Journal of Environmental Planning and Management

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/cjep20

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To cite this article: Jichuan Sheng & Hui Wang (11 Dec 2023): Community-based incentive coordination in payments for ecosystem services: China's Wolong Nature Reserve, Journal of Environmental Planning and Management, DOI: 10.1080/09640568.2023.2285245

To link to this article: https://doi.org/10.1080/09640568.2023.2285245

Journal of Environmental Planning and Management, 2023
https://doi.org/10.1080/09640568.2023.2285245

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Community-based incentive coordination in payments for ecosystem services: China's Wolong Nature Reserve

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(*Received 3 June 2023; final version received 14 November 2023*)

Community-based Payments for Ecosystem Services (CB-PES) have received continued attention because of their ability to help Payments for Ecosystem Services (PES) improve local outcomes and sustain community support. This study scrutinizes the role of community-based incentive coordination in PES using the case of China's Wolong Nature Reserve (WNR). Combining theoretical modeling and empirical analysis of the WNR, this study demonstrates that CB-PES can deploy a range of incentive-coordinated techniques and practices, eventually improving economic outcomes for stakeholders and environmental benefits for society. In addition, this study also highlights the fact that CB-PES aiming to achieve incentive coordination rely on participatory intermediary governance. Finally, designing community-based incentive coordination mechanisms in PES remains challenging, as it also depends on coordinated conservation efforts to optimize the economic outcomes and environmental benefits of PES.

Keywords: Community participation; eco-compensation; community-based PES; payments for ecosystem services; Wolong Nature Reserve

1. Introduction

Widespread interest has been drawn to Payment for Ecosystem Services (PES), a strategy for environmental policy that aims to ensure sustainable ecological conservation (Fletcher *et al.* 2016; Wunder 2015). Theoretically, PES is designed around the voluntary participation of individual landholders (Southgate and Wunder 2009; Wunder 2005). In practice, however, PES often evolves into top-down and government-led policies and projects (Kosoy, Corbera, and Brown 2008). Community participation is extremely limited in this government-led PES. Individuals in communities in such PES are responsible for providing ecosystem services (ES), and the community is not involved in designing and managing the PES (Rawlins and Westby 2013).

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For instance, vertical eco-compensation as a PES application in China relies exclusively on a government-led management system to consolidate political power to achieve watershed governance goals (Sheng and Han 2022). However, most government-led PES programs often end up failing to achieve substantial conservation results (Rosa da Conceição, Börner, and Wunder 2015). Communities have traditionally been involved only in providing ecosystem services (ES) rather than PES management. As the critical role of communities in influencing environmental management and development outcomes became better understood, the need to include broad community participation in PES was recognized, leading to the development of community-based PES (CB-PES) (Danielsen *et al.* 2010; Dougill *et al.* 2012; Stringer and Paavola 2013). Scale (local rather than national or international) and specific goals for interacting with communities are two ways that CB-PES differentiates from government-led PES (Brownson *et al.* 2019). Unlike the limited community participation in government-led PES, CB-PES allows for community participation in the design, implementation, and monitoring of local PES programs, which often contributes to greater equity in the distribution of benefits and flexibility of the PES system (Hayes and Murtinho 2018; Brownson *et al.* 2020; Kerr, Vardhan, and Jindal 2014; Bremer, Farley, and Lopez-Carr 2014).

However, there is no consensus in existing studies on the impact of community participation in PES on economic outcomes and environmental benefits. Community-wide economic outcomes in CB-PES may be enhanced by developing stakeholder relationships (Gross-Camp *et al.* 2012), improving community management and revenue distribution (Leimona *et al.* 2015), and enhancing community regulation (Dougill *et al.* 2012). For instance, the PES in the Mexican cloud forest has significantly improved economic outcomes for the community after gaining support from community leaders, local councils, NGO intermediaries, and the government (Denham 2017). However, other studies disagree with this view. Corbera, Kosoy, and Tuna (2007) and Sommerville, Milner Gulland, *et al.* (2010) both argued that community participation does not directly impact the economic outcomes of the community after studying CB-PES in Central America and Madagascar, respectively. In addition, the impact of community participation in PES on environmental benefits is still uncertain. Adhikari and Agrawal (2013) argued that community participation in PES improves ES supply on a larger spatial scale, thereby achieving environmental improvements. Brownson *et al.* (2020) also argued that community participation in PES can enrich biodiversity, resulting in broad environmental benefits. However, Nguyen *et al.* (2022) argued that PES does not directly benefit every individual in the community, making it difficult for communities to reach a consensus on implementing forest conservation activities, thus posing a challenge to the environmental benefits of PES.

