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Institute for Economic Studies, Keio University
2-15-45 Mita, Minato-ku, Tokyo 108-8345, Japan
ies-office@adst.keio.ac.jp
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Zijin Xie
Graduate School of Economics, Keio University
2-15-45, Minato-ku, Tokyo, Japan
xiezijinyuki@gmail.com

Ayumi Onuma
Faculty of Economics, Keio University
2-15-45, Mita, Minato-ku, Tokyo, Japan
onuma@econ.keio.ac.jp

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Xie Zijin[a] and Ayumi Onuma*[b]

[a] *Graduate School of Economics, Keio University*

[b] *Faculty of Economics, Keio University*

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Integrated conservation development projects (ICDPs) are considered important for enhancing biodiversity conservation and local development in developing countries. These projects usually share benefits with local communities and incorporate locals in biodiversity management. While some studies shed light on the effectiveness of ICDPs in biodiversity conservation, most of them do not consider the employment of locals in biodiversity management. Moreover, existing literature assumes that national parks are for-profit organizations whereas they are generally nonprofit entities. We develop a bioeconomic model to investigate the effect of introducing ICDPs in nonprofit as well as for-profit national parks with the employment of local labor in tourism on biodiversity conservation. We demonstrate that there are conditions for the ICDP to be successful in enhancing biodiversity. Under these conditions, if biodiversity improves or has no impact on agricultural productivity, the nonprofit national parks invariably bring higher utility to locals and improve biodiversity than for-profit national parks. Otherwise, nonprofit national parks do not necessarily bring higher utility to locals or improve biodiversity, as compared to for-profit national parks. Moreover, the ICDP is evaluated in terms of social welfare, and we show that a subsidy/taxation on wage rates will bring the market equilibrium to a social optimum.

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*Corresponding author. Faculty of Economics, Keio University, 2-15-45, Mita, Minato-ku, Tokyo 108-8345, Japan. E-mail: onuma@econ.keio.ac.jp

1 Introduction

Integrated conservation development projects (ICDPs) are considered important in sustainable national park management and biodiversity conservation. In contrast to traditional national park management, which eliminates locals' interests and participation, ICDPs aim to realize biodiversity conservation and social development by sharing benefits with local communities and incorporating locals in the operations of national parks (Wells et al., 1992).

ICDPs, originally proposed by the World Wide Fund for Nature (WWF) in 1985, are widely promoted in developing countries (Hughes and Flintan, 2001). ICDPs usually transfer revenue from tourism or trophy hunting to the locals and create job opportunities for them (Johannesen, 2006). For example, since 2003, the Wildlife Conservation Society (WCS), Cambodia Office, has been rewarding locals for protecting birds (Svadlenak-Gomez et al., 2007). Meanwhile, the CAMPFIRE program in Zimbabwe shared revenue earned mainly from trophy hunting with the locals during 1989–2001, which amounted to over US$20 million (Frost and Bond, 2008), while also creating 701 jobs for them (USAID, 2009). This benefit-sharing policy is also applied for habitat protection. The Tarangire Elephant Project in Tanzania, which was launched to protect the habitat of elephants, uses revenue from photo-tourism and game hunting to compensate local communities for not turning grassland into agricultural land (Svadlenak-Gomez et al., 2007).

However, the effectiveness of ICDPs is debated in the existing literature. On one hand, Measham and Lumbasi (2013) demonstrate two successful cases of ICDPs and conclude that projects that allow locals to have higher ownership are more likely to succeed. On the other hand, several studies anticipate the failure of ICDPs. For example, Svadlenak-Gomez et al. (2007) introduce a "payments for conservation" scheme in Savannakhet Province of Laos. In this program, the WCS offers financial support for the development of local villages; in return, locals are asked to report deer sightings and get involved in deer protection. However, there is concern that once the payment decreases, locals will stop cooperating with WCS and stop reporting poaching incidents (Svadlenak-Gomez et al., 2007). Similar observations have been noted in other studies where the authors conclude that there is hardly any connection between conservation and local development needs because the locals would treat the money from the projects as new sources of income instead of a reason to conserve wildlife (Barrett and Arcese, 1995; Bookbinder et al., 1998; Wells et al., 1992).

ICDPs are examined in the context of resource economics as well: As far as we know, Barrett and Arcese (1998) are the first attempt to analyze this issue. Their study simulates the dynamics of the wildebeest population of the Serengeti ecosystem and the production behavior of local households under an ICDP, where managers of the protected areas share hunted game meat with local households. The results of the simulation show that the wildebeest population decreases in a short period under this ICDP; thus, the scheme might be unsustainable. Moreover, Skonhoft (1998) introduces a national park with tourism and hunting licenses as well as conflicts between the livestock of locals and wildlife. Although he does not explicitly use the term ICDP, this study shows that when the national park shares profit from the tourism with local people, the wildlife stock decreases in the long run. In addition, Johannesen and Skonhoft (2005) explore the conservation effect of ICDPs, where some revenue from a national park is transferred to local people. They conclude that the effect of ICDPs on wildlife populations and social welfare is ambiguous. Similarly, Winkler (2011) considers an ICDP that distributes a proportion of tourism revenue to local communities. He proves that the social optimum level of wildlife population cannot be achieved under the revenue distribution scheme, so ICDPs fail in their goals. Furthermore, Fischer et al. (2010) analyze the participation of a local community in wildlife conservation by receiving benefits from selling hunting licenses and ecotourism. In the study, the anti-poaching behavior of a local community under different management regimes and benefit-sharing schemes are discussed. The authors conclude that a benefit-sharing regime does not necessarily guarantee an increase in wildlife population; in particular, the effect of the scheme is ambiguous when the park agency maximizes its profit.

However, the first four studies ignore the aspect of people's participation; they only discuss the allocation of local labor in private production activities, such as agricultural production, hunting, or raising livestock. However, it has been pointed out that the participation of local communities is indispensable for the sustainability of ICDPs or community-based natural resource management (CBNRM)(Mbaiwa, 2014)[1]. Thus, in examining the effect of ICDPs, it may be essential to consider the participation of local people. In this sense, Fischer et al. (2010) are significant because they incorporate the anti-poaching behavior of local people. However, their focus is on the effect of increased sharing of benefits on the wildlife population under the sale of three different types of hunting licenses and they do not consider the negative effects of hiring locals because local participation in anti-poaching behavior leads to reduced poaching. However, the type of inclusion of local people, such as for tourism, which we consider in this paper,

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[1] Similar statement has also been emphasized by Milupi et al. (2017) and Wells et al. (1992), such as "[j]ob opportunity can create local goodwill and economic contribution" (Wells et al., 1992, p. 37) and "[c]ommunity participation helps to ensure sustainability, make development activities more effective, and builds local capacity"(WWF, 2006, p. 15).

could be harmful to biodiversity, which is pointed out by Kasereka et al. (2006) and Geffroy et al. (2015). Thus, considering such negative effects might be necessary for designing a desirable ICDP involving local people.

In addition, these studies assume that a national park maximizes its profit, which is the difference between the revenue from tourism or the sale of hunting licenses and the operation cost. However, the objective of national parks[2] is to protect natural biodiversity along with its underlying ecological structure as well as promote education and recreation (Dudley, 2008, p. 16). Thus, we suppose that the principle of profit maximization does not always apply to national parks.

The objective of this paper is to explore the effect of an ICDP on biodiversity conservation by considering the inclusion of locals in tourism that national parks conduct, with the supposition that a national park's behavior is nonprofit as well as for-profit. In the operation of the nonprofit park, we assume that tourism is conducted to gain revenue, where all the revenue is divided between paying locals and improving biodiversity. Hansmann (1980) describes this in the behavior of nonprofit organizations as "nondistribution constraint," following which we formalize the behavior of the nonprofit park as maximizing biodiversity by using the revenue collected by tourists. Meanwhile, locals determine how much labor is engaged in the park and agricultural production. Here, agricultural production is positively, neutrally, or negatively influenced by biodiversity, that is, biodiversity has positive, zero, or negative externality. We define a community-based ICDP as one that hires locals through the local labor market, and whose equilibrium endogenously determines the wage rate, where the labor market reflects the participation of locals and the payment for them from the national park

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[2] "National park" here refers to the national park in IUCN (International Union for Conservation of Nature) protected area category II.

gaining benefits of the participation. It also reflects that the effect of ICDP is influenced by locals through their decision over the participation in ICDP, depending on the profitability from agricultural production.

Our contribution to the bioeconomic literature is three-fold. First, we show that local participation, on its own, does not always help biodiversity conservation and local development under a community-based ICDP, which is contrary to the claim that the local population's participation is indispensable for the success of community-based ICDPs (Mbaiwa, 2014; Milupi et al., 2017; Wells et al., 1992). We demonstrate that to achieve success, some other conditions are necessary. Second, this paper explores the different effects of nonprofit national parks and for-profit national parks on the biodiversity conservation and local social welfare. Although for-profit behavior can be justified in privately owned protected areas (Dudley, 2008), it could be replaced with nonprofit behavior to evaluate the role of national parks in biodiversity conservation. Contrary to the intuitive expectation, we demonstrate that it is possible that the for-profit park employs more labor and generates higher biodiversity than the nonprofit park. Third, we show that a tax/subsidy on wage rate can be used to maximize social welfare where social welfare is defined as the sum of social benefits of biodiversity and utility of local people.

The rest of this paper is organized as follows. Section 2 defines the dynamic and steady-state of biodiversity. The labor market equilibrium under the two types of national parks is described in Section 3. Section 4 analyzes the results of the social optimum and discusses how government intervention can achieve it. Concluding remarks are provided in Section 5.

2 The Bioeconomic Model

Let us consider a national park, which manages biodiversity as well as conducts tourism based on the biodiversity. The national park gains revenue from the entrance fee paid by tourists. Subsequently, a proportion of the revenue is invested in purchasing the equipment or building facilities to conserve biodiversity. In this paper, we call the total amount of equipment and facilities "conservation capital stock (CCS)," which is expressed by K, and assume that CCS is central to the management of the park along with the number of disciplined staff there, which is denoted by n. Here, park management refers to a set of conservation activities including natural habitat preservation, poaching prevention, and introduced species control, which will result in a raised bio-growth rate. Let us denote the level of management by $M = M(K, n)$ as $M_K > 0$ and $M_n > 0$. Moreover, we assume that the rest of the revenue after the investment will be transferred to the local government before an ICDP is introduced.

The national park launches a community-based ICDP that includes locals who live in the vicinity of the park into the tourism operations. We suppose that the number of tourists will rise as a result of the participation of the locals[3]. Although increasing tourism brings higher revenue, it has a larger negative impact on the aggregate biodiversity. As mentioned in Introduction, tourism negatively impacts biodiversity and the environment because tourists may trample plants and disturb wildlife. Researchers have also found evidence that animals used to human presence are more likely to be killed by predators (for more details, see Geffroy et al., 2015; Kasereka et al., 2006).

Based on the above assumptions, the biodiversity level in the national park is

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[3] Locals are usually familiar with the behavior of local animals, so they could guide tourists efficiently. Additionally, their local customs and cultural heritage attract tourism.

determined by the growth of biodiversity, the management of park, and the negative impact of tourism. Assuming that the biodiversity is represented as a scalar[4], we express the bio-growth function by $G(X, M)$, where X is the biodiversity level in the park with $G_X \gtreqless 0$ and $G_M > 0$ (bio-growth rate under better management is higher). Recalling that $M = M(K, n)$, with the assumption that n is constant at $\bar{n}$, we rewrite $G(X, M(K, \bar{n}))$ by $F(X, K)$ with $F_K > 0$ (more CCS increases the bio-growth rate). We assume that F is a logistic function, with $F_X > 0$ up to some X_{MSY} and $F_X < 0$ for $X > X_{MSY}$ with $F_{X_{MSY}} = 0$ for a given K. Thus, the rate of change of biodiversity is given by

$$\frac{dX}{dt} = F(X, K) - \alpha V(\tau, E, X), \tag{1}$$

where $\alpha V(\tau, E, X)$ expresses the negative impact of tourism on biodiversity as a function of the number of tourists $V(\tau, E, X)$, which depends on the entry fee τ, local labor E, and X. We assume that $V_\tau < 0$ (higher ticket price decreases tourists), $V_E > 0$, and $V_X > 0$ (local labor or biodiversity increases the number of tourists).

Since our analysis is developed at the equilibrium level, the steady-state level of biodiversity is determined by $dX/dt = 0$ in (1) as:

$$F(X, K) = \alpha V(\tau, E, X) \tag{2}$$

from which the steady-state X under the ICDP is expressed with $X(E, K, \tau)$ as a function of K, τ, and E, while $X(0, K, \tau)$ denotes the level of biodiversity before the

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[4] This assumption follows Fischer et al. (2010), who assume that the wildlife in a national park can be represented as a composite species. In this paper, biodiversity as a scalar can stand for the biomass in the national park as well as the wildlife.

ICDP. We define that the introduction of ICDP effectively enhances biodiversity under a labor supply $\bar{E}$ with a given (K, τ), if it holds at $\bar{E}$ that

$$X(\bar{E}, K, \tau) - X(0, K, \tau) = \int_0^{\bar{E}} \frac{dX(E, K, \tau)}{dE} dE > 0. \tag{3}$$

That is, after the national park starts to hire local labor, steady-state biodiversity is always greater than $X(0, K, \tau)$ if we ensure $dX/dE > 0$. Therefore, in this study, $dX/dE > 0$ for each E is regarded as the condition for an ICDP to be successful, that is, to contribute to enhancing the level of biodiversity.

Recalling that the national park utilizes a part of the revenue from tourism in CCS. We suppose that K has the form as:

$$\begin{aligned} \dot{K} &= I - \delta K, \\ I &= (1-\gamma)\tau V(\tau, E, X), \end{aligned} \tag{4}$$

where δ is the depreciation rate of CCS. The amount of investment I is determined by the total revenue of the park $\tau V(\tau, E, X)$ at the investment rate $1-\gamma$. Since we focus on the steady state, the investment, I, must be equivalent to the replacement of the depreciated CCS. That is, the CCS in the steady state is determined by

$$K = \frac{(1-\gamma)\tau V(\tau, E, X)}{\delta}. \tag{5}$$

(5) implies that steady-state K is a function of γ, τ, and $V(\tau, E, X)$. Substituting (5) into (2) yields that the steady-state equilibrium X can be solved as a function of γ, τ, and E, that is, $X(K, E, \tau)$ can be expressed by $X(E, \gamma, \tau)$.

We then explore the condition for $X_E \equiv dX/dE > 0$. By differentiating $X(E, \gamma, \tau)$

with respect to E,

$$X_E \equiv \frac{dX}{dE} = \frac{V_E(\alpha - \frac{1}{\delta}F_K(1-\gamma)\tau)}{F_X + V_X(\frac{1}{\delta}F_K(1-\gamma)\tau - \alpha)}. \tag{6}$$

Throughout the paper, we assume that steady state is locally stable, which means

$$F_X + V_X(\frac{1}{\delta}F_K(1-\gamma)\tau - \alpha) < 0 \tag{7}$$

by Appendix A. (6) and (7) imply that $X_E > 0$ if $\frac{1}{\delta}F_K(1-\gamma)\tau - \alpha > 0$. Furthermore, it must be $F_X < 0$ for (7), while $\frac{1}{\delta}F_K(1-\gamma)\tau - \alpha > 0$. Therefore, in view of (6) and (7), we have the following proposition:

Proposition 1. *Suppose that the steady state is locally stable, that is, (7) holds. Then,* $X_E > 0$ *holds if and only if* $X > X_{MSY}$ *and* $\frac{1}{\delta}F_K(1-\gamma)\tau > \alpha$.

This proposition states that, first, the level of biodiversity must be sufficiently large to exceed X_{MSY}. That is, an ICDP should not be introduced if X is small. Second, the effects through the change in the number of tourists and the marginal bio-growth rate determine the success of this ICDP. Once the national park starts to hire labor, CCS increases by $\frac{1}{\delta}(1-\gamma)\tau V_E$, which increases the bio-growth by $\frac{1}{\delta}F_K(1-\gamma)\tau V_E$. In contrast, increasing the number of tourists yields a negative effect of αV_E. As long as the increase in biodiversity brought by increasing CCS dominates the increased damage by tourism, implementing this ICDP is effective for biodiversity conservation. Figure 1 depicts successful and unsuccessful cases under local stability.

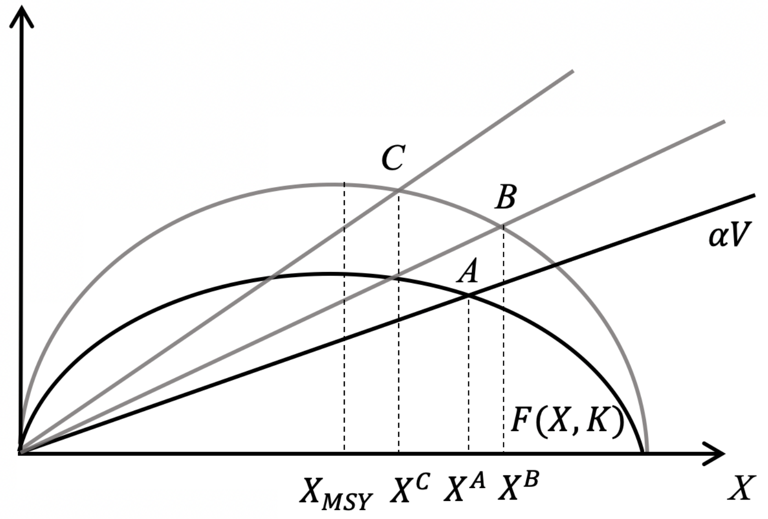

Fig. 1: The effect of increasing local labor on steady-state biodiversity level

In Figure 1, the inverse U-shaped curve expresses $F(X, K)$, while the upward sloping line shows αV. Here, A is the original equilibrium of the park before an ICDP is implemented. That is, at A, $X = X(0, \gamma, \tau)$ and $V = V(\tau, 0, X)$, while under ICDP, we have $X = X(E, \gamma, \tau)$ and $V = V(\tau, E, X)$ with $E > 0$. Recalling that when the national park hires local people, it increases tourism and consequently contributes to CCS, that is, K, by revenue, but inevitably faces a higher negative impact on biodiversity. Thus, αV rotates to the left, and the $F(X, K)$ curve moves upward. There are two possible locations for the new steady state, B and C in the figure. B refers to where ICDP is effective for increasing biodiversity ($\frac{1}{\delta}F_K(1-\gamma)\tau > \alpha$), that is, $X^B > X^A$. However, C refers to $\frac{1}{\delta}F_K(1-\gamma)\tau < \alpha$, that is, $X^A > X^C$. In this case, implementing this ICDP leads to lower biodiversity, which shows that this ICDP is not successful in conserving.

Additionally, for later use, we derive the effects of changing τ and γ on steady-state biodiversity under the conditions of stability and $X_E > 0$. Differentiating $X(E, \gamma, \tau)$

with respect to γ and τ, we obtain

$$X_\tau \equiv \frac{dX}{d\tau} = \frac{V_\tau(\alpha - \frac{1}{\delta}F_K(1-\gamma)\tau) - \frac{1}{\delta}F_K(1-\gamma)V}{F_X + V_X(\frac{1}{\delta}F_K(1-\gamma)\tau - \alpha)}, \tag{8}$$

$$X_\gamma \equiv \frac{dX}{d\gamma} = \frac{\frac{1}{\delta}F_K\tau V}{F_X + V_X(\frac{1}{\delta}F_K(1-\gamma)\tau - \alpha)}. \tag{9}$$

We rewrite the numerator of (8) as:

$$\alpha V_\tau + \frac{1}{\delta}(1-\gamma)F_K V(\varepsilon_\tau - 1), \tag{10}$$

where $\varepsilon_\tau \equiv -\frac{\tau V_\tau}{V}$ is the entry fee elasticity of demand for tourism. If $\varepsilon_\tau \leq 1$, $X_\tau > 0$; otherwise, $X_\tau \lesseqgtr 0$. This implies that when tourism is inelastic or unit elastic, the increase in τ raises the revenue of the national park despite the decrease in tourism. That is, there will be more revenue to invest in conservation while decreasing the negative impact of tourism, which eventually increases biodiversity. Moreover, it holds that $X_\gamma < 0$ from (9) because increasing γ reduces the CCS investment, which results in a reduced bio-growth rate.

3 Management of National Parks

So far, we have focused on the effectiveness of the community-based ICDP. It is only when $X_E > 0$ that the national park is willing to introduce ICDP. Therefore, our argument hereafter is developed under the conditions ensuring $X_E > 0$. We assume that there is a national park, which takes either of two types: nonprofit and for-profit park agencies. Each maximizes its objective by determining E, while τ and γ are exogenously determined for the park agencies. We will first analyze the optimal solution for a nonprofit agency and subsequently for a for-profit agency. The difference between the solutions under labor market equilibrium will be demonstrated in the last subsection.

3.1 Nonprofit National Park

When a national park is nonprofit, it aims to maximize the aggregate biodiversity level subject to the budget constraint. As the steady-state biodiversity level is expressed by $X(E, \gamma, \tau)$, the problem for a nonprofit park agency is

$$\begin{aligned} \max_{E} \quad & X(E) \\ \text{s.t.} \quad & \bar{\tau}V(\bar{\tau}, E, X) \geq wE + I. \end{aligned} \tag{11}$$

From (4), the budget constraint can be rewritten as $\bar{\gamma}\bar{\tau}V(\bar{\tau}, \bar{\gamma}, E) \geq wE$.

Since we discuss where the introduction of ICDP is effective, that is, the objective function $X(E)$ is an upward sloping curve, the nonprofit national park will employ as much labor as possible considering the budget constraint. E^{NP} (superscript "NP" stands for the optimal solution of nonprofit agency) is solving the budget constraint:

$$\bar{\tau}\bar{\gamma}V(\bar{\tau}, E^{NP}, X) = wE^{NP}. \tag{12}$$

Under the nonprofit national park, we show that the following property holds:

Lemma 1. *For the solution of a nonprofit national park,* $w > \bar{\tau}\bar{\gamma}(V_E + V_X X_E)$ *at* E^{NP}.

Proof. The Lagrangian function of (11) is

$$\mathscr{L} = X(E) + \lambda(\bar{\gamma}\bar{\tau}V(\bar{\tau}, E, X) - wE), \tag{13}$$

where λ is the Lagrange multiplier. The first-order condition for the maximum is

$$X_E = \lambda[w - \bar{\gamma}\bar{\tau}(V_E + V_X X_E)], \tag{14}$$

which implies that $\lambda \neq 0$ and $\bar{\gamma}\bar{\tau}(V_E + V_X X_E) \neq w$ at E^{NP} because of $X_E > 0$. Note that $V_E + V_X X_E \equiv \frac{dV}{dE}$. If $\bar{\gamma}\bar{\tau}\frac{dV}{dE} > w$ at E^{NP}, then, for a sufficiently small $dE > 0$, it holds that $\bar{\tau}\bar{\gamma}\frac{dV}{dE}dE > wdE$, which means that increasing E by $dE > 0$ to increase X more at E^{NP} is feasible because of $X_E > 0$. This contradicts that E^{NP} maximizes X, so we obtain $w > \bar{\tau}\bar{\gamma}\frac{dV}{dE}$ at E^{NP}. □

3.2 For-Profit National Park

Let us now analyze the optimality of a for-profit national park. The objective function of this type of national park is maximizing profits, which is formalized below.

$$\max_{E} \quad \pi = \bar{\tau}V(\bar{\tau}, E, X) - (wE + I). \tag{15}$$

First-order condition for this problem is

$$w = \bar{\tau}\bar{\gamma}(V_E + V_X X_E). \tag{16}$$

Equation (16) implies that E^{FP} (superscript "FP" denotes the optimal solution of the for-profit national park) is determined to satisfy the net marginal cost of labor w equals marginal revenue $\bar{\tau}\bar{\gamma}(V_E + V_X X_E)$. Based on (12) and (16), we have the following remark:

Remark 1. *A nonprofit national park demands more labor than a for-profit one.*

Proof. On the contrary, assume that $E^{FP} \geq E^{NP}$. To begin with, assume that $E^{FP} = E^{NP}$. Then, $dV(E^{FP})/dE = dV(E^{NP})/dE$, which is a contradiction to Lemma 1 and (16). Next, assume that $E^{FP} > E^{NP}$. However, this means that there exists $E > E^{NP}$ satisfying $wE = \bar{\gamma}\bar{\tau}V(\bar{\tau}, E, X)$, which leads to $X(E) > X(E^{NP})$ because of $X_E > 0$. This contradicts that X is maximized by E^{NP}. Thus, we obtain $E^{FP} < E^{NP}$. $\square$

3.3 Labor Market Equilibrium

In this subsection, we consider a labor market in which the demand for labor in national parks and the supply of local labor is adjusted by the wage rate. Labor demand is determined in (12) and (16). We clarify labor supply below.

Following the assumptions of previous bioeconomic research (Johannesen, 2007; Rondeau and Bulte, 2007), people who live near protected areas generally engage in agriculture. We assume that a representative individual is endowed with H units of labor and allocates labor for agriculture and for the national park under the time endowment constraint:

$$H = L + E,$$

where L is the labor input for agricultural production.

This representative individual maximizes her or his utility, which is defined as:

$$u(c), \ c = wE + pQ(L, X),$$

that is, total consumption c equals total income, which is the sum of the payment from the park and income from agriculture. The price of agricultural products is fixed at p. Agricultural production $Q(L, X)$ is determined by agricultural labor and biodiversity level because biodiversity can increase agricultural production with the help of pollinators such as honeybees or reduce the output because of wildlife damage[5]. We assume that $Q_L > 0$ and $Q_{LL} < 0$ (i.e., $\partial Q_L/\partial E > 0$). Note that the level of biodiversity X is exogenous for individuals; therefore, it becomes an exogenous variable in the agricultural production function. By maximizing the instantaneous utility function, the individual decides L as follows:

$$\frac{w}{p} = Q_L. \tag{17}$$

This condition denotes that the optimal agricultural labor input is determined when the real wage rate (marginal opportunity cost of agriculture) equals the marginal agricultural production of labor (marginal benefit). The supply of $E = H - L$ is determined simultaneously.

Recalling the demand for labor in (12) and (16), together with (17), the market equilibriums (subscript "m" stands for market equilibrium) are determined by

$$w_m^{NP} = pQ_L(E_m^{NP}, X_m^{NP}) = f(E_m^{NP}) + \frac{X_E(E_m^{NP})}{\lambda}, \tag{18}$$

$$w_m^{FP} = pQ_L(E_m^{FP}, X_m^{FP}) = f(E_m^{FP}), \tag{19}$$

where we define

$$f(E) \equiv \bar{\tau}\bar{\gamma}(V_E + V_X X_E), \tag{20}$$

with $df/dE < 0$[6]. We have the following lemma:

Lemma 2. *At the market equilibrium, it holds that $E_m^{FP} \neq E_m^{NP}$.*

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[5] In this paper, the positive effect of biodiversity on agriculture is expressed by $Q_{LX} > 0$ for each L and X. This is because $Q_X(L_0, X_0) = \int_0^{L_0} Q_{LX}(L, X_0)dL \gtreqless 0$, so $Q_X \gtreqless 0$ is derived from $Q_{LX} \gtreqless 0$.

[6] We assume that the second-order condition for (15) holds, that is, $\bar{\tau}\bar{\gamma}\frac{d^2V}{dE^2} < 0$.

Proof. On the contrary, suppose that $E_m^{FP} = E_m^{NP}$. However, (18) and (19) produce $\frac{X_E(E_m^{NP})}{\lambda} = 0$, which contradicts our assumption $X_E > 0$. Therefore, we prove the claim of the lemma. $\square$

We propose the following:

Proposition 2. *If the biodiversity increases or has no effect on marginal agricultural production, that is,* $Q_{LX} \geq 0$, *then employment, wage rate, and the utility of locals as well as biodiversity at the market equilibrium are higher under nonprofit park than under for-profit park, that is,* $E_m^{NP} > E_m^{FP}, w_m^{NP} > w_m^{FP}, u(c_m^{NP}) > u(c_m^{FP})$ *and* $X_m^{NP} > X_m^{FP}$.

Proof. See Appendix B. $\square$

The next proposition deals with the case $Q_{LX} < 0$, for which we define function $g(E)$ as

$$g(E) \equiv Q_L(T - E, X(E)) \tag{21}$$

where $g'(E) = -Q_{LL} + Q_{LX}X_E \gtreqless 0$ when $Q_{LX} < 0$.

Proposition 3. *Suppose that biodiversity decreases the marginal agricultural production, that is,* $Q_{LX} < 0$. *If* $g'(E) < 0$ *and* X_E *is sufficiently small, then it holds that* $E_m^{FP} > E_m^{NP}$, $X_m^{FP} > X_m^{NP}$, *but* $w_m^{NP} > w_m^{FP}$ *and* $u(c_m^{NP}) > u(c_m^{FP})$. *If* $g'(E) \geq 0$ *or* $g'(E) < 0$ *with a slightly larger* X_E, *then* $E_m^{NP} > E_m^{FP}$, $X_m^{NP} > X_m^{FP}$, *but* $w_m^{NP} \gtreqless w_m^{FP}$ *and* $u'(c_m^{NP}) \gtreqless u(c_m^{FP})$.

Proof. See Appendix B. $\square$

Proposition 3 suggests that although the nonprofit park always demands more labor than the for-profit park, it does not always result in the employment of more labor under the labor market equilibrium if $g'(E) < 0$ and X_E is small. This unanticipated finding suggests that there is a special case in which the nonprofit park will not lead to higher biodiversity at the market equilibrium, which we refer to as Case A. In contrast, for the case where $E_m^{NP} > E_m^{FP}$ holds, that is, when $g'(E) \geq 0$ or $g'(E) < 0$ with a slightly larger X_E, we call it Case B. The summarization of Propositions 2 and 3 is given in Table 1.

	$Q_{LX} \geq 0$	$Q_{LX} < 0$	
		Case A[a]	Case B[b]
Biodiversity level	$X_m^{NP} > X_m^{FP}$	$X_m^{FP} > X_m^{NP}$	$X_m^{NP} > X_m^{FP}$
Labor	$E_m^{NP} > E_m^{FP}$	$E_m^{FP} > E_m^{NP}$	$E_m^{NP} > E_m^{FP}$
Wage rate	$w_m^{NP} > w_m^{FP}$	$w_m^{NP} > w_m^{FP}$	$w_m^{NP} \gtrless w_m^{FP}$
Utility of locals	$u(c_m^{NP}) > u(c_m^{FP})$	$u(c_m^{NP}) > u(c_m^{FP})$	$u(c_m^{NP}) \gtrless u(c_m^{FP})$[c]

[a] Case A: $g'(E) < 0$ and X_E is sufficiently small.
[b] Case B: $g'(E) \geq 0$ or $g'(E) < 0$ with a slightly larger X_E.
[c] Here, if $g'(E) < 0$, then $w_m^{NP} < w_m^{FP}$ and $u(c_m^{NP}) < u(c_m^{FP})$; otherwise, $w_m^{NP} > w_m^{FP}$ but the magnitude of the relationship between $u(c_m^{NP})$ and $u(c_m^{FP})$ is ambiguous.

Table 1: Summary of results

4 Social Optimum

This section investigates the optimal solution for the local society under an ICDP, which we call "social optimum." In previous literature, social welfare function is usually defined as the sum of national parks' profits and the utility of locals (see, e.g., Skonhoft and Solstad, 1998). However, Clark et al. (2010) define a social planner that also considers the benefits to the public due to the existence of natural resources. Following this study, we consider the social benefits of biodiversity and then define the social welfare function as $W = \eta X + u(c)$, where $\eta X > 0$ reflects the existence value of biodiversity for the society, which is also positively related to biodiversity level.

The social planner optimizes resource allocation by determining the levels of E

provided by local people, of T which is the transfer of income from the park to the locals, as well as the levels of I and τ. Thus, the problem for the social planner is

$$\begin{aligned} \max_{T,E,\tau,\gamma} \quad & \eta X(\gamma,\tau,E) + u(T + pQ(L, X(\gamma,\tau,E))) \\ \text{s.t.} \quad & \tau V(\tau,E,X) \geq T + I, \end{aligned} \tag{22}$$

where I is indirectly determined by optimizing with γ. The Lagrangian function is $\mathscr{L} = \eta X(\gamma,\tau,E) + u(T + pQ(L, X(\gamma,\tau,E))) + \mu(\tau V(\tau,E,X) - T - I)$, where μ is the Lagrange multiplier. The first-order conditions for the social planner are

$$u' = \mu, \tag{23}$$

$$u'p(Q_L - Q_X X_E) = \mu\gamma\tau(V_E + V_X X_E) + \eta X_E, \tag{24}$$

$$-\eta X_\tau = u'pQ_X X_\tau + \mu\gamma(\tau V_\tau + \tau V_X X_\tau + V), \tag{25}$$

$$-\eta X_\gamma = u'pQ_X X_\gamma + \mu\tau(\gamma V_X X_\gamma + V). \tag{26}$$

(24) shows that E^s (superscript “s” stands for social optimum) is determined at the level where the marginal effects of labor on agricultural product (left-hand side) equal the sum of marginal revenue of park and marginal biodiversity value (right-hand side). (25) shows that the social planner should decide τ^s such that the marginal effect of the entry fee, τ, on the social value of biodiversity ηX_τ is identical to the marginal utility of the entry fee $u'(pQ_X X_\tau + \gamma(\tau V_\tau + \tau V_X X_\tau + V))$. Finally, (26) states that the marginal effect of the wage share ratio, γ, on the social value of biodiversity ηX_γ is equal to the marginal utility of the wage share ratio $u'(pQ_X X_\gamma + \tau\gamma V_X X_\gamma + \tau V)$, where X_γ^s must be negative from (9).

We also examine the implementation of the social optimum under the ICDP with a national park. We set τ and γ at the social optimum levels, that is, $\tau = \tau^s$ and $\gamma = \gamma^s$. The social planner then introduces a subsidy or tax on wage rate w. Under such a scheme, the labor supply of locals becomes

$$w + t = pQ_L, \tag{27}$$

where t is the subsidy or tax rate on w.

We discuss the method used to implement the social optimum under a for-profit national park. The market equilibrium under government intervention is expressed by (16) and (27), as

$$pQ_L - t = \gamma^s\tau^s(V_E + V_X X_E). \tag{28}$$

Let us define t as

$$t = X_E(pQ_X + \frac{\eta}{u'}), \tag{29}$$

then (28) leads to

$$pQ_L - X_E(pQ_X + \frac{\eta}{u'}) = \gamma^s\tau^s V_E + \gamma^s\tau^s V_X X_E, \tag{30}$$

$$\Leftrightarrow X_E(\eta + u'pQ_X + u'\gamma^s\tau^s V_X) = u'pQ_L - u'\gamma^s\tau^s V_E. \tag{31}$$

This says that if the social planner specifies t as t^* such that

$$t^* = X_E^s(pQ_X^s + \frac{\eta}{u'}), \tag{32}$$

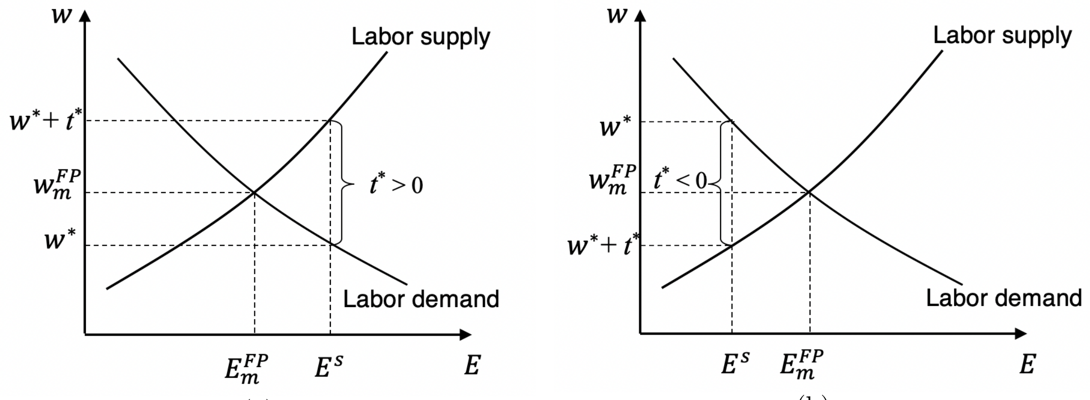
where X_E^s and Q_X^s are evaluated at (γ^s, τ^s, E^s), the market equilibrium achieves the social optimum because we observe that (31) is the same as (24). We summarize this in the proposition below:

Proposition 4. *Suppose that the government taxes locals for each unit supply of E, as in (32), then, the market equilibrium under a for-profit park achieves the social optimum.*

Hereafter, we denote the right-hand side of (32) as

$$\phi \equiv X_E^s(pQ_X^s + \frac{\eta}{u'}). \tag{33}$$

We use figures of the labor market to show how the social optimum E^s is achieved under t^*, and that the equilibrium wage rate results in w^*. Figure 2 shows the labor supply of locals and the demand of the for-profit national park where E_m^{FP} refers to the equilibrium labor at the market-clearing wage rate w_m^{FP} before the government intervention is considered. Note that figure 2 and its explanation are not applicable to the case where $g'(E) < 0$ and $|\phi|$ is sufficiently small (see Appendix C for discussions).



(a) (b)

Fig. 2: Government intervention and the social optimum

Figure 2 (a) is the case with $t^* > 0$, where ϕ is positive. Before the implementation of government intervention, the national park underhires labor at market equilibrium

($E_m^{FP} < E^s$) because the park ignores ϕ. Considering the welfare of the local society, the social planner encourages the national park to increase labor employment at wage rate $w^* < w_m^{FP}$, and compensates locals to work in the national park at wage rate $w^* + t^*$ to realize the social optimum.

However, if $\phi < 0$, the social planner levies taxes ($t^* < 0$) on wage rate $w^* > w_m^{FP}$ to decrease the labor supply (see figure 2 (b)). In this case, the national park overhires labor at equilibrium level without government intervention ($E_m^{FP} > E^s$) because it does not consider the potential negative impact of biodiversity on agriculture.

Moreover, the magnitude of the relationship between E_m^{FP} and E^s is ambiguous when $g'(E) < 0$, regardless of the sign of ϕ. Nevertheless, we prove in Appendix C that if $\phi > 0$ (resp. the absolute value of $\phi < 0$) is sufficiently small, then it is possible that $E_m^{FP} > E^s$ ($E_m^{FP} < E^s$). That is, the social planner may compensate (tax) locals to lower (increase) the labor supply when the for-profit park overhires (underhires) labor.

To implement the social optimum in the case of a nonprofit national park, let us introduce a subsidy θ such that

$$\theta^* = \gamma^s \tau^s [(V_E^s + V_X^s X_E^s) - \frac{V^s}{E^s}] + \phi. \tag{34}$$

Let the government subsidy be θ for each labor that the nonprofit park hires such that $(w - \theta)E$ is the net payment from the national park, while the total wage that the workers receive is wE. Under this scheme, the optimum condition for a nonprofit park is

$$w = \frac{\gamma^s \tau^s V}{E} + \theta = \gamma^s \tau^s (V_E + V_X X_E) + \phi \tag{35}$$

while the optimum condition for the locals is

$$w = pQ_L. \tag{36}$$

Therefore, the labor market achieves the social optimum $(pQ_L = \gamma^s \tau^s (V_E + V_X X_E) + X_E(pQ_X + \frac{\eta}{u'}))$. This is summarized in the following proposition.

Proposition 5. *Suppose that the government subsidizes each unit of labor in the national park, as in (34), then , the market equilibrium under a nonprofit national park achieves the social optimum.*

In the case of a nonprofit national park, the magnitude of the relationship between E_m^{NP} and E^s is ambiguous in almost all the cases. However, when $\phi < 0$ and $g'(E) \geq 0$, we can conclude that the nonprofit park overhires labor (see Appendix D for details).

5 Discussions and Concluding Remarks

ICDPs are designed to conserve the ecosystem and contribute to the local development by including the local population in the operations of national parks and by transferring benefits received from the creation of such parks to local communities. However, existing literature on ICDPs in economics largely ignores the aspect of inclusion by assuming that monetary transfers are provided to locals without employment. The exception is Fischer et al. (2010), but they do not suggest an optimal design of ICDP as well as its negative effects on biodiversity. To overcome this problem, this study assumes that a national park implements a community-based ICDP that incorporates locals into the operations of a national park by hiring them through the local labor market to assist in tourism, where tourism is assumed to have a negative impact on biodiversity. Moreover, considering that national parks are not always for-profit entities, this paper examines how effective an ICDP is as a nonprofit national park, compared to a for-profit one.

We analyze the effect of increasing labor on the steady-state biodiversity level. This indicates two conditions for implementing ICDP to improve biodiversity conservation: (1) the biodiversity level is larger than MSY level, and (2) the increase in marginal bio-growth rate brought by increasing labor dominates the negative impact of tourists. We also observe that if biodiversity enhances the productivity of agriculture, then the market-clearing labor under the nonprofit park is greater than that of the for-profit park. By hiring more local labor, a nonprofit park always brings a higher biodiversity level and a higher utility to locals in this case. However, when biodiversity decreases agricultural production, the biodiversity level and labor employment at market equilibrium under the for-profit park may be greater than that for the nonprofit park in cases where increasing labor cannot increase the biodiversity level significantly. Nevertheless, the nonprofit park brings more utility to locals in this case. Otherwise, the nonprofit park may hire more labor and thus bring higher biodiversity levels but still be ambiguous about bringing higher utility to locals. Moreover, this model has identified that the optimal level of social welfare can be achieved by government intervention through tax/subsidy.

Although the focus of this paper is to study the effect of a community-based ICDP, we provide several implications about the role of tourism in biodiversity conservation and local development. The conservation effect of tourism has been under debate, even though it is generally regarded as a sustainable way of utilizing biodiversity resources. The problems of habitat degradation and wildlife disturbance due to infrastructure development and tourists have been raised in some studies (see Buckley et al., 2016; Singleton et al., 2004). Our first observation is that the downside of tourism on biodiversity levels should not be overlooked in the bioeconomic model; otherwise, the conservation effect of tourism would be over-estimated. We suggest that the effect of tourism on biodiversity conservation critically depends on the local circumstances, ecological conditions, and management policies. Under appropriate management, tourism could fund ICDPs or national parks to conduct biodiversity conservation. Moreover, although we generally believe that tourism can contribute to local development by bringing income to local communities through job creation, it is argued that ecotourism may not benefit local communities or conservation because of the low wage levels (Zacarias and Loyola, 2017). Our model suggests that the implementation of ecotourism and ICDPs could improve local welfare under a competitive labor market where there is no monopsony by national parks. The effect of ICDPs under a monopsony labor market will be left for future studies.

Although we implicitly consider the existence of the poaching in relation to CCS, we do not explicitly include the behavior of poachers in the model, even though poaching is regarded as a serious threat to biodiversity conservation in protected areas (Skonhoft and Solstad, 1996). The national park may hire more labor for their anti-poaching effort and increase the investment in CCS considering the issue of poaching. It may be interesting to study ICDPs by taking the aspect of poaching into consideration under two types of labor markets, where one is for tourism and the other is for anti-poaching efforts.

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Appendix A Local Stability

Consider the dynamics system in (1) and (4) for a given E. Let $(\bar{X}, \bar{K})$ represents the steady state. Conditions for local stability are

$$\mathrm{Tr}A = F_X - \alpha V_X - \delta < 0 \tag{A1}$$

$$|A| = -\delta(F_X - \alpha V_X) - F_K(1-\gamma)\tau V_X > 0. \tag{A2}$$

where

$$A = \begin{pmatrix} F_X - \alpha V_X & F_K \\ (1-\gamma)\tau V_X & -\delta \end{pmatrix} \tag{A3}$$

Appendix B Comparison between E_m^{NP} and E_m^{FP}

PROOF OF PROPOSITION 2

Since we have Lemma 2, to suppose the contrary leads to $E_m^{FP} > E_m^{NP}$ so that

$X_m^{FP} > X_m^{NP}$ for $Q_{LX} \geq 0$. This supposition implies that

$$pQ_L(E_m^{FP}, X_m^{FP}) \geq pQ_L(E_m^{FP}, X_m^{NP}) > pQ_L(E_m^{NP}, X_m^{NP}). \tag{A4}$$

However, if $E_m^{FP} > E_m^{NP}$, owing to $f'(E) < 0$, we obtain

$$f(E_m^{NP}) = pQ_L(E_m^{NP}, X_m^{NP}) - \frac{X_E(E_m^{NP})}{\lambda} > pQ_L(E_m^{FP}, X_m^{FP}) = f(E_m^{FP}) \tag{A5}$$

which contradicts (A4), so it must be $E_m^{NP} > E_m^{FP}$ such that $X_m^{NP} > X_m^{FP}$ by $X_E > 0$. Based on this result, we have $pQ_L(E_m^{NP}, X_m^{NP}) > pQ_L(E_m^{FP}, X_m^{FP})$, and thereby, $w_m^{NP} > w_m^{FP}$. The total income of locals under a nonprofit park is

$$\begin{aligned} c_m^{NP} &= w_m^{NP} E_m^{NP} + \int_{E_m^{FP}}^{H} pQ_L(E, X_m^{NP})dE \\ &= w_m^{NP} E_m^{FP} + \int_{E_m^{FP}}^{E_m^{NP}} pQ_L(E_m^{NP}, X_m^{NP})dE + \int_{E_m^{NP}}^{H} pQ_L(E, X_m^{NP})dE. \end{aligned} \tag{A6}$$

Total income under for-profit park is

$$\begin{aligned} c_m^{FP} &= w_m^{FP} E_m^{FP} + \int_{E_m^{FP}}^{H} pQ_L(E, X_m^{FP})dE \\ &= w_m^{FP} E_m^{FP} + \int_{E_m^{FP}}^{E_m^{NP}} pQ_L(E, X_m^{FP})dE + \int_{E_m^{NP}}^{H} pQ_L(E, X_m^{FP})dE. \end{aligned} \tag{A7}$$

Since $\partial Q_L/\partial E = -Q_{LL} > 0$, $\int_{E_m^{FP}}^{E_m^{NP}} pQ_L(E_m^{NP}, X_m^{NP})dE > \int_{E_m^{FP}}^{E_m^{NP}} pQ_L(E, X_m^{FP})dE$, so $c_m^{NP} > c_m^{FP}$.

PROOF OF PROPOSITION 3

First, suppose that $E_m^{FP} > E_m^{NP}$ such that $X_m^{FP} > X_m^{NP}$. When $g'(E) \geq 0$, it implies $pQ_L(E_m^{FP}, X_m^{FP}) \geq pQ_L(E_m^{NP}, X_m^{NP})$. However, this means that

$$pQ_L(E_m^{FP}, X_m^{FP}) > pQ_L(E_m^{NP}, X_m^{NP}) - \frac{X_E(E_m^{NP})}{\lambda} \tag{A8}$$

so that it must hold $f(E_m^{FP}) > f(E_m^{NP})$, which implies that $E_m^{NP} > E_m^{FP}$ due to $f'(E) < 0$. However, this contradicts our earlier supposition. Therefore, it must hold that $E_m^{NP} > E_m^{FP}$ under $g'(E) \geq 0$.

Second, suppose that $E_m^{FP} > E_m^{NP}$, but under $g'(E) < 0$. Then, we have $pQ_L(E_m^{FP}, X_m^{FP}) < pQ_L(E_m^{NP}, X_m^{NP})$ by $g'(E) < 0$. This supposition is feasible only when $\frac{X_E(E_m^{NP})}{\lambda}$ is sufficiently small so as to hold:

$$pQ_L(E_m^{FP}, X_m^{FP}) < pQ_L(E_m^{NP}, X_m^{NP}) - \frac{X_E(E_m^{NP})}{\lambda}. \tag{A9}$$

Otherwise, we obtain a contradiction similar to (A8) so that it holds $E_m^{FP} < E_m^{NP}$.

With respect to the market-clearing wage rate, when $E_m^{FP} > E_m^{NP}$ holds, (18) and (19) with $g'(E) < 0$ imply that $w_m^{NP} > w_m^{FP}$. Meanwhile, if $E_m^{NP} > E_m^{FP}$, then $w_m^{NP} \gtrless w_m^{FP}$. Based on this observation, we then discuss c_m^{NP} and c_m^{FP} in three cases.

Case 1: When $E_m^{FP} > E_m^{NP}$ and $w_m^{NP} > w_m^{FP}$, income under the nonprofit park is

$$c_m^{NP} = w_m^{NP} E_m^{NP} + \int_{E_m^{NP}}^{E_m^{FP}} pQ_L(E, X_m^{NP}) dE + \int_{E_m^{FP}}^{H} pQ_L(E, X_m^{NP}) dE; \tag{A10}$$

Under for-profit park is

$$c_m^{FP} = w_m^{FP} E_m^{NP} + \int_{E_m^{NP}}^{E_m^{FP}} pQ_L(E_m^{FP}, X_m^{FP}) dE + \int_{E_m^{FP}}^{H} pQ_L(E, X_m^{FP}) dE. \tag{A11}$$

Since $\partial Q_L / \partial E > 0$, we have $\int_{E_m^{NP}}^{E_m^{FP}} pQ_L(E, X_m^{NP}) dE > \int_{E_m^{NP}}^{E_m^{FP}} pQ_L(E_m^{NP}, X_m^{NP}) dE$. Then, from $w_m^{NP} > w_m^{FP}$, i.e., $\int_{E_m^{NP}}^{E_m^{FP}} pQ_L(E_m^{NP}, X_m^{NP})dE = w^{NP}(E^{FP} - E^{NP}) > w^{FP}(E^{FP} - E^{NP}) = \int_{E_m^{NP}}^{E_m^{FP}} pQ_L(E_m^{FP}, X_m^{FP})dE$, we conclude that $c_m^{NP} > c_m^{FP}$.

When $E_m^{NP} > E_m^{FP}$, we have $w_m^{FP} > w_m^{NP}$ when $g'(E) < 0$ and $w_m^{NP} \geq w_m^{FP}$ when $g'(E) \geq 0$. In both cases, c_m^{NP} and c_m^{FP} have the same expression as (A6) and (A7).

Case 2: When $E_m^{NP} > E_m^{FP}$ under $g'(E) < 0$, then $w_m^{FP} > w_m^{NP}$ holds. (A6) and (A7) lead to $c_m^{FP} > c_m^{NP}$ since $\int_{E_m^{FP}}^{E_m^{NP}} pQ_L(E, X_m^{FP})dE > \int_{E_m^{FP}}^{E_m^{NP}} pQ_L(E_m^{FP}, X_m^{FP})dE = w^{FP}(E^{NP} - E^{FP}) > w^{NP}(E^{NP} - E^{FP}) = \int_{E_m^{FP}}^{E_m^{NP}} pQ_L(E_m^{NP}, X_m^{NP})dE$.

Case 3: When $E_m^{NP} > E_m^{FP}$ under $g'(E) \geq 0$, we have $w_m^{NP} \geq w_m^{FP}$. Even though $w_m^{NP} E_m^{FP} \geq w_m^{FP} E_m^{FP}$, we have $\int_{E_m^{NP}}^{H} pQ_L(E, X_m^{NP})dE < \int_{E_m^{NP}}^{H} pQ_L(E, X_m^{FP})dE$ but $\int_{E_m^{FP}}^{E_m^{NP}} pQ_L(E_m^{NP}, X_m^{NP})dE \gtrless \int_{E_m^{FP}}^{E_m^{NP}} pQ_L(E, X_m^{FP})dE$ due to $Q_{LX} < 0$, so the magnitude of the relationship between c_m^{NP} and c_m^{FP} is ambiguous.

Appendix C Comparison between E_m^{FP} and E^s

(i) The case of $Q_{LX} \geq 0$

We show that when $Q_{LX} \geq 0$, it holds that $E^s > E_m^{FP}$. From (33), $Q_{LX} \geq 0$ leads to $\phi > 0$. Recalling (20) and (33), we express (24) as

$$pQ_L(E^s, X^s) = f(E^s) + \phi \tag{A12}$$

in the following contents. On the contrary, suppose that $E_m^{FP} > E^s$, which implies $pQ_L(E_m^{FP}, X_m^{FP}) > pQ_L(E^s, X^s)$. Under the condition that $pQ_L(E_m^{FP}, X_m^{FP}) > pQ_L(E^s, X^s)$, (19) and (A12) lead to

$$f(E_m^{FP}) = pQ_L(E_m^{FP}, X_m^{FP}) > pQ_L(E^s, X^s) - \phi = f(E^s). \tag{A13}$$

(A13) suggests that $f(E_m^{FP}) > f(E^s)$, that is, $E^s > E_m^{FP}$, which contradicts the supposition. Therefore, we obtain that if $Q_{LX} \geq 0$, then $E^s > E_m^{FP}$.

(ii) The case of $Q_{LX} < 0$ *with* $g'(E) < 0$

Meanwhile, if $Q_{LX} < 0$, then (33) implies $\phi \gtreqless 0$. We show that when $g'(E) < 0$, it holds either $E_m^{FP} > E^s$ with a sufficiently small $\phi > 0$ or $E^s > E_m^{FP}$ when $\phi < 0$ with $|\phi|$ being sufficiently small.

First, suppose $E_m^{FP} > E^s$ for $\phi > 0$, which implies that $pQ_L(E_m^{FP}, X_m^{FP}) < pQ_L(E^s, X^s)$ by $g'(E) < 0$. Under the condition of $pQ_L(E_m^{FP}, X_m^{FP}) < pQ_L(E^s, X^s)$, (19) and (A12) suggest that if ϕ is sufficiently small, then

$$f(E_m^{FP}) = pQ_L(E_m^{FP}, X_m^{FP}) < pQ_L(E^s, X^s) - \phi = f(E^s). \tag{A14}$$

(A14) implies that $f(E^s) > f(E_m^{FP})$, that is, $E_m^{FP} > E^s$ holds.

Second, suppose that $E^s > E_m^{FP}$ for $\phi < 0$ under $g'(E) < 0$. We have $pQ_L(E_m^{FP}, X_m^{FP}) > pQ_L(E^s, X^s)$ under this supposition. Under the condition of $pQ_L(E_m^{FP}, X_m^{FP}) > pQ_L(E^s, X^s)$, (19) and (A12) mean that if the absolute value of ϕ is sufficiently small, then

$$f(E_m^{FP}) = pQ_L(E_m^{FP}, X_m^{FP}) > pQ_L(E^s, X^s) - \phi = f(E^s). \tag{A15}$$

(A15) shows that $f(E_m^{FP}) > f(E^s)$, and thus $E^s > E_m^{FP}$ holds if the absolute value of ϕ is sufficiently small.

(iii) The case of $Q_{LX} < 0$ *with* $g'(E) \geq 0$

In this case, we demonstrate that it holds that $E^s > E_m^{FP}$ when $\phi > 0$ and

$E_m^{FP} > E^s$ when $\phi < 0$.

We present the first property. On the contrary, if we suppose that $E_m^{FP} > E^s$, then we have $pQ_L(E_m^{FP}, X_m^{FP}) \geq pQ_L(E^s, X^s)$. $pQ_L(E_m^{FP}, X_m^{FP}) \geq pQ_L(E^s, X^s)$ with (19) and (A12) imply (A15). Thus, when $\phi > 0$, (A15) leads to $f(E_m^{FP}) > f(E^s)$, that is, $E^s > E_m^{FP}$. This result contradicts the supposition. Thus, we obtain $E_m^{FP} > E^s$.

Next, we show that when $\phi < 0$, it holds $E_m^{FP} > E^s$. On the contrary, suppose that $E^s > E_m^{FP}$. Then, it holds $pQ_L(E^s, X^s) \geq pQ_L(E_m^{FP}, X_m^{FP})$ because $g'(E) \geq 0$. $pQ_L(E^s, X^s) \geq pQ_L(E_m^{FP}, X_m^{FP})$ with (19) and (A12) mean (A14). When $\phi < 0$, (A14) implies $f(E_m^{FP}) > f(E^s)$, that is, $E_m^{FP} > E^s$. This also generates a contradiction.

Appendix D Comparison between E_m^{NP} and E^s

We show that $E_m^{NP} > E^s$ for $\phi < 0$ when $Q_{LX} < 0$ and $g'(E) \geq 0$. On the contrary, suppose that $E^s \geq E_m^{NP}$, which implies $pQ_L(E^s, X^s) \geq pQ_L(E_m^{NP}, X_m^{NP})$. This with (A12) and (18) lead to $f(E^s) + \phi \geq f(E_m^{NP})$. If $\phi < 0$, it must hold that $f(E^s) > f(E_m^{NP})$, which means that $E_m^{NP} > E^s$. This contradicts our supposition.

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