological restoration. Countries in the LMRB can restore their ecology through fines and pollution control. This paper presents a framework of how countries in the LMRB choose pollution control models to achieve ecological restoration.

Although these three pollution control modes play a certain role in restoring the ecological environment and realizing more sustainable development, they have different effects. In other words, every pollution control model is aimed at ecological restoration. However, a certain governance model may not achieve the desired results. Choosing the right pollution control mode can realize the recovery of ecological environment faster and better, and then achieve sustainable development. The path selection of the three pollution control modes is shown in Figure 1.

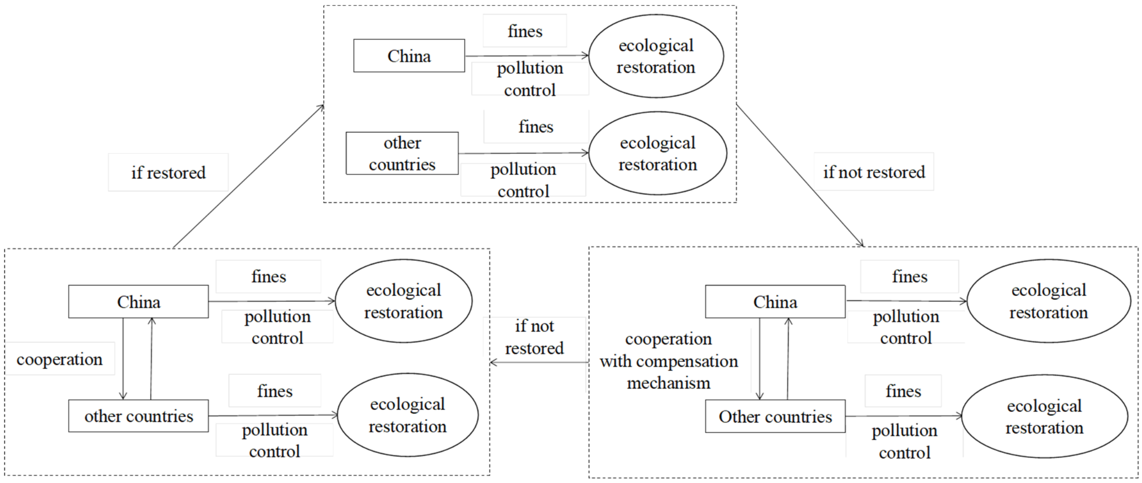

Figure 1. The path selection of the three management modes.

Pollution control is only the first step. Let habitats be re-naturalized/restored/re-wild through automatic natural dynamics, and maintain/protect/respect natural dynamics, forming a normalized mechanism for cooperation between countries. The ultimate goal of the "Two Mountain Theory" is to construct this normalization mechanism. The "Two Mountains Theory" can change the mode of economic development, and strengthen the comprehensive control of environmental. This theory can further accelerate ecological protection and restoration. The theory puts forward a solution to the seemingly irreconcilable contradiction between environmental protection and economic development in an easy-to-understand way.

2.4.2. "Two Mountains Theory" Based on Cooperation

Through the comparative analysis of the different pollution control modes mentioned, the applicable scope of different pollution control modes can be obtained. Then, this paper can find out how to choose pollution control mode to quickly carry out ecological restoration and sustainable development. However, in the process of protecting the ecological environment and economic development, the cooperation of all countries is necessary. The specific mode of the "Two Mountains Theory" based on cooperation is shown in the Figure 2.

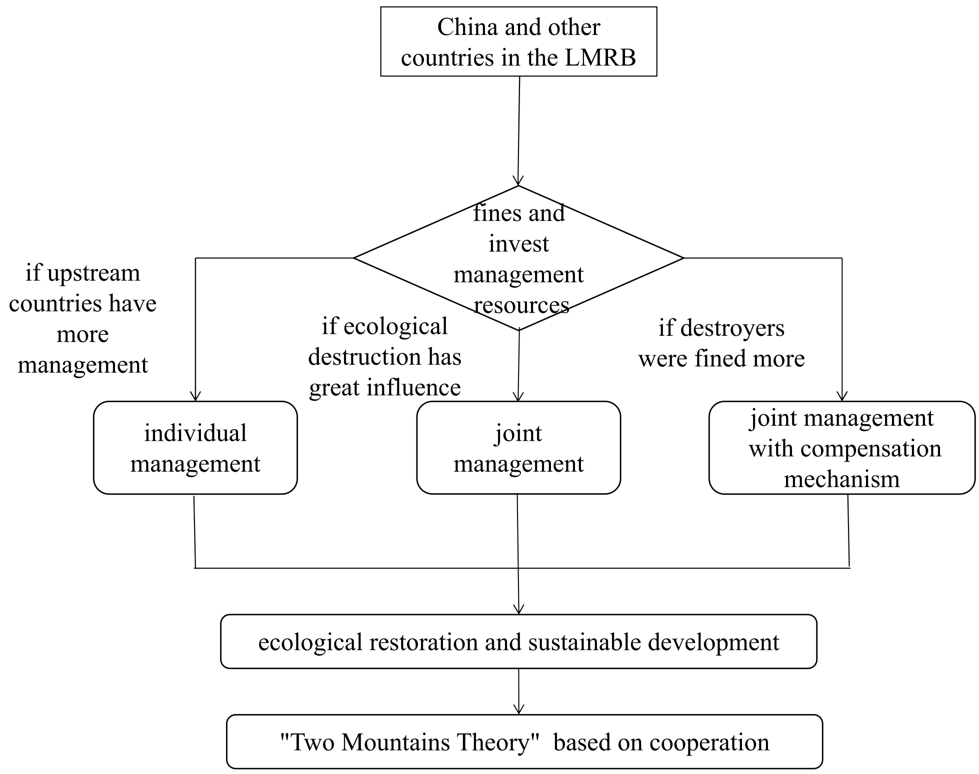

Figure 2. Specific path of "Two Mountains Theory" based on cooperation.

3. Equilibrium Results

The LMRB has a special spatial position relationship. The upstream and downstream countries can deal with the ecological destruction problem through three ways: individual pollution control, cooperative pollution control and joint pollution control under the compensation mechanism. In the first few sections of this article, the paper only discusses the optimal fines for enterprises that cause ecological damage and the optimal resource input amount under each pollution control method, but does not make a comparative analysis. This section will compare and analyze the optimal amount of fines and the optimal amount of resource input under the three pollution control methods, and then draw relevant conclusions.

3.1. Separate Management and Joint Management

As can be seen from the above, the optimal fines for enterprises that cause ecological damage and the optimal resource input for pollution control under the condition of pollution control alone are as follows:

$$G_i^*(t) = -\frac{\pi}{2}A_i(t) - \frac{\alpha}{2}e^{\rho t}V_x(t,x) + \frac{b}{2} \tag{14}$$

$$A_i^*(t) = \begin{cases} \pi\sum\limits_{h=1}^{i}[b - G_i(t)] - \pi\sum\limits_{h=1}^{i-1}A_h(t) - \alpha e^{\rho t}V_x(t,x) & 2 \le i \le N \\ \pi(b - G_i(t)) - \alpha e^{\rho t}V_x(t,x) & i = 1 \end{cases} \tag{15}$$

Under the condition of joint pollution control, the optimal amount of fine and the optimal resource input for pollution control are as follows:

$$G_i^*(t) = \frac{b}{2} - \frac{\sum\limits_{k=2}^{i}k}{2(i-1)}\pi A_i(t) - \frac{\sum\limits_{k=2}^{i}k}{2(i-1)}\alpha e^{\rho t}W_x(t,x) \tag{16}$$

$$A_i^*(t) = \frac{\pi \sum_{k=2}^{i} k\Big(b - G_i(t)\Big) - \sum_{k=2}^{i} k\alpha e^{\rho t} W_x(t,x)}{\left[\pi \sum_{k=2}^{i} 2(k-1)\right] + i - 1} \tag{17}$$

If the effect of pollution control resources and long-term ecological destruction on the utility function is certain, when $-\alpha e^{\rho t}W_x(t,x) - \pi A_i(t) > 0$, it can be obtained that $G_i^*(t) < \overset{*}{G}_i(t)$. When $-\alpha e^{\rho t}W_x(t,x) - \pi A_i(t) < 0$, it can be obtained that $G_i^*(t) > \overset{*}{G}_i(t)$. When $-\alpha e^{\rho t}W_x(t,x) - \pi A_i(t) = 0$, it can be obtained that $G_i^*(t) = \overset{*}{G}_i(t)$. When $\sum_{h=1}^{i-1} A_h(t)$ is small, we can get $A_i^*(t) > \overset{*}{A}_i(t)$. When $\sum_{h=1}^{i-1} A_h(t)$ is large, we can get $A_i^*(t) \leq \overset{*}{A}_i(t)$.

When the impact of the pollution, habitat destruction and other human impacts are greater than the benefit of pollution control, the fines for enterprises that cause ecological damage under joint control is more. When the impact of the pollution, habitat destruction and other human impacts are relatively small compared to the benefits generated by pollution control, the fines for enterprises under separate control are more. When more resources are invested in upstream pollution control, compared with joint pollution control, fewer pollution control resources are needed for separate pollution control.

The LMRB's countries need to cooperate to set up a penalty agency if the net discharge has a significant impact on the ecological environment. By fining countries that discharge large amounts of the pollution, habitat destruction and other human impacts, the basin's ecosystem can be protected. When the upstream countries have a large amount of pollution control, the downstream countries will have less human disturbance to the Lancang-Mekong River ecosystem. In this case, good results can be achieved by relying on the self-regulation ability of the ecosystem, and there will be less need for downstream countries to cooperate in pollution control [50]. On the contrary, if the upstream countries invest less in pollution control, the Lancang-Mekong River ecosystem will be damaged. It is not enough to rely on the self-recovery ability of the ecosystem, and the downstream countries must strengthen cooperation and human intervention to make the LMRB ecosystem develop towards a virtuous cycle [51].

3.2. Comparative Analysis of Two Kinds of Cooperative Governance

As can be seen from the above, the optimal resource input for pollution control under the compensation mechanism is as follows:

$$\overset{\frown}{A}{}_i^*(t) = \frac{\left(\frac{i^2}{2} + \frac{i}{2} - 1\right)\pi b + (i-1)b}{(2i^2-2)\pi + 3(i-1)} - \frac{(i^2+i-2)\alpha e^{\rho t} W_x(t,x)}{(2i^2-2)\pi + 3(i-1)} \tag{18}$$

When $G_i(t)$ is small, we can get $\overset{*}{A}_i(t) > \overset{\wedge *}{A}_i(t)$. When $G_i(t)$ is large, we can get $\overset{*}{A}_i(t) \leq \overset{\wedge *}{A}_i(t)$. As i gets bigger, $\overset{\wedge *}{A}_i(t)$ gets smaller, and vice versa, as i gets smaller, $\overset{\wedge *}{A}_i(t)$ gets bigger.

When the fines for enterprises are small, the establishment of compensation mechanism for the pollution, habitat destruction and other human impacts can reduce the input of pollution control resources. When the fines for enterprises are large, the establishment of compensation mechanism for the pollution, habitat destruction and other human impacts can increase the input of pollution control resources. The more countries that participate in cooperative governance, the less they need to invest in pollution control.

According to the above, under the compensation model, all fines imposed on enterprises that cause ecological damage are used for pollution control. When fines are higher, more pollution control is invested. In this case, it is easier to restore the ecological environment. The more countries in the LMRB participate in cooperation to control the pollution, habitat destruction and other human impacts, the better the ecological environment will recover [52].

3.3. Numerical Analysis

In the previous sections of this paper, the author constructed models to obtain the optimal fines for enterprises that cause ecological damage and the optimal pollution control resources under the three pollution control modes of Lancang-Mekong River countries: individual pollution control, cooperative pollution control and joint pollution control under the compensation mechanism. The stereogram of the change of pollution control input amount and fines for enterprises that cause ecological damage with time in the cooperation link can be characterized by numerical analysis. This section will analyze its construction model. The basic values of relevant parameters are assumed as follows, and sensitivity analysis of parameters will be conducted in order not to lose generality.

The discount factor is 0.9. Taking Vietnam in the Lancang-Mekong River Basin as an example, this paper analyzes the relationship between pollution parameters. In 2011, 50 million tons of river sand were mined [53], and the market price per ton of river sand was RMB 200. According to the results released by the National Bank of Vietnam, the refinancing interest rate in Vietnam was 5%. The bank's interest rate is also a kind of profit from the perspective of economics. If the profit of mining sand and stone is equal to the interest rate, the profit obtained by mining sand and stone every year is 200 × 5000 × 5% = RMB 500 million. If each ton of river sand is mined to pollute 2 tons of water, the treatment cost per ton of water is RMB 2, and the damage to other ecological environment is RMB 0.5 [40]. Then, the annual sewage treatment cost is 5000 × 2 × 2.5 = RMB 250 million. According to the data obtained, the ratio of industrial production to pollution control effect is 2. The gain per unit of pollution control effect is 1. The state earns 2 per unit of industrial production.

The decay rate of the pollution, habitat destruction and other human impacts is 0.8. The long-term impact of unit industrial pollutants on the LMRB was 1.

The optimal fines for enterprises that cause ecological damage and the optimal input amount of pollution control resources under the cooperation conditions are shown in Figures 3 and 4 (refer to Definition 4 in the Appendix A for the specific solving process):

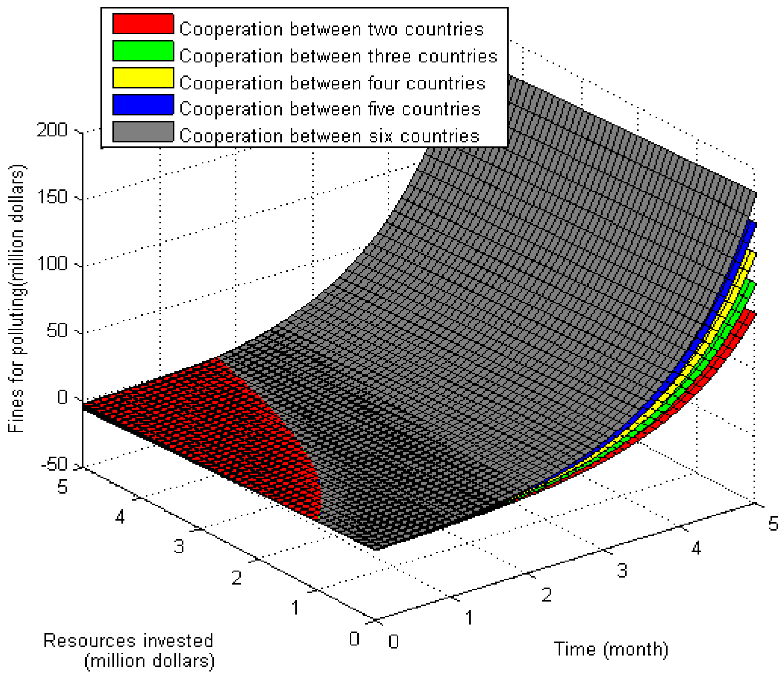

Figure 3. Optimal fines amount under cooperative condition.

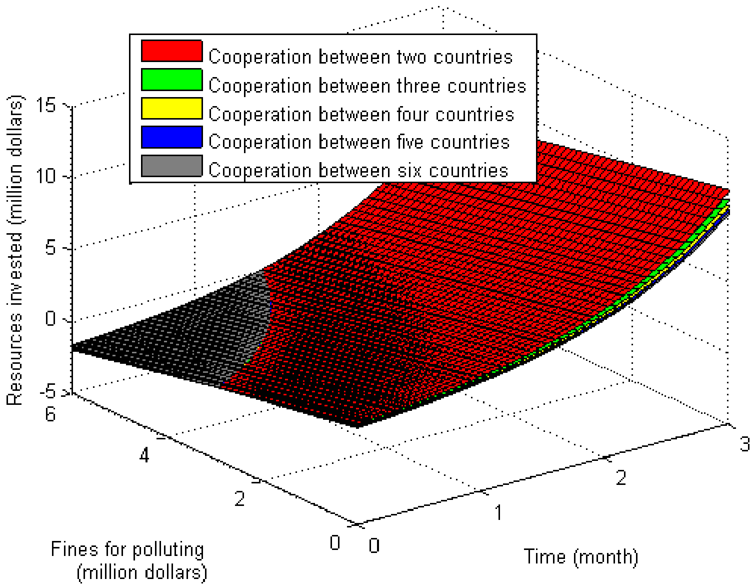

Figure 4. Optimal resource input for pollution control under cooperative condition.

The visibility of Figures 3 and 4 is not strong. In order to better show the changes of three-dimensional graphics, this paper made vertical sections of Figures 3 and 4, respectively. Figure 3 is cut along "Resource invested = 2" and "Resource invested = 4" respectively, and Figure 4 is cut along "Fines for polluting = 3" and "Fines for polluting = 6" respectively, yielding the following four figures.

Figures 3, 5 and 6 show the trend of fines imposed on polluters over time. Figures 4, 7 and 8 show the change trend of optimal pollution resource input over time. The difference between the two graphs is that the penalty imposed on polluting enterprises is taken as the dependent variable in Figures 3, 5 and 6, while the optimal input of polluting resources is taken as the dependent variable in Figures 4, 7 and 8.

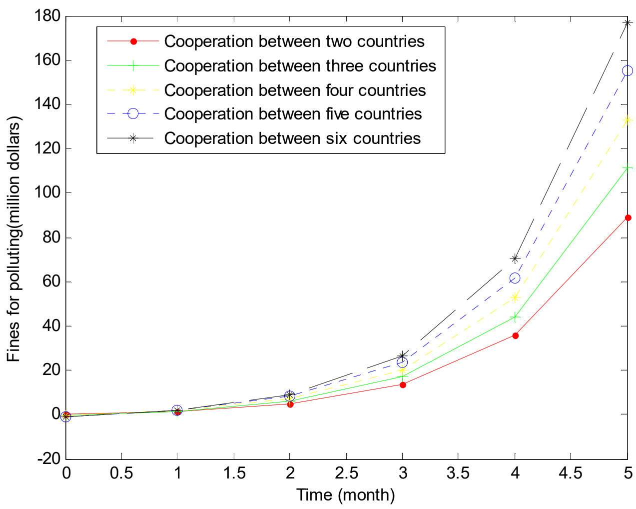

Figure 5. When the input pollution control resources are USD 2 million.

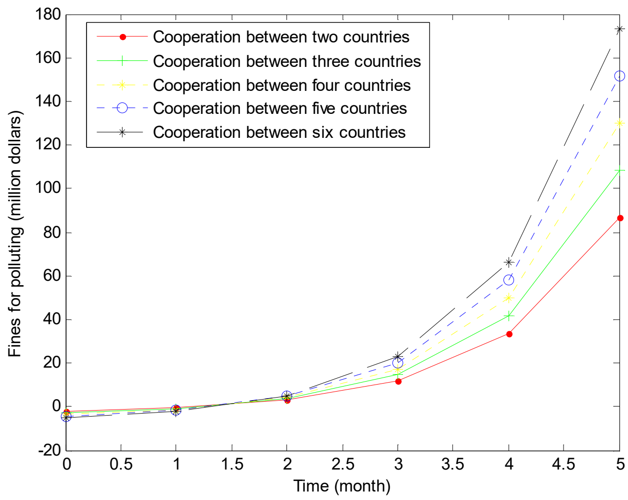

Figure 6. When the input pollution control resources are USD 4 million.

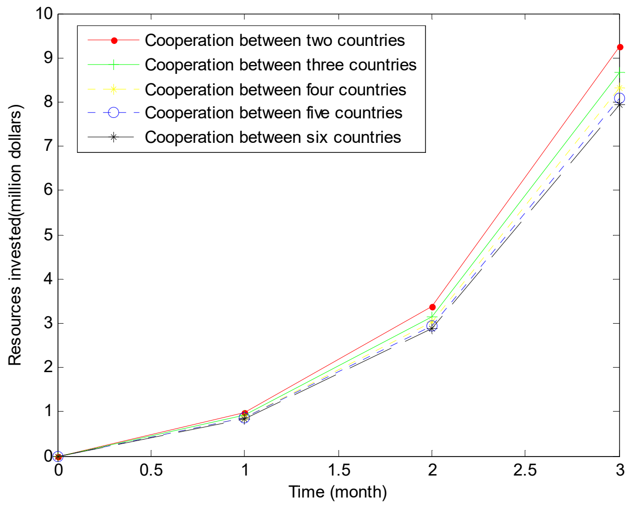

Figure 7. When the fine for polluting enterprises is USD 3 million.

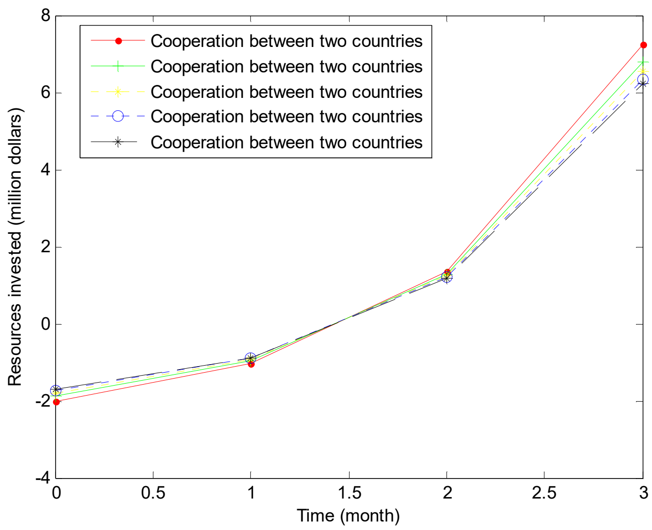

Figure 8. When the fine for polluting enterprises is USD 6 million.

The above six charts can show the relevant conclusions of cooperation in pollution control among countries in the LMRB. If more resources are invested in pollution control at the beginning of the pollution control, fewer countries will participate in the cooperation, and fewer fines will be imposed on enterprises that cause ecological damage. If the more fines are imposed on polluting companies, the more countries will cooperate and the more resources will be invested in pollution control.

Rather than imposing fines on polluters, the country's investment in pollution control resources can better help restore habitats in the LMRB. As the ecological environment of the LMRB recovers, countries will gradually reduce the disturbance to the ecosystem [54]. When transnational rivers are seriously polluted, countries should strengthen pollution control. Once the ecological environment, habitat and natural landscape of the basin have been restored, they should reduce intervention and focus on its self-regulation. At this time, if there are polluting enterprises, the punishment should be strengthened.

4. Discussion

As a freshwater resource shared by many countries, the Lancang-Mekong River can find a common divisor in line with the interests of all countries in order to achieve pollution control. Untreated sewage from upstream countries will affect urban life, industrial and agricultural irrigation water in downstream countries and even damage the ecosystem of the entire basin. No country in the LMRB can be immune from the pollution, habitat destruction and other human impacts, and strengthening cooperation on pollution control between countries has become a historical necessity [55]. As for the pollution control problem, the existing research mostly uses the traditional game methods such as static game, dynamic game and cooperative game [56], and few scholars consider the one-way externality of the transnational river water pollution control problem. In this paper, differential game is used to find the answer to this difficult problem. Differential game is a time continuous game. In addition, the restoration of ecological habitats is a long-term process. Differential game can analyze the ecological restoration and sustainable development of habitat more effectively.

If the upstream countries do more to control the pollution, habitat destruction and other human impacts in its own river basin, downstream countries will need fewer resources to control the pollution, habitat destruction and other human impacts. Strengthening economic cooperation among Lancang-Mekong countries is not only conducive to the economic growth and stability of the countries in the basin, but also to the new development of the countries in the basin in regional economic cooperation. It is also conducive to the building of the ASEAN Economic Community, narrowing the economic development gap among ASEAN countries, and facilitating the coordinated development of China, Southeast Asia and South Asia. The Lancang-Mekong Cooperation (LMC) promoted by China is a new sub-regional cooperation mechanism tailored to the common needs of the six countries and an important part of the overall cooperation between China and ASEAN [57]. Therefore, the Second Lancang-Mekong Cooperation (LMC) Leaders' Meeting held in Cambodia in January 2018 issued the Five-year Plan of Action for Lancang-Mekong Cooperation (2018–2022) [58] and the Phnom Penh Declaration of the Second Lancang-Mekong Cooperation (LMC) Leaders' Meeting [59]. Thanks to the continuous cooperation of countries in the upper and lower reaches of the LMRB to control pollution, the wildlife in the basin has become more abundant, while the water has become clearer, and the natural landscape such as grass and mountains has become more beautiful [60].

The restoration of ecological environment, habitat and natural landscape in the LMRB cannot always depend on ecological governance activities. Countries in the basin should withdraw from pollution control activities at an appropriate time. The ecological environment has a certain self-regulation ability. The ecosystem of the Lancang-Mekong River has negative feedback regulation ability, resistance stability and resilience stability. In addition, it has the ability to resist external disturbance and restore the original state. However, the countries in the LMRB should not increase the intensity of the pollution, habitat destruction and other human impacts. Once the ecological environment is damaged, it needs to consume a lot of material and financial resources to repair it. This will require continuous pollution control until the Lancang-Mekong ecosystem recovers to a certain extent. The purpose of ecological restoration is to improve, restore or rebuild the natural ecosystem, which has been degraded, damaged or destroyed, so as to enhance its self-regulation and self-repair function and maintain ecological balance [55]. For the damaged or destroyed ecosystem, because the original ecological balance has been broken, natural restoration alone is likely to be unable to reverse the damaged ecosystem, or the reversal cycle is long, and appropriate artificial restoration measures must be used. The damage of ecological environment, habitat and natural landscape can be stopped quickly and reversed by the aid of artificial restoration. Finally, it can create conditions and environment for natural restoration, accelerate restoration process and improve restoration efficiency.

Different from some papers that focus on ecosystem health assessment in the LMRB [61], this paper mainly studied how to protect and restore the ecosystem in this basin. Due to the self-regulation capacity of the LMRB, the ecological environment of the Lancang-Mekong River has always been able to restore its own balance. However, countries in the LMRB should not increase the destruction of the ecological environment and reduce the governance of the ecological environment just because the ecological environment has self-regulation ability. Countries in the basin should choose appropriate pollution control models. Every country should strike a balance between ecological protection and economic development. When the ecological environment, habitat and natural landscape of the LMRB are restored to a certain stage, countries should reduce their intervention in the basin. In addition, the Lancang-Mekong River can gradually restore its ecological environment, habitat and natural landscape to a better state by virtue of its self-recovery ability.

Different from some scholars studying how to protect the ecological environment by micro means [62], this paper provides macro theories and ideas. The “Two Mountains Theory” based on cooperation can have a significant positive impact on the sustainable development of the world’s ecological environment, habitats and natural landscapes. For example, Kenya and five east African countries fully carried out ecological protection cooperation in the construction of the Nairobia-Mombasa Railway. In this process, Kenya is sticking to both economic and environmental benefits. The project successfully protected the Mombasa mangrove forest and ensured the free passage of all types of wildlife [63]. In building coal-fired power plants, Bali uses advanced technology and cooperates fully with other countries to control the pollution, habitat destruction and other human impacts while keeping the nearby cove natural [64]. This not only promotes the economic development, but also effectively protects the ecological environment.

5. Conclusions

This article introduces this practice of “Two Mountains Theory” with an example of pollution control in the LMRB. This paper assumes that countries along the Lancang-Mekong River can deal with the pollution, habitat destruction and other human impacts by fining enterprises that cause pollution, habitat destruction, biodiversity loss and investing pollution control resources. Considering the spatial and positional relationship between the upper and lower reaches of the Lancang-Mekong River, this paper constructs a differential game model of pollution control between the upper and lower reaches of the Lancang-Mekong River under separate pollution control, joint pollution control and compensation mechanism. The research considers that the upstream and downstream countries can carry out water pollution control by imposing fines on enterprises that cause ecological damage and investing in pollution control facilities. Firstly, the differential game model of pollution control by individual countries and international cooperation is established. Then, a differential game model of joint pollution control with compensation mechanism is established under the cooperation framework. Finally, the feedback Nash equilibrium of each state is obtained. The study shows that at the beginning stage of management, if more pollution control resources are input, fewer countries will participate in cooperation. When the amount of fines for enterprises is relatively small, the establishment of ecological destruction compensation mechanism is not conducive to the input of pollution control resources. That is, after ecological governance reaches a certain stage, it is necessary to protect the ecological environment, habitat and natural landscape through the self-regulation ability of natural ecology. The coordinated development of economic development and ecological civilization construction is the core purpose of the "Two Mountains Theory". Therefore, the case of the Lancang-Mekong River fully illustrates the feasibility of the "Two Mountains Theory" based on cooperation.

The research in this paper can also be expanded. For example, this paper only assumes that the source of ecological destruction in the Lancang-Mekong River comes from industrial enterprises, without considering ecological damage caused by agriculture and other reasons. In future studies, ecological damage caused by agriculture and other reasons can be taken into account to study related issues. In addition, the research in this paper is not only applicable to pollution control issues, but also has certain reference significance for related issues such as the distribution of cross-border water resources and the anti-terrorism.

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Appendix A

Definition A1. *The strategy set* $\left\{\left[G_i^*(t), A_i^*(t)\right] = \left[\varphi_i^G(t), \varphi_i^A(t)\right], 2 \leq i \leq 6\right\}$ *provides a feedback solution to a Nash equilibrium for differential game (6). When there are functions* $V(t,x)\,:\,[0,T]\,\times R\,\rightarrow\,R$ *that can be continuously differentiated, the following partial differential equations are satisfied*:

$$\begin{aligned} -V_t(t,x) = \max_{G_i,A_i}\Bigg\{ & \left[\pi\left(\sum_{h=1}^{i} q_h^*(t) - \sum_{h=1}^{i-1} A_h(t)\right)A_i(t) + G_i(t)q_i^*(t) - \tfrac{1}{2}A_i^2(t) - x_i(t)\right]e^{-pt} \\ & +V_x(t,x)\left[\alpha\left(\sum_{h=1}^{i} q_h^*(t) - \sum_{h=1}^{i} A_h(t)\right) - \delta x_i(t)\right]\Bigg\} \end{aligned} \tag{A1}$$

Among them, $V(t,x)$ represents the return function of country i ($2 \leq i \leq 6$) in time $[t,T]$. It can be expressed as:

$$V_i = \int_t^T e^{-\rho(\tau-t)}\left(\pi\left[\sum_{h=1}^{i} q_h(\tau) - \sum_{h=1}^{i-1} A_h(\tau)\right]A_i(\tau) + G_i(\tau)q_i(\tau) - \frac{1}{2}A_i^2(\tau) - x_i(\tau)\right)d\tau \tag{A2}$$

Definition A2. *The strategy set* $\left\{\left[G_i^*(t), A_i^*(t)\right] = \left[\varphi_i^G(t), \varphi_i^A(t)\right], i = 1\right\}$ *provides a feedback solution to a Nash equilibrium for differential game (6). When there are functions* $V(t,x)\,:\,[0,T] \times R \rightarrow R$ *that can be continuously differentiated, the following partial differential equations are satisfied*:

$$\begin{aligned} -V_t(t,x) = \max_{G_1,A_1}\Big\{ & \left[\pi q_1^* A_1(t) + G_1(t)q_1^*(t) - \tfrac{1}{2}A_1^2(t) - x_1(t)\right]e^{-pt} \\ & +V_x(t,x)\left[\alpha\left(q_1^*(t) - A_1(t)\right) - \delta x_1(t)\right]\Big\} \end{aligned} \tag{A3}$$

Definition A3. *The strategy set*

$$\left\{\left[G_1^*(t),\cdots,G_i^*(t),A_1^*(t),\cdots,A_i^*(t)\right]=\left[\varphi_1^G(t,x),\cdots,\varphi_i^G(t,x),\varphi_1^A(t,x),\cdots,\varphi_i^A(t,x)\right],2\le i\le 6\right\}$$

provides a feedback solution to a Nash equilibrium for differential game (9). When there are functions $V(t,x):[0,T]\times R\to R$ *that can be continuously differentiated, the following partial differential equations are satisfied:*

$$\begin{aligned}-W_t(t,x)=\max_{G_2\cdots G_i,A_2\cdots A_i}&\Bigg\{\sum_{k=2}^{i}\Big[\Big(k\pi q_i^*(t)-(k-1)\pi A_i(t)\Big)A_i(t)+G_i(t)q_i^*(t)\\&-\tfrac{1}{2}A_i^2(t)-x_k(t)]e^{-\rho t}+\sum_{k=2}^{i}\Big[\Big(kq_i^*(t)-kA_i(t)\Big)\alpha-\delta x_k(t)\Big]W_x(t,x)\}\end{aligned}\tag{A4}$$

Among them, $W_i(t,x)$ represents the return function of country i (i = 1) in time $[t,T]$. It can be expressed as:

$$W_i=\sum_{k=2}^{i}\int_t^T e^{-\rho(\tau-t)}\left(\pi\left[\sum_{h=1}^{k}q_h(\tau)-\sum_{h=1}^{k-1}A_h(\tau)\right]A_k(\tau)+G_k(\tau)q_k(\tau)-\frac{1}{2}A_k^2(\tau)-x_k(\tau)\right)d\tau\tag{A5}$$

In this paper, partial derivatives are obtained for $G_2(t)$, $G_3(t)$, $G_4(t)$, $G_5(t)$, $G_6(t)$:

$$G_2^*(t)=\frac{b}{2}-\pi A_2(t)-\alpha e^{\rho t}W_x(t,x)$$

$$G_3^*(t)=\frac{b}{2}-\frac{5\pi}{4}A_3(t)-\frac{5}{4}\alpha e^{\rho t}W_x(t,x)$$

$$G_5^*(t)=\frac{b}{2}-\frac{7\pi}{4}A_5(t)-\frac{7}{4}\alpha e^{\rho t}W_x(t,x)$$

$$G_6^*(t)=\frac{b}{2}-2\pi A_6(t)-2\alpha e^{\rho t}W_x(t,x)$$

By mathematical induction, we can obtain:

$$G_i^*(t)=\frac{b}{2}-\frac{\sum_{k=2}^{i}k}{2(i-1)}\pi A_i(t)-\frac{\sum_{k=2}^{i}k}{2(i-1)}\alpha e^{\rho t}W_x(t,x)$$

In this paper, partial derivatives are obtained for $A_2(t)$, $A_3(t)$, $A_4(t)$, $A_5(t)$, $A_6(t)$:

$$A_2^*(t)=\frac{2\pi}{2\pi+1}\Big(b-G_2(t)\Big)-\frac{2}{2\pi+1}\alpha e^{\rho t}W_x(t,x)$$

$$A_3^*(t)=\frac{5\pi}{6\pi+2}\Big(b-G_3(t)\Big)-\frac{5}{6\pi+2}\alpha e^{\rho t}W_x(t,x)$$

$$A_4^*(t)=\frac{9\pi}{12\pi+3}\Big(b-G_4(t)\Big)-\frac{9}{12\pi+3}\alpha e^{\rho t}W_x(t,x)$$

$$A_5^*(t)=\frac{14\pi}{20\pi+4}\Big(b-G_5(t)\Big)-\frac{14}{20\pi+4}\alpha e^{\rho t}W_x(t,x)$$

$$A_6^*(t)=\frac{20\pi}{30\pi+5}\Big(b-G_6(t)\Big)-\frac{20}{30\pi+5}\alpha e^{\rho t}W_x(t,x)$$

Similarly, by mathematical induction, we can obtain:

$$A_i^*(t) = \frac{\pi \sum\limits_{k=2}^{i} k\Big(b - G_i(t)\Big) - \sum\limits_{k=2}^{i} k\alpha e^{\rho t} W_x(t,x)}{\left[\pi \sum\limits_{k=2}^{i} 2(k-1)\right] + i - 1}$$

Definition A4. *The strategy set* $\left\{ \left[\overset{\frown}{A}_1^*(t), \cdots, \overset{\frown}{A}_i^*(t)\right] = \left[\overset{\frown}{\varphi}_1^A(t,x), \cdots, \overset{\frown}{\varphi}_i^A(t,x)\right], 2 \le i \le 6 \right\}$ *provides a feedback solution to a Nash equilibrium for differential game (13). When there are functions* $V(t,x) : [0,T] \times R \to R$ *that can be continuously differentiated, the following partial differential equations are satisfied*:

$$\begin{aligned} -W_t(t,x) = \max_{A_2 \cdots A_i} \Bigg\{ \sum_{k=2}^{i} \Bigg[\pi \Bigg(\sum_{h=1}^{k} \overset{\frown}{q}_h^*(t) - \sum_{h=1}^{k-1} \overset{\frown}{A}_h(t) \Bigg) \overset{\frown}{A}_k(t) + \overset{\frown}{A}_k(t) \overset{\frown}{q}_k^*(t) - \tfrac{1}{2} \overset{\frown}{A}_k^2(t) - \overset{\frown}{x}_k(t) \Bigg] \\ \cdot e^{-pt} + W_x(t,x) \sum_{k=2}^{i} \Bigg[\alpha \Bigg(\sum_{h=1}^{k} \overset{\frown}{q}_h^*(t) - \sum_{h=1}^{k} \overset{\frown}{A}_h(t) \Bigg) - \delta \overset{\frown}{x}_k(t) \Bigg] \Bigg\} \end{aligned} \tag{A6}$$

In this paper, partial derivatives are obtained for $\overset{\frown}{A}_2(t)$, $\overset{\frown}{A}_3(t)$, $\overset{\frown}{A}_4(t)$, $\overset{\frown}{A}_5(t)$, $\overset{\frown}{A}_6(t)$:

$$\overset{\frown}{A}_2^*(t) = \frac{2\pi b + b}{6\pi + 3} - \frac{4\alpha}{6\pi + 3} e^{\rho t} W_x(t,x)$$

$$\overset{\frown}{A}_3^*(t) = \frac{5\pi b + 2b}{16\pi + 6} - \frac{10\alpha}{16\pi + 6} e^{\rho t} W_x(t,x)$$

$$\overset{\frown}{A}_4^*(t) = \frac{9\pi b + 3b}{30\pi + 9} - \frac{18\alpha}{30\pi + 9} e^{\rho t} W_x(t,x)$$

$$\overset{\frown}{A}_5^*(t) = \frac{14\pi b + 4b}{48\pi + 12} - \frac{28\alpha}{48\pi + 12} e^{\rho t} W_x(t,x)$$

$$\overset{\frown}{A}_6^*(t) = \frac{20\pi b + 5b}{70\pi + 15} - \frac{40\alpha}{70\pi + 15} e^{\rho t} W_x(t,x)$$

Similarly, by mathematical induction, we can obtain: [6]

$$\overset{\frown}{A}_i^*(t) = \frac{\left(\frac{i^2}{2} + \frac{i}{2} - 1\right)\pi b + (i-1)b}{(2i^2 - 2)\pi + 3(i-1)} - \frac{(i^2 + i - 2)\alpha e^{\rho t} W_x(t,x)}{(2i^2 - 2)\pi + 3(i-1)}$$

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