Furthermore, a growing number of studies have highlighted the impact of incentive distribution on CB-PES (Sommerville, Jones, *et al.* 2010; Corbera, Brown, and Adger 2007). However, these studies have neglected the coordination of stakeholder interests in CB-PES, and the lack of such incentive coordination may induce conflicts of interest among stakeholders (Langemeyer *et al.* 2018). Since conservation interventions increasingly depend on positive incentives at the community level to encourage individual conservation behavior, there is a need to focus on the incentive coordination between stakeholders and its impact on economic and environmental outcomes throughout the lifecycle of the intervention (Sommerville, Jones, *et al.* 2010).

Government-led PES have been widely criticized for having low economic and environmental benefits due to high transaction costs (Zhang, Zinda, and Li 2017). Intermediaries in government-led PES (e.g. community councils, local experts, social entrepreneurs, and NGOs) are often able to coordinate stakeholder interests, facilitate transactions between government and private sellers, and reduce public and private costs (Schröter *et al.* 2018; C. Chen *et al.* 2020). Embedding local social actors in government-led PES to foster a new governance model with intermediary participatory governance features enables coordination between government and landholders (Chen *et al.* 2020; Schröter *et al.* 2018).

This study aims to adopt a differential game approach to scrutinize the micro-mechanisms by which community participation affects PES. In game theory, differential games aim to resolve conflicts in dynamic systems by modeling where one or more state variables evolve over time according to differential equations. Through the case of rural communities in China's Wolong Nature Reserve (WNR), this study explores how the nature conservation behavior of stakeholders depends on the incentive coordination of CB-PES and evolves. The results show that CB-PES can deploy a range of incentive-coordinated techniques and practices, eventually improving economic outcomes for stakeholders and environmental benefits for society. In addition, this study also highlights the fact that CB-PES, aiming to achieve incentive coordination, relies on participatory intermediary governance. Finally, designing community-based incentive coordination mechanisms in PES remains challenging, as it also depends on coordinated conservation efforts to optimize the economic outcomes and environmental benefits of PES.

Overall, the main contributions of this study are reflected in examining incentive coordination in CB-PES in a non-liberal, non-western context, and the economic outcomes of stakeholders and environmental benefits. Specifically, this study adds to the scant literature on CB-PES in the Chinese context by developing one of the initial investigations of PES community participation in the WNR (Chen *et al.* 2020). Moreover, this study adds new empirical analysis to the scant studies on PES community participation (Hayes and Murtinho 2018; Pagdee and Kawasaki 2021). Theoretically, this study adds to the body of work that examines incentive coordination in CB-PES through the lens of differential games (Thompson and Friess 2019; Chen *et al.* 2020). Studies on community-based incentive coordination in PES have not followed pace in this area, despite a growing body of literature that critically examines the connection between community participation and PES (Chen *et al.* 2020). The insights provided by this study on the application of community-based incentive coordination to raise stakeholder revenue and increase social ecosystem service value (ESV) may add something fresh to the body of knowledge in this field. This study will show how community-based incentive coordination in WNR's rural communities offers new evidence for researchers to observe how CB-PES contributes to improved global ecology. Furthermore, while existing research on CB-PES has considered the influence of conservation preferences and perceptions of stakeholders in the community on conservation behaviors (Thompson and Friess 2019; Pagdee and Kawasaki 2021), it has neglected the possibility of coordinating between these stakeholder preferences. Therefore, this study considers how stakeholders' conservation behavior is impacted by the coordinated level of conservation, which adds a heuristic analysis to the body of knowledge on CB-PES.

