Imperfect Competition and Common Resource Exploitation: An Analysis of Renewable Resource Management with Non-use Values

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Abstract

This article analyzes the importance of non-use values in the management of natural resources under an oligopoly model. By constructing a duopolistic framework, the interaction among the effects of non-use values, market power, and common exploitation is investigated. While the problem of common exploitation often results in over-depletion without cooperation, the effects of non-use values and market power provide economic incentives for exploiters to reduce harvests. In the presence of non-use values, the extent of inefficiency caused by common exploitation in an oligopolistic market can substantially differ from what results from the model of a perfectly competitive market without non-use values. The non-cooperative equilibrium, the cooperated equilibrium, and the socially optimal equilibrium are characterized to examine the inefficiency caused by the problem of common exploitation under an oligopolistic framework with non-use values. It is found that the degree of inefficiency will depend on whether the economic incentives for conserving the resource stemming from non-use values and market power can completely offset the effect of common exploitation. The role of non-use value appears to be important, especially for the case that non-use values influence the results for different levels of competitiveness in the output market of oligopoly.

Keywords: common resource exploitation, non-use value, over-exploitation

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1. Introduction

The depletion of natural resources caused by the problem of common property has been a well-known result in economic literature. A lack of property rights to the resources leads to excess exploitation without taking into account the impacts of individual harvesting on the benefit of society as a whole. While some studies focus on the inefficiency of common resource exploitation, the conservation of natural resources motivated by non-use values remains relatively less emphasized. Without involving the exploitation of the resources, non-use values simply stem from non-consumptive motives to preserve the resources. It is argued that how the inclusion of non-use values is properly measured can become critical for judging whether the stock of the resource is over-depleted to a level under efficiency. In most previous studies, the analysis on the issue of common exploitation has not been considered in a framework of imperfect competition incorporating the non-use values. This study attempts to fill this gap by considering a duopolistic model of two exploiters with non-use values for a common resource. Unlike traditional models, this study emphasizes that not only the consumers but also the resource exploiters have non-use values. The reason why the resource exploiters also have non-use values is that conserving the common resource may be used by an oligopolistic firm as a scheme of marketing strategy in differentiating itself from others. This forms the potential inter-relationship between market power and non-use values in the interaction with the effect of common exploitation.

In the case of common exploitation, the natural resources are likely to be over-depleted, because individual exploiters behave to maximize their own benefits without considering the impacts of their actions on others' benefits. Therefore, the efficiency outcome can only be achieved by a proper definition of property rights through the cooperative scheme among exploiters. Levhari and Mirman (1980) examine the difference between private equilibrium and social equilibrium by considering the strategic aspect with a model of each exploiter taking into account the others' actions. Based on this type of framework, Fischer and Mirman (1996) further extend the analysis to incorporate the biological interaction between different species of resources to investigate the inefficiency of common exploitation. It is shown that the Nash equilibrium of non-cooperative harvesting could lead to over-exploitation or under-exploitation compared to the social equilibrium of cooperative harvesting, and the extent and direction of inefficiency are related to the type of biological interaction between different species of resources.

In the literature of common resource management, the presence of market power in the strategic aspect had not been emphasized until Reinganum and Stokey (1985), and Karp (1992). While Reinganum and Stokey stress the importance of the period of commitment made by oligopolistic exploiters in characterizing the non-cooperative equilibrium, Karp focuses on the welfare effects of the number of oligopolistic resource extractors. Datta and Mirman (1999) examines the effect of market power in a model considering both dynamic and biological externalities. With the consideration of market power, individual exploiters might be encouraged to reduce their exploitation in order to raise the price of outputs and the effects of over-exploitation caused by common exploitation could be offset. Datta and Mirman argue that the non-cooperative equilibrium can be efficient when biological externality and harvesting externality offset each other, while the inefficiency generated by market power effect is dominated by the inefficiency of common exploitation. Nonetheless, the results from these studies are mainly based on a framework excluding the non-use values and only consider the harvesting benefits in the model to examine the interplay between the market power and the problem of common exploitation. The effect of market power along with non-use values on resource management remains largely unexplored in the literature of common resource exploitation.

In the past decades, non-use values of natural resources have raised a tremendous amount of considerations since the concept was introduced by Krutilla (1967). From the conservation point of view, people might place values on the natural resources simply for their existence to avoid the possibility of species extinction. Studies such as McConnell (1983) and Loomis (1988) further incorporate the non-use values into the economic theory of individual preferences. However, the motives for people to place non-use values on natural resources still need to be justified so as to form the basis for the recognition of benefits that can be provided by the resources solely from their existence.

Among others, altruistic motives have been well studied since Madariaga and McConnell (1987). Most notable, McConnell (1997) constructs models of three types of altruism in attempting to clarify the doubts about the roles of non-use values in resource valuation. Lazo et al. (1997) characterizes the efficiency condition for the existence of an environmental good by incorporating the altruistic motives into their model. Horan and Shortle (1999) extensively investigates the optimal management of renewable resources with the inclusion of existence and humane values in an application to the case of minke whales.[1] Moreover, Alexander (2000) considers the influence of existence values on resource management in modelling species extinction.

While the inclusion of non-use values appears to play an important role in the conservation of wildlife and natural resources, the problem of over-depletion is complicated by the fact that the world's biological diversity is mostly located within a small number of countries (McNeely et al. 1990). In some areas, populations of numerous wildlife species have been severely depleted to levels near the danger of extinction. For instance, the population of African elephants has been depleted for their valuable ivories, but three southern African countries, Botswana, Namibia and Zimbabwe, hold about 46% of ivory stock in Africa (Milliken 1997).[2] In addition, only a few countries such as Azerbaijan, Iran, Kazakhstan, Russia, and

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[1] Here the humane values are based on individuals' willingness to pay to prevent the death or inhumane treatment of individual members of a valued species.

[2] The trade ban on ivory implemented in 1989 by the Convention on International Trade in Endangered Species of Wild Faun and Flora (CITES) has been a controversial subject (Babier et al, 1990, Bulte and van Kooten, 1996).

Turkmenistan have engaged in the Caspian sturgeon fishery for their roe to make high quality caviars. In the last decade after the breakdown of the former Soviet Union, the steady decline of sturgeon stocks in this area has raised concerns over the conservation and sustainability of sturgeon fishery.[3] The conservation of Northwest Atlantic seals, which are hunted by Canada and Greenland, is also another controversial subject in recent years.[4] Despite the Canadian government has implemented a management policy since 1987 for long-term sustainable seal hunting, animal right activities are still advocating the prohibition of seal hunting.[5]

In considering the exploitation of a common resource, when the output market is oligopolistic, there are two types of economic incentives to reduce harvesting – market power and non-use values. Non-use values may simply stem from the existence of the resource, especially for the case when the resource is important for the biological diversity within a specific area or when under the danger of extinction. For exploiters, use values from commercial harvesting sometimes co-exist with non-use values that are related to preserving

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3 The Caspian Sea once accounted for 95% of world caviar, though this figure has declined closer to 90%. When the decline of sturgeon stocks in this region became evident, CITES decided to regulate the international trade in sturgeons in 1997. The five Caspian states have started a coordinated programme for surveying and managing sturgeon stocks in 2002. For more details, see also about the historical background of Caspian sturgeon in CITES World, Official Newsletter of the Parties, Issue No. 8, Dec. 2001.

4 According to the Department of Fisheries and Oceans, Canada, the total catch of seals in the area was 228, 886 in 2001.

5 In 2004, the Canadian government has given fishermen permission to hunt about 350,000 seals.

options for future use, bequeathing the resource for future generations, or utilizing for aesthetic purposes through eco-tourism. Despite the fact that non-use values have become substantially significant in the valuation of natural resources, incorporating non-use values in a framework of an oligopolistic market has been overlooked in the analysis of common resource exploitation. In an oligopolistic market, since the market power may induce individual exploiters to limit harvesting in order to raise the price of output, this phenomenon interacts with the effects of common exploitation and non-use values. In the absence of cooperation, an individual exploiter will determine its optimal harvesting strategy by taking into account these factors altogether. Therefore, it is not necessarily true that non-cooperative harvesting will lead to over-exploitation with economic incentives for limiting harvesting from the market power and the non-use values of conservation.

2. Motives and limitations

One interesting point that has not been emphasized previously is that when exploiters' non-use values influence the degree of competitiveness in the oligopolistic market or vice versa, how the outcomes vary for different demand specifications. The competitiveness in the oligopolistic market may be affected by several potential reasons. First is the number of firms in the oligopolistic market, and second is the heterogeneity among oligopolistic firms. Apparently, more firms in the oligopolistic market will move the outcome more closely to the result of a perfectly competitive market. This issue has been explored in previous studies (e.g., Cornes et al., 1986; Mason et al., 1988) in a setting without non-use value. As for the second reason, the asymmetry among the firms such as the structure of a leader-follower oligopoly is also related to the outcome of non-cooperative equilibrium (e.g., Bruce, 1990).

However, if exploiters have non-use values, then market power also gives them the power to exploit their non-use values. In contrast, these values will never be seen under open access competition. Thus, the inter-relationship between market power and non-use values is of potential interest. The interaction between the competitiveness of oligopoly and non-use values may rise from the benefits of conserving the common resource for the oligopolistic firms. Given the homogeneity among the outputs produced by different firms, the competition among oligopolistic firms may take in different forms such as marketing strategies or public relationships with consumers and government regulations. Therefore, non-use value may be used by a firm as a scheme of building a good reputation or differentiating itself from others for being aware of the importance of resource conservation. Or, the resource exploiter can benefit from a proper conservation when the resource can be exploited for a direct usage as well as a non-consumptive usage of eco-tourism.

Though a more formal setup for the inter-relationship between market power and non-use values is needed to specify the marketing or signaling scheme of differentiating a firm from others for getting benefits from non-use values, this study attempts to incorporate market power and non-use value simultaneously in the interplay with the effect of common exploitation. A further study on the model formation of specifying the inter-relationship between market power and non-use values will certainly be beneficial. This issue is left for future research. Another limitation of this study is caused by the non-linearity of model setup. As many previous studies also have confronted, due to the non-linearity of dynamics of the resource exploitation, it is very difficult to find analytical results in general forms without further usages of numerical examples. In addition, the model setup with a non-linearity of differential game usually would imply the occurrence of multiple equilibria, and this further complicates the possibility of obtaining analytical results. Meanwhile, in order to keep the model as simple as possible to obtaining analytical results without losing its generality, the demand function assumed in later part of this paper is a linear form since a non-linear demand function would bring no further economic implications to the results. The slope parameter on the demand curve is indicative of the price elasticity of demand for the outputs.

The purpose of this study is to try and bridge the gap between the common resource exploitation and the non-use values placed on natural resources in a framework of oligopoly. By constructing a model of duopoly in the market for harvesting outputs, the non-cooperative Nash equilibrium can be characterized to compare with the cooperative equilibrium and the social equilibrium. At the same time, the roles of market power and non-use values in affecting the differences in these three types of solutions will also be discussed. Given the interaction among market power, the problem of common exploitation, and non-use values, the inefficiency of exploitation can be investigated. It is found that, under certain assumptions, the extent of inefficiency resulting from non-cooperative harvesting will depend on whether the effects of non-use values and market power can offset the effect of common exploitation.

This paper is organized as follows. Section 3 constructs the theoretical frameworks and derives the conditions for non-cooperative, cooperative, and socially optimal equilibria. Section 4 obtains the solutions for these different types of equilibrium by assuming particular functional forms for the model. Discussions on the impacts of market power and non-use values are offered by numerical examples in Section 5. Finally, some concluding remarks are provided in Section 6.

3. The Model

To analyze the issue raised by the impact of market power and non-use values on the exploitation of a common resource, a basic model structure needs to be constructed. We simply assume the output market has a form of duopoly in which both resource exploiters can affect the price of harvest output, but consumers are price takers. In addition, both of the duopolistic exploiters and the consumers place non-use values on conserving the resource.[6] From the exploiters' perspective in

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[6] Here, it is assumed that the oligopolistic exploiters place non-use values on the common resource simply for the resource's existence and conservation concerns instead of altruistic reasons. For instance, in order to gain reputation for being aware of protecting the environment or to ease the political pressure from environmental groups, commercial advertisements often show that the industries are developing new technologies in reducing pollution, making donations to conserve wildlife, and making efforts to protect the environment, to preserve the world's biological diversity, to maintain sustainable

this market structure, the harvesting decision has to be made to maximize the total benefits not only from the harvesting profits, but also from the non-use values of conserving the resource. Facing a downward sloping demand curve, an increase in harvesting will lead to a decline in the price of output. Thus, resource exploiters have to consider the impacts of harvesting on the growth of the resource, the price of output, as well as the non-use values.

In the duopolistic market without cooperation, individual exploiter chooses the level of harvesting in response to the other person's action in order to maximize one's own total present benefits from harvesting and conserving the resource. While the exploiters cooperate to form a monopoly, the problem involves maximizing their joint benefits from the harvesting profits and non-use values. However, the social optimal solution will differ from the non-cooperative and cooperative solutions since the exploiters have incentives to keep the output at a lower level in order to maintain a higher price in the imperfectly competitive market. As a result, the social optimal solution will require maximizing the sum of producer surplus, consumer surplus, and the total non-use values.

Three effects emerging from the duopolistic market will

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developments, and so on. The non-use values based on the size of the stock are the non-market value considered by previous studies of resource management such as Krutilla (1967), Dasgupta (1982), Loomis (1988), Kopp (1992), Bishop and Welsh (1992), Larson (1993), Freeman (1993), Bulte et al. (1998), and Metrick and Weitzman (1996). Alternatively, another non-market value related to the flow of exploitation is called the humane value based on the perspective that people receive disutility from harvesting the resource (e.g. Andersen 1993, Horan and Shortle 1999).

affect the exploiters' harvesting levels. First, the market powers will induce resource exploiters to maintain lower levels of harvesting. Second, the problem of a common resource will encourage non-cooperative exploiters to harvest more of the resource. Finally, the non-use values will provide economic incentives for exploiters to harvest less. While these three effects interact to determine the resource stock and exploiters' harvesting levels at the equilibrium, it is of interest to ask whether a non-cooperative solution will necessarily result in higher levels of exploitation than the cooperative solution? With this framework of model, it is possible to compare the differences among the non-cooperative Nash equilibrium, the cooperative equilibrium, and the social optimal equilibrium.

Before constructing the model, it is useful to make a note regarding the type of Nash equilibrium. As with many other problems encountered in the environmental and resource management, our model specification for analyzing the common exploitation with an oligopolistic output market will be under a differential game structure. Considering the players' strategic behaviors in the non-cooperative exploitation of a renewable resource, the model construction will require specifying the difference between the open-loop and closed-loop (in which each player takes as given the other's control decision as a function of the current state) equilibrium in a dynamic game. Because the open-loop Nash equilibrium is not strongly time-consistent as noted by Basar (1989), the closed-loop Nash equilibrium is usually preferred. Nevertheless, given the features of resource exploitation, it is difficult to find the closed-loop equilibrium with the non-linear resource dynamics. Given this difficulty, we use the open-loop equilibrium to compare with the cooperative and socially optimal solutions. A comprehensive analysis of closed-loop equilibrium is left for further research, and only a brief discussion on this issue is provided.

3.1 The Open-loop Nash Equilibria

We begin the model construction in an open-loop structure by considering the model with two exploiters, exploiter *1* and exploiter *2*, harvesting the common resource so as to maximize their own total discounted present benefits from the harvesting profits and the non-use value on the resource. The non-cooperative solution for individual exploiter $i = 1,2$ is to solve the following problem:

$$Max \int_0^\infty e^{-\delta t} [\pi^i (x, y_i) + U^i (x)] dt, \tag{1}$$

subject to

$$\dot{x} = G(x) - \sum_{i=1}^{2} y_i . \tag{2}$$

Here π^i is exploiter i's harvesting benefit, U^i is the non-use value, y_i is the level of harvest for exploiter i, x is the stock of the resource, $G(x)$ is the growth function for the resource, and δ is the discount rate.

Given the objective function and constraint, we can solve for the non-cooperative solution by setting up the current-value Hamiltonian for exploiter i as

$$H^i = \pi^i (x, y_i) + U^i (x) + \lambda_i [G(x) - \sum_{i=1}^{2} y_i], \tag{3}$$

where λ_i is the shadow price of the resource dynamics or the co-state variable. Hence, the first order conditions will be

$$\pi_y^i = \lambda_i , \tag{4}$$

$$\dot{\lambda}_i = \delta\lambda - \left[\pi_x^i + U_x^i + \lambda_i G_x\right], \tag{5}$$

as well as equation (2). By differentiating (4) and substituting into (5), we can obtain

$$\dot{\pi}_y^i = [\delta - G_x]\pi_y^i - \left[\pi_x^i + U_x^i\right]. \tag{6}$$

Thus, the open-loop Nash solution can be characterized as the system of differential equations (6) and (2).

Equation (6) describes that the change in the marginal profit of harvesting equals the difference between the marginal return of harvesting and the marginal return of conserving the resource. Given some particular forms of profit, non-use value, and growth functions, as well as specific parameter values, the explicit form for the system of differential equations can be found to draw the steady-state locus for the total harvesting y and the resource stock x. It is evident that the functional forms and parameter values will affect the steady-state locus for y and x and their corresponding intersection. Some examples are provided in section 3 to discuss the influences of market power and non-use values on the equilibrium with different parameter values. The market power and non-use values are expected to have opposite effects on the equilibrium level of resource stock. Whether these two opposite effects can completely offset each other, such as the result of a common exploitation with a perfectly competitive output market, will depend on their relative magnitudes.

3.2 The Cooperative Equilibria

Unlike the non-cooperative solution, if the duopolistic exploiters cooperate to form a monopoly in the output market, then the optimization problem can be described as maximizing the exploiters' joint benefits of harvesting profits and non-use values as

$$Max \int_0^{\infty} e^{-\delta t} \sum_{i=1}^{2} \left[\pi^i(x, y_i) + U^i(x)\right] dt, \tag{7}$$

subject to equation (2). Similarly, the current-value Hamiltonian for this problem can be written as

$$H^c = \sum_{i=1}^{2} \left[\pi^i(x, y_i) + U^i(x)\right] + \lambda \left[G(x) - \sum_{i=1}^{2} y_i\right]. \tag{8}$$

The first order conditions will be

$$\pi_y^i = \lambda \,, \tag{9}$$

$$\dot{\lambda} = \delta\lambda - \left\{ \sum_{i=1}^{2} \left[\pi_x^i + U_x^i\right] + \lambda G_x \right\}, \tag{10}$$

and equation (2). By differentiating (9) with respect to t and substituting the result into (10), it yields

$$\dot{\pi}_y^i = \left[\delta - G_x\right]\pi_y^i - \sum_{i=1}^{2} \left[\pi_x^i + U_x^i\right], \qquad i = 1,2. \tag{11}$$

The cooperative solution can be characterized as a system of differentiation equations (11) and (2). Compared with the open-loop solution (6), it is obvious that equation (11) consists of the marginal values of resource stock for both exploiters as shown in the second term on the right-hand side. It indicates that the cooperative solution is different from the open-loop Nash solution by taking into account both of the exploiters' marginal returns of conserving the resource.

3.3 Social Optimization

When considering the social optimization problem, one needs to maximize the sum of the total surplus of consumers and producers in the output market, and the total non-use values from conserving the common resource. We assume that the consumers have a downward-sloping demand curve such that the price of output is decreasing in the total harvest as $p = p(y)$, and $p' < 0$. Aside from two resource exploiters as the producers in the output market, we suppose that there are n consumers with the non-use value for individual consumer j as $w^j(x)$ for $j = 1,2,\ldots,n$. Thus, the social optimization problem can be written as

$$Max \int_0^\infty e^{-\delta t}\left[\int_0^y p(q)dq - \sum_{i=1}^{2} C^i(x, y_i) + \sum_{i=1}^{2} U^i(x) + \sum_{j=1}^{n} w^j(x)\right]dt, \tag{12}$$

subject to equation (2). The current-value Hamiltonian for this optimization problem will be

$$H^s = \int_0^y p(q)dq - \sum_{i=1}^{2} C^i(x, y_i) + \sum_{i=1}^{2} U^i(x) + \sum_{j=1}^{n} w^j(x) + \lambda_s\left[G(x) - \sum_{i=1}^{2} y_i\right]. \tag{13}$$

Solving this problem yields the first order conditions as

$$p - C_y^i = \lambda_s, \tag{14}$$

$$\dot{\lambda}_s = \delta\lambda_s - \left[\sum_{i=1}^{2} C_x^i + \sum_{i=1}^{2} U_x^i + \sum_{j=1}^{n} w_x^j + \lambda_s G_x\right], \tag{15}$$

as well as equation (2). Differentiating (14) with respect to t yields

$$\dot{p} - \dot{C}_y^i = \delta\left[p - C_y^i\right] - \left[\sum_{i=1}^{2} C_x^i + \sum_{i=1}^{2} U_x^i + \sum_{j=1}^{n} w_x^j + (p - C_y^i) G_x\right]. \tag{16}$$

The social optimal solution can be characterized as a system of differential equations (16) and (2). Equation (16) simply describes the dynamics of net social surplus in the form of the difference between the change in the price of output and the change in the marginal cost of harvesting on the left-hand side. This difference should be equal to the return of marginal harvesting invested in the capital market minus the return of conserving a marginal unit of resource on the right-hand side of the equation.

3.4 The Closed-loop Nash Equilibria

Since the open-loop Nash equilibrium is not strongly time consistent, the closed-loop Nash equilibrium has to be solved to obtain the solution with the property of a Markov perfect equilibrium. In order to solve for the closed-loop Nash equilibrium, we assume that the strategy of exploiter i is $y_i = h(x), i = 1,2$. Using the technique of dynamic programming, the Hamilton-Jacobi-Bellman equation for exploiter i can then be written as

$$\delta V^i(x) = Max \left\{\pi^i(x, y_i) + U^i(x) + V_x^i\left[G(x) - y_i - h(x)\right]\right\}, \tag{17}$$

where $V^i(x)$ is the value function associated with the optimal control problem, and $i = 1, 2$. Therefore,

$\pi_y^i = V_x^i$.

This leads to

$$\delta V^i(x) = \pi^i(x, y_i) + U^i(x) + \pi_y^i\left[G(x) - y_i - h(x)\right].$$

Differentiating with respect to x, we can obtain

$$\delta V_x^i = \pi_x^i + U_x^i + \pi_y^i\left[G_x - h'\right] + \pi_{yx}^i\left[G(x) - y_i - h(x)\right].$$

That is,

$$\pi_x^i + U_x^i + \pi_y^i\left[G_x - h'(x) - \delta\right] + \pi_{yx}^i\left[G(x) - y_i - h(x)\right] = 0, \quad i = 1, 2. \tag{18}$$

Note that the explicit solution for the closed-loop Nash equilibrium can be obtained and the result will be analytically tractable in the case of a linear-quadratic framework where the value function is quadratic when the objective function is quadratic and the dynamics are linear. A non-linear framework with non-linear value function becomes more difficult to solve and it is not easy to attain the analytical result. Further discussions on this issue can be seen in Tsutsui and Mino (1990), Dockner and Long (1993), and Xepapadeas et al. (2002).

4. Examples

To further characterize the equilibrium conditions, we need to know the specific forms of the profit functions, $\pi^i(x, y_i)$, the functions of non-use value, $U^i(x)$ and $w^j(x)$, and the growth function of the common resource, $G(x)$. First, we assume the inverse demand curve for exploiting output in a linear form as

$$p = a - b\sum_{i=1}^{2} y_i, \tag{19}$$

where a and b are positive constants. Regarding the market power of the exploiters in the output market, the value of parameter b can simply reflect how the changes in the quantity of output affect the price. Given $\partial p / \partial y_i = -b$, the higher the value of b is, the larger market power the resource exploiters will have.

The cost of harvesting for exploiter i is assumed as

$$C^i(x, y_i) = (k - x)cy_i, \tag{20}$$

where c and k are positive constants. With this cost function, exploiter is marginal cost of harvesting will be $\partial C^i / \partial y_i = (k - x)c$, and it is decreasing in the resource stock x. That is, the marginal cost of harvesting will increase as the resource stock decreases. At the same time, the marginal stock effect will be $\partial C^i / \partial x = -cy_i \leq 0$, and the total cost of harvesting increases as the resource stock decreases.

After assuming the explicit forms of inverse demand function and the cost functions, the harvesting benefits for exploiter i will be

$$\pi^i(x, y_i) = py_i - C^i(x, y_i) = [a - b(y_1 + y_2)]y_i - (k - x)cy_i, \quad i = 1,2. \tag{21}$$

Aside from the harvesting benefits, the resource exploiters also place non-use values on the common resource, and the growth function need to be specified to obtain the explicit solution. Here, the functions of non-use value are assumed to take log-linear forms and the common resource has a logistic growth function as

$$U^{i}(x)=\alpha_{i}\ln x, \quad i=1,2, \tag{22}$$

$$w^{j}(x)=\varepsilon_{j}\ln x, \quad j=1,2,\ldots.,n, \tag{23}$$

$$G(x)=rx\left(1-\frac{x}{K}\right)=\beta x-\gamma x^{2}. \tag{24}$$

Parameters α_i and ε_j reflect the exploiter *i*'s, and the consumer *j*'s concern about the resource conservation, $\beta = r, \gamma = r/K$, r is the resource's intrinsic growth rate, and K is the environmental carrying capacity. The marginal non-use value for an individual exploiter and consumer will be $U_x^i = \alpha_i / x$ and $w_x^j = \varepsilon_j / x$, respectively, and they are decreasing in the resource stock x. Having the specific forms of harvesting benefit and non-use value functions, it is possible to explicitly obtain the equilibrium conditions for different optimization problems described in the previous section.

4.1 Open-loop Nash Equilibria

Given the assumptions made previously, we can solve for the equilibrium conditions in terms of the economic and biological parameters. This allows us to further examine how the market power of exploiters and the non-use values of the common resource affect the equilibrium levels of exploitation and resource stock at the steady state. According to equations (6) and (2), we can obtain the open-loop Nash equilibrium conditions as

$$-2b\dot{y}_1 - b\dot{y}_2 + c\dot{x} = [\delta - G_x][a - 2by_1 - by_2 - (k - x)c] - \left[cy_1 + \frac{\alpha_1}{x}\right],$$

$$-2b\dot{y}_2 - b\dot{y}_1 + c\dot{x} = [\delta - G_x][a - 2by_2 - by_1 - (k - x)c] - \left[cy_2 + \frac{\alpha_2}{x}\right],$$

$$\dot{x} = G(x) - y_1 - y_2.$$

Denote $y_1 + y_2 = y$, $\dot{y}_1 + \dot{y}_2 = \dot{y}$, and sum up the first two differential equations of the system. The open-loop Nash equilibrium is then given by a set of differential equations as

$$\dot{y} = \frac{-1}{3b}\left\{\begin{array}{l}[\delta - \beta + 2\gamma x][2a - 3by - 2(k - x)c] - \left[cy + \dfrac{\alpha_1 + \alpha_2}{x}\right] \\ -2c\left[\beta x - \gamma x^2 - y\right]\end{array}\right\}, \quad (25)$$

$$\dot{x} = \beta x - \gamma x^2 - y. \quad (26)$$

The system of differential equations (25) and (26) contains economic parameters a, b, c, α_i , ε_j , and δ , as well as biological parameters k, β , and γ . In particular, we will focus on the market power parameter b, and the non-use value parameters α_i and ε_j to examine their impacts on the equilibrium level of harvesting y and resource stock x. Before examining the effects of market power and non-use value, it is important to make some remarks on the analysis of the equilibrium. Given the non-linear features of the differential equation system characterizing the equilibrium, the number of steady states depends on the assumptions made on the functional forms of $U^i(x)$, $w^j(x)$, $G(x)$, and $G^i(x)$. Consequently, the properties of the equilibrium for our model would vary with the parameters assumed in these functional forms.

As shown in Brock and Starrett (2003) who analyze the ecology of a lake, the non-convexities in an ecological or environmental management problem could result in multiple steady states with possibly complex eigenvalues, while some steady states are locally stable and others are locally unstable. Here, in our model, $U^i(x)$, $w^j(x)$, and $G(x)$ are assumed to be concave in the state variable *x*, $\partial^2 C^i / \partial y_i^2 = 0$, and $\partial^2 C^i / \partial x^2 = 0$. However, in the objective function incorporating harvesting benefits and non-use values, the harvesting *y*, as a flow, generates positive benefits, but the decease in resource stock *x* caused by harvesting *y* leads to negative benefits. As shown in Kurz (1968), when the objective function incorporates the state and the control variables, the optimality conditions can have multiple stationary points. A more general discussion on non-convexities related to environmental and resource managements can also be found in Dasgupta and Mäler (2003).

Given the features of our model, we simply assume some particular values of parameters to examine the effects of market power and non-use values on the equilibrium. If a =1000, b = 0.75, c = 0.001, $k = 3\times10^5$, $\alpha_1 = 10$, $\alpha_2 = 10$, $\beta = 0.03$, $\gamma = 10^{-8}$, and $\delta = 0.03$, then with Mathematica (Wolfram 2003), the phase diagram in the (*x, y*)-plane can be drawn in Figure 1.A. The dashed line curve, including one vertical asymptote, represents the steady states for *y*, and the solid curve represents the steady states for *x*. There are three positive intersections at (*x* = 284.96, *y* = 8.54067), (*x* = 20712.2, *y* = 578.465), and (*x* = 268173, *y* = 853.524). It is obvious that the assumed values of parameters will affect the locus of steady state for y and x as well as their intersection. Given the definitions of these parameters in our model, it is expected that the smaller value of market power b and the higher non-use values α_1 and α_2 will lead to higher equilibrium levels of harvesting y and resource stock x at the steady state.

In an imperfectly competitive market, when the duopolistic exploiters face a steeper downward-sloping demand curve with a higher value of parameter b, they will have a higher incentive to maintain a lower level of harvesting to raise the price of output. Similarly, when the exploiters have higher non-use values on conserving the resource with higher values of parameters α_1 and α_2, they will tend to keep a higher stock of the resource. These two effects encouraging exploiters to conserve will interact with the effect of over-harvesting caused by common exploitation. Unlike previous findings neglecting the non-use values, how the open-loop Nash equilibrium differs from the cooperative and socially optimal solutions will be emphasized in this study. We will discuss this issue in the later part of the paper.

The values of biological parameters k, β, and γ are assumed to be consistent with the features of renewable resources such as fishery, dolphins, seals, whales, and other marine mammals. Of course, the issue of common resource is also widely discussed in areas related to the management of oil pools, wetlands, hunting grounds, shallow lakes, ponds, and transboundary stock pollution, etc. The choices of parameter values will be substantially different from case to case, but a similar approach is still applicable.

4.2 Cooperative Equilibria

According to equations (11) and (2), the cooperative equilibrium conditions can be obtained by substituting the specific forms of the inverse demand function, the cost function, and the non-use value function as assumed earlier. This yields a system of differential equations as

$$\dot{y} = \frac{-1}{3b}\left\{ \begin{array}{l} [\delta - \beta + 2\gamma x][2a - 3by - 2(k - x)c] - 2\left[cy + \dfrac{(\alpha_1 + \alpha_2)}{x}\right] \\ -2c\left[\beta x - \gamma x^2 - y\right] \end{array} \right\}, \tag{27}$$

as well as equation (26).

Using the same parameter values, the phase diagram in the (x, y) plane is drawn in Figure 2. There are also three positive intersections at (x = 431.897, y = 12.9383), (x = 18200.4, y = 512.888), and (x = 268456, y = 846.828). Compared with the open-loop Nash equilibria in Figure 1, the steady-state curve for the harvesting level y of cooperative equilibria is substantially different. The cooperative equilibria has a monotonically positive-slope curve for the steady-state harvesting level y, but there is a vertical line at x = 284.96 for the open-loop Nash equilibria. Since the steady-state curves for the cooperative equilibria have different paths from the open-loop Nash equilibria, it cannot be concluded that the cooperative equilibria have higher steady- state levels of harvesting y and resource stock x.

4.3 Social Equilibria

According to equations (16) and (2), the system of differential equations characterizing the social equilibrium become

$$\dot{y} = \frac{-1}{b}\left\{\begin{array}{l} c(\beta x - \gamma x^2 - y) + \delta\left[a - by - (k - x)c\right] - \\ \left[-cy + \dfrac{\alpha_1 + \alpha_2}{x} + \dfrac{\sum_{j=1}^{n}\varepsilon_j}{x} + \left[a - by - (k - x)c\right](\beta - 2\gamma x)\right] \end{array}\right\}, \tag{28}$$

along with equation (26).

The phase diagram in the (x, y) plane, with the same parameter values as those used at the open-loop equilibrium and the number of consumers is assumed to be n = 20, is drawn in Figure 3. There are also three positive intersections at (x = 1283.5, y = 38.3402), (x = 54219.4, y = 1332.61), and (x = 245745, y = 1333.3). The shape of the steady-state curve for harvesting level y is similar to that of the open-loop Nash equilibria, but the vertical asymptote occurs with a higher resource stock at x = 1283.5 for the social equilibria.

4.4 Closed-loop Nash Equilibria

As mentioned in the previous section, the difficulty of obtaining the closed-loop equilibrium is due to the problem of not knowing what the value function will look like. If the value function is linear quadratic, then the solution will be analytically tractable. On the other hand, if the value function is non-linear, then the problem become much more complicated. Even though some technique has been provided in recent studies such as Pakes and McGuire (1994, 2001), and

Xepapadeas et al. (2002), we leave this issue of non-linearity for further research. Here, we simply assume a linear strategy, such that the value function is linear quadratic, so as to discuss the result and make the comparison with other types of equilibrium.

If the steady-state levels of resource x are known as x_{cl}, then according to the resource dynamics equation, $y_1 + y_2 = y = 2h(x)$, and it follows that

$$h(x_{cl}) = \frac{1}{2}G(x_{cl}) = \frac{1}{2}\left[\beta x_{cl} - \gamma x_{cl}^2\right], \qquad (29)$$
$$h'(x_{cl}) = \frac{1}{2}\beta - \gamma x_{cl}.$$

With this strategy function, we can obtain

$$cy_i + \frac{\alpha_i}{x} + \left[a - by_i - b(y_1 + y_2) - (k - x)c\right]\left[\frac{1}{2}\beta - \delta - \gamma x\right]$$
$$+ c\left[\frac{1}{2}\beta x - \gamma x^2 - y_i\right] = 0, \qquad i = 1,2 \qquad (30)$$

As a result, the closed-loop Nash equilibrium is given by

$$cy + \frac{\alpha_1 + \alpha_2}{x} + \left[\frac{1}{2}\beta - \delta - \gamma x\right]\left[2a - 3by - 2(k - x)c\right] + c\left[\beta x - 2\gamma x^2 - y\right] = 0, \qquad (31)$$

as well as equation (26).

The phase diagram in the (x, y) plane, with parameter values as those at the open-loop equilibrium, is drawn in Figure 4. There are also three positive intersections at (x = 0.952419, y = 0.0285725), (x = 22621.4, y = 627.47), and (x = 265181, y = 923.331). Note that the solution will depend on the chosen steady-state x_{cl} for solving the system of differential equations.

Therefore, when the steady state x_{cl} is equal to the steady- state under the social optimal equilibrium, the closed-loop equilibrium will have the same level of resource stock as the social optimum. However, it is not necessarily that the paths to the steady state are the same.

5. Market Power and Non-use Value

In an oligopolistic market, the producers with market powers have economic incentives to reduce their outputs to the level below the efficient quantity that would be produced under a perfectly competitive market. Nevertheless, in our model of common exploitation, exploiters tend to over-exploit the resource without a proper definition of property rights and this will act in opposite to the effect caused by the market powers. With market powers, non-cooperative exploiters have to consider the negative effect of their harvesting on the price of output while having the incentives to over-exploit the common resource. That is, the over-exploitation caused by the problem of a common resource can be partially offset by the incentive to under-exploit induced by the market power in the output market.

When the exploiters have non-use values for conserving the resource, and this leads to a situation where the non-cooperative exploiters have to simultaneously consider the effects of market power, common exploitation, as well as the non-use values. It is expected that when higher non-use values are placed on the resource and the exploiters have stronger market powers, the inefficiency of common exploitation will be less severe. Thus, it is of interest to examine how the market power and the non-use values influence different types of solutions attained in previous sections. A comparison with the cooperative solution as well as the efficient solution can be made by using different parameter values of b, α_1, α_2, and ε_j in our model.

As shown in Figure 5, when the value of market power parameter b changes from 0.75 to 0.5, and then to 0.25 as the market power becomes smaller, the steady- state curve of harvesting level y for the open-loop equilibria will move further to the right. In contrast, Figure 6 shows that when the parameters of non-use values α_1, and α_2 increase from 10, to 50, and then to 100, the steady-state curve of y will move upward to the right as the exploiters place higher non-use values on conserving the resource. These similar results can also be seen in Figure 7 and Figure 8 for the case of cooperative equilibria as well as in Figure 9 and Figure 10 for the case of social equilibria.

Comparing Figure 5 with Figure 6, it appears that a slight decrease of the market power parameter will lead to a relatively large scale of moving outward for the steady-state curve of y. On the other hand, a large increase in the non-use value tends to move the steady-state curve of y outward only slightly. In Figure 5, the dashed line represents the steady-state curve of y for the parameter value of market power b = 0.75, the solid line is drawn with b = 0.5, and the bold solid line results from b = 0.25. Corresponding to different values of b, the open-loop Nash equilibrium levels of resource stock x and harvesting y are represented in Table 1. Similarly, the equilibrium levels of x and y at the steady state for the cooperative solution are shown in Table 2.

Comparing the second and fourth columns in Table 1 and Table 2, it can be found that the cooperative solution results in higher equilibrium levels of resource stock x and harvesting y. However, for the second highest resource stock x among the three equilibria as shown in the third columns in Table 1 and Table 2, the cooperative solution does not results in higher levels of x and y than the open-loop Nash solution. Apparently, this is caused by the fact that the steady-state curve of y takes different paths for the open-loop Nash equilibrium and the cooperative equilibrium. Therefore, it is possible that the open-loop Nash equilibrium results in higher levels of x and y at the steady state than the cooperative equilibrium. It is also noteworthy that the differential equation system characterizing the solution will result in multiple stationary points. As pointed out by Brock and Starrett (2003), for a certain range of values of economic and biological parameters, the solution will have three stationary points. Two of the stationary ones are stable saddle points and the intermediate point is an unstable spiral source. However, in general the outcome is quite parameter dependent, and in this study we only focus on cases with the different chosen values for parameters b, α_1, α_2, and ε_j, representing the market power and the non-use values.

Table 3 shows the effects of market power and non-use values on the social equilibria. As the parameter value of market power decreases to b = 0.25, there will be only one positive equilibrium located at (x = 1270.96, y = 37.9672). However, among the three equilibria, when the equilibrium level of resource stock x is the lowest as in the second column, changes in the value of b appear to have just a slight effect on the equilibrium. As b decreases from 0.72 to 0.5 and 0.25, equilibrium x declines from 1283.5 to 1277.15 and 1270.96, respectively. On the other hand, increasing the parameter values of non-use values from α_1, α_2, and ε_j will have larger impacts when the equilibrium levels of x and y are the lowest among the three equilibria. Compared to the second column in Table 2, the social equilibrium also has higher steady-state levels of x and y.

6. Concluding Remarks

When the output market for the exploitation of a common resource is imperfectly competitive, the inefficiency of common exploitation may be partially offset by the economic incentive to reduce harvests induced by market power. However, the non-use values stemming from non-consumptive reasons to conserve the resource have not particularly been emphasized in this area of research. While neglecting the effect of non-use values on the equilibrium levels of the resource stock, only market power will induce exploiters to reduce harvests in order to mitigate the inefficiency of common exploitation. This paper analyzes the importance of non-use values in the management of a common resource with a model of oligopoly.

By constructing a framework of duopolistic exploitation, the incorporation of non-use values appears to be significant for determining the degree of inefficiency of common exploitation. In our model setting, economic incentives to reduce harvests arise not only from market power, but also from non-use values that will interact with the over-harvesting tendency of common exploitation. In particular, when the exploiters have a greater degree of market power in the output market along with higher non-use values of the resource, the inefficiency of common exploitation can be largely reduced. Thus, the degree of inefficiency from common exploitation will critically depend on the relative magnitudes of the effects from non-use values, market power, and common exploitation. In this study, non-cooperative, cooperative, and socially optimal equilibria are characterized. In addition, the impacts of non-use values, and market power on the levels of equilibrium resource stock and harvesting are analyzed for different types of solutions through some examples with specific assumptions on the functional forms.

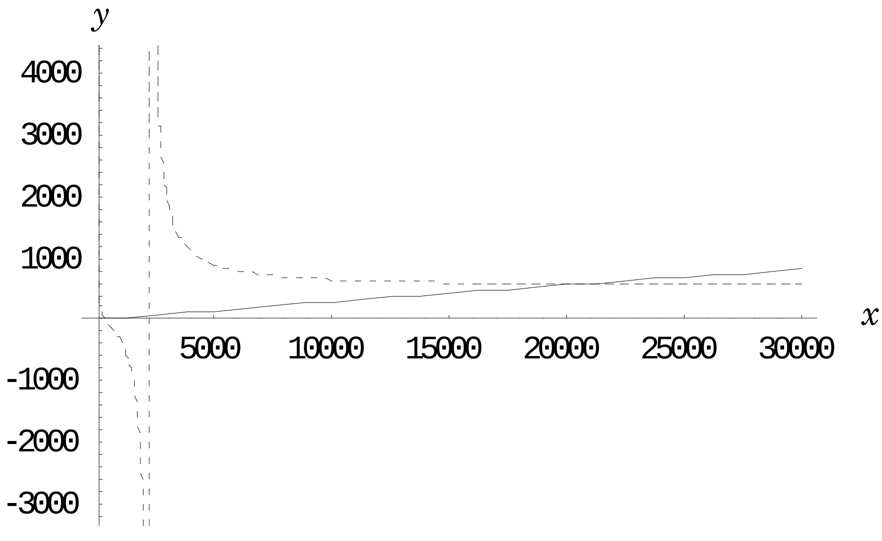

Figure 1: Phase diagram, Open-loop Nash equilibrium

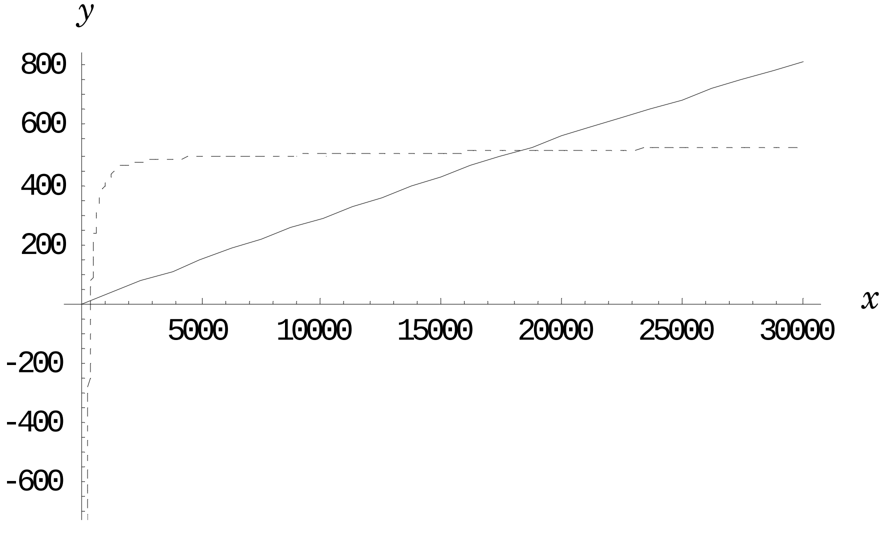

Figure 2: Phase diagram, cooperative equilibrium

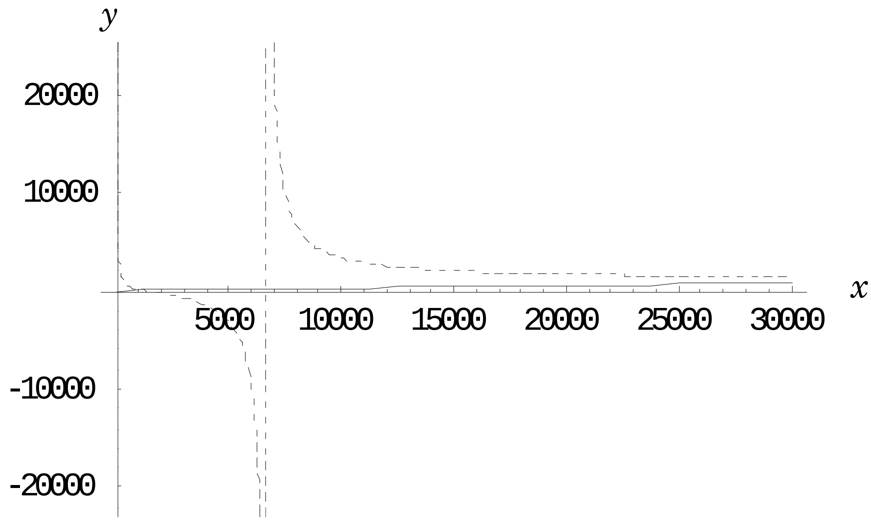

Figure 3: Phase diagram, social equilibrium

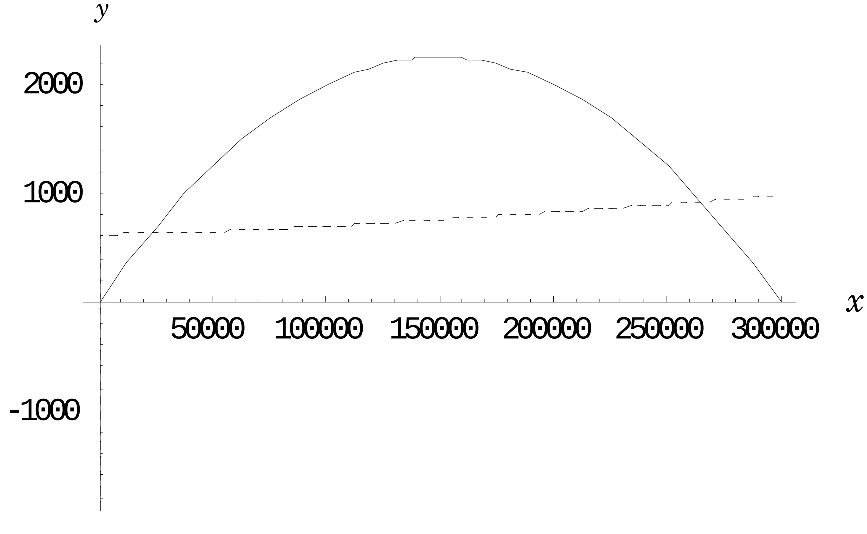

Figure 4: Phase diagram, close-loop equilibrium

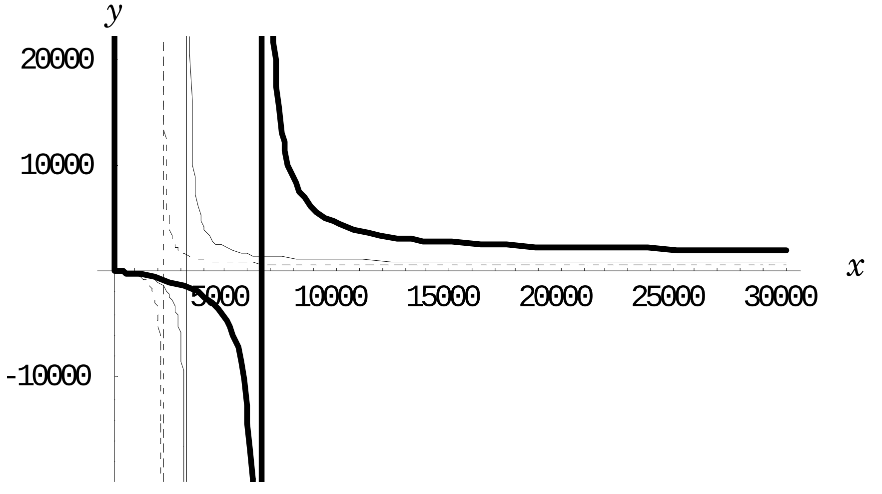

Figure 5: Open-loop Nash Equilibria (b = 0.75, 0.5, and 0.25)

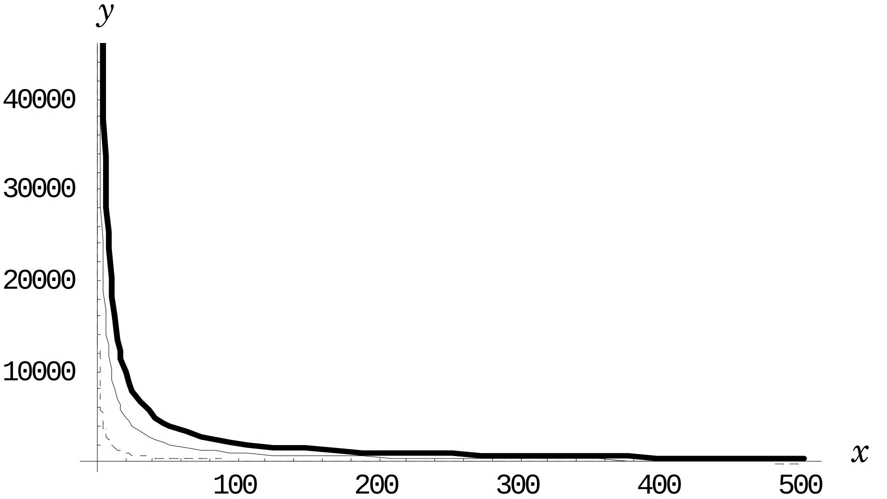

Figure 6: Open-loop Nash Equilibria (α_1, α_2 = 10, 50, and 100)

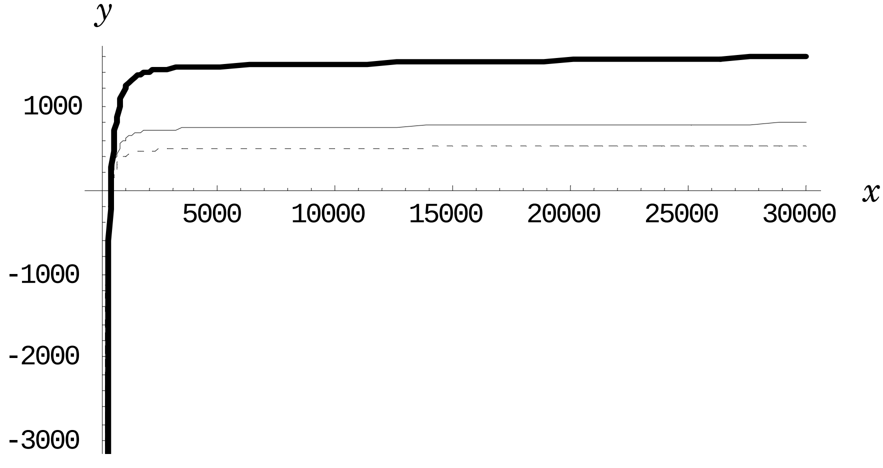

Figure 7: Cooperative Equilibria (b = 0.75, 0.5, and 0.25)

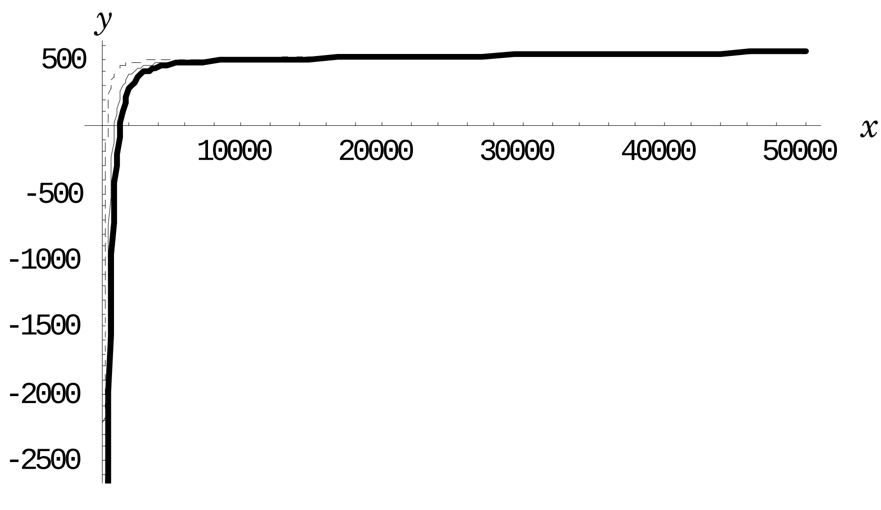

Figure 8: Cooperative Equilibria (α_1, α_2 = 10, 50, and 100)

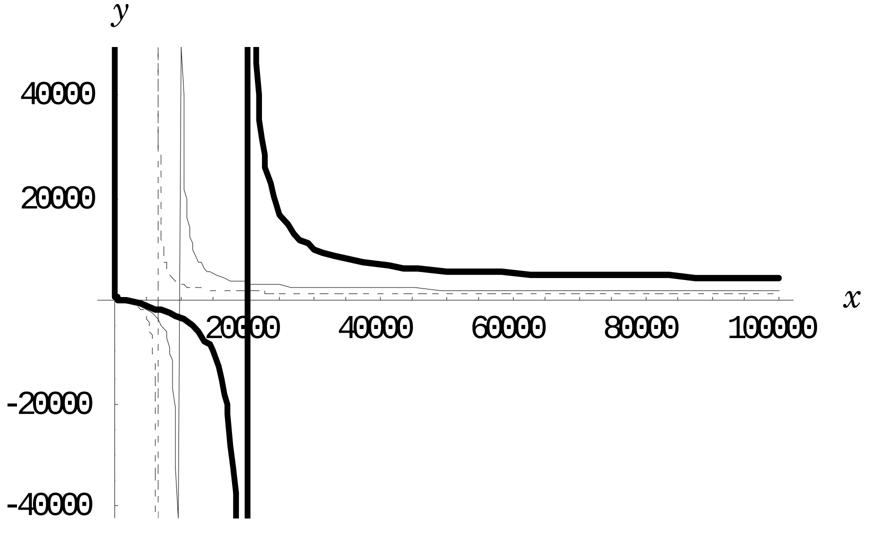

Figure 9: Social Equilibria (b = 0.75, 0.5, and 0.25)

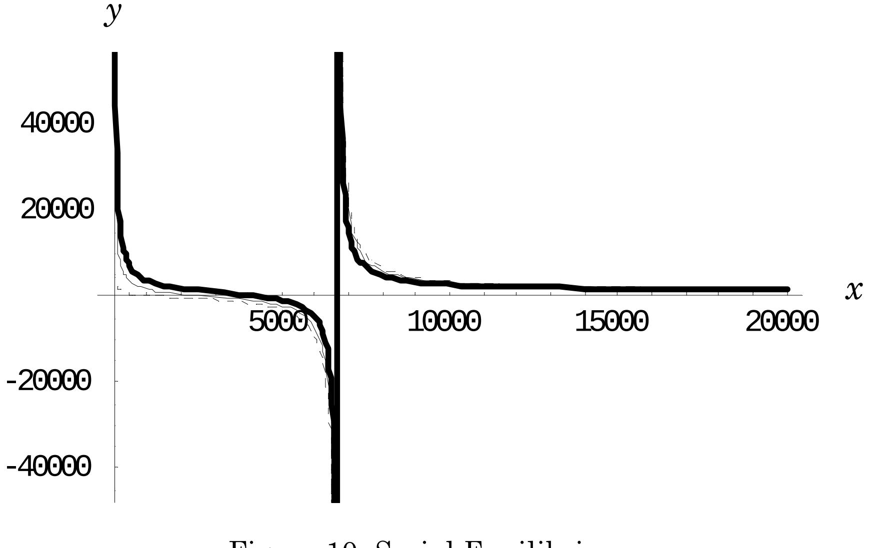

Figure 10: Social Equilibria

$(\alpha_1, \alpha_2, \varepsilon_j) = (10,10,15), (50,50,75), (100,100,150)$

Table 1. Effects of market power and non-use value on the open-loop equilibria

Parameter Value	Equilibrium levels of resource stock x and harvesting y, (x, y)		
$\alpha_1 = \alpha_2 = 10$ b=0.75	(284.96, 8.54067)	(20712.2, 578.465)	(268173, 853.524)
$\alpha_1 = \alpha_2 = 10$ b=0.5	(284.218, 8.51846)	(33330.6,888.824)	(250000, 1250)
$\alpha_1 = \alpha_2 = 10$ b=0.25	(283.486, 8.49653)	(99998, 1999.98)	(166667, 2222.22)
$\alpha_1 = \alpha_2 = 10$ b=0.75	(284.96, 8.54067)	(20712.2, 578.465)	(268173, 853.524)
$\alpha_1 = \alpha_2 = 50$ b=0.75	(643.282, 19.2571)	(20695.4, 578.032)	(268173, 853.522)
$\alpha_1 = \alpha_2 = 100$ b=0.75	(916.46, 27.4098)	(20674.3, 577.487)	(268173, 853.519)

Table 2. Effects of market power and non-use value on the cooperative equilibria

Parameter Value	Equilibrium levels of resource stock x and harvesting y, (x, y)		
$\alpha_1 = \alpha_2 = 10$ b=0.75	(431.879, 12.9383)	(18200.4, 512.888)	(268456, 846.828)
$\alpha_1 = \alpha_2 = 10$ b=0.5	(429.939, 12.8797)	(28238, 791.653)	(250755, 1234.84)
$\alpha_1 = \alpha_2 = 10$ b=0.25	(428.026, 12.8225)	(82737.7, 1797.58)	(177259, 2175.69)
$\alpha_1 = \alpha_2 = 10$ b=0.75	(431.879, 12.9383)	(18200.4, 512.888)	(268456, 846.828)
$\alpha_1 = \alpha_2 = 50$ b=0.75	(982.258, 29.3653)	(18157.3, 511.751)	(268456, 846.824)
$\alpha_1 = \alpha_2 = 100$ b=0.75	(1407.43, 42.0247)	(18102.8, 510.314)	(268456, 846.818)

Table 3. Effects of market power and non-use value on the social equilibria

Parameter Value	Equilibrium levels of resource stock x and harvesting y, (x, y)		
$\alpha_1 = \alpha_2 = 10, \varepsilon = 15$ b=0.75	(1283.5, 38.3402)	(54219.4, 1332.61)	(245745, 1333.3)
$\alpha_1 = \alpha_2 = 10, \varepsilon = 15$ b=0.5	(1277.15, 38.1514)	(99968, 1999.68)	(200008, 1999.92)
$\alpha_1 = \alpha_2 = 10, \varepsilon = 15$ b=0.25	(1270.96, 37.9672)	-	-
$\alpha_1 = \alpha_2 = 10, \varepsilon = 15$ b=0.75	(1283.5, 38.3402)	(54219.4, 1332.61)	(245745, 1333.3)
$\alpha_1 = \alpha_2 = 50,$ $\varepsilon = 75$ b=0.75	(2925.37, 86.9053)	(54066.9, 1329.68)	(245752, 1333.16)
$\alpha_1 = \alpha_2 = 100,$ $\varepsilon = 100$ b=0.75	(4200.5, 124.251)	(53874.2, 1325.98)	(245761, 1332.98)

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不完全競爭與共有資源的開發：一個具有非使用價值的再生性資源管理的分析

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摘　要

本文分析在一個寡占市場下，非使用價值對於自然資源的開發管理之重要性。藉由建立一個雙占模型的分析架構，非使用價值、市場力量與共有資源間的相互關聯性在本文中被詳細探討。當共有資源的開發在資源開發者彼此間不合作的情形下，常引發過度開發的問題時，非使用價值與市場力量的存在卻具有減少開發的經濟誘因。因此，當非使用價值存在，寡占市場的共有資源開發之不效率程度將與在完全競爭市場下、不具有非使用價值的情況有所差異。共有資源開發的不效率程度，在本文中以寡占市場與具有非使用價值的架構下，對於不合作均衡、合作均衡與社會最適均衡等三種結果進行比較分析可以得知。本文的結果發現，不效率的程度，會因非使用價值與市場力量所引起的減少資源開發的經濟誘因，是否能夠完全抵銷共有資源過度開發的效果而有所不同。其中，非使用價值所扮演的角色是重要的，特別是當非使用價值的多寡會影響到寡占市場中不同廠商間的競爭程度。

關鍵詞：共有資源開發、非使用價值、過度開發
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