2. Materials and methods

2.1. Study area

The WNR was established in 1963 as one of the first comprehensive national reserves in China to protect the forest ecosystem and rare species of flora and fauna in southwest China, including the giant panda. In addition, China also established the WNR Administration in 1979 to be responsible for conserving natural resources within the reserve. The reserve is located in Wenchuan County, Sichuan, with approximately 200,000 hectares (see Figure 1). In 1980, the WNR joined the Man and Biosphere Reserve Network of the United Nations Educational, Scientific and Cultural Organization (UNESCO) and cooperated with the World Wildlife Fund to establish the China Research Centre for the Conservation of Giant Pandas (Li Chao and Wen 1984). The WNR has six administrative villages under Wolong Township and Gengda Township. In 2005, the WNR had a resident population of more than 5,000 people, including 4,532 in agriculture. Human activities, including farming, deforestation, transportation, tourism, and medicine collection by local people, have affected nearly a quarter of the WNR, and the more affected areas cannot be restored to giant panda habitat in the short term (Ouyang *et al.* 2001). The loss and fragmentation of the giant panda habitat have become more severe as the population increases in the WNR (Liu *et al.* 1999, 2001).

China has developed several PES programs since 1999, the largest of which is the Grain for Green Program (GFGP), to safeguard the giant panda habitat in the WNR (Yang *et al.* 2013). The GFGP aims to convert steep-slope cropland to forest and grassland and maintain forest cover (Liu *et al.* 2008; Chen *et al.* 2009). To date, the GFGP offers many potential ES, including, but not limited to, increasing forest cover,

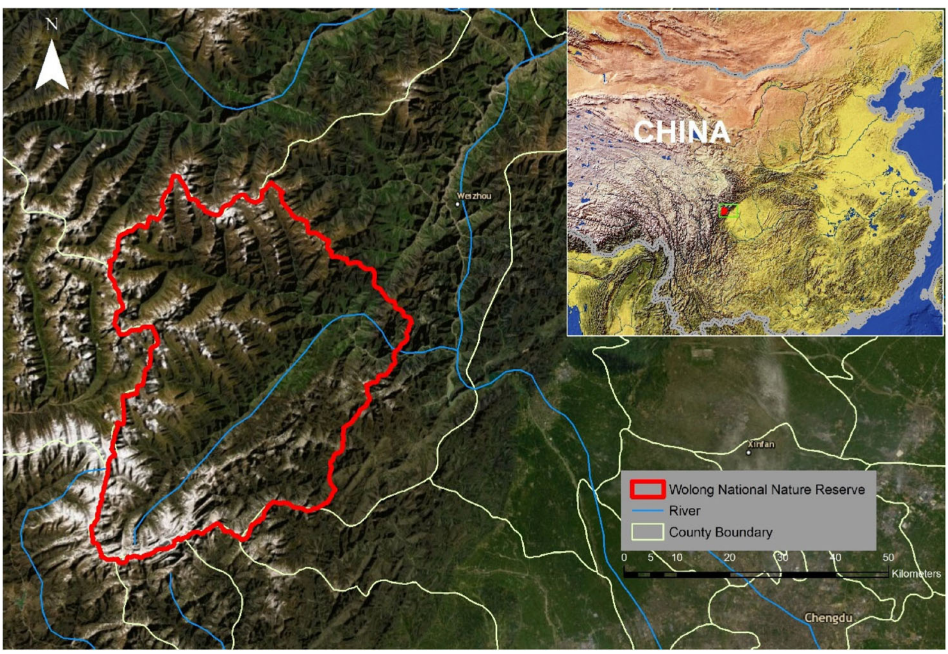

Figure 1. The map of Wolong national Nature Reserve.

reducing stream sediment and nutrient loss to maintain soil fertility, and reducing desertification (Liu and Diamond 2005; Liu *et al.* 2008). Due to the fact that participating households are paid for forest conservation practices, the GFGP also generates revenues for rural households.

WNR was included in the newly established National Park to protect biodiversity further. WNR was included in the Giant Panda National Park (GPNP) pilot in 2017 and officially became part of the newly established GPNP in 2021. Accordingly, the WNR Administration was also incorporated into the new national park management system in 2019 and became the GPNP's Aba Management Branch (Huang *et al.* 2020).

2.2. WNR's key eco-compensation program: grain for Green Program

The WNR's GFGP, one of the eco-compensation programs in China, compensates rural households for their conservation behavior through monetary transfers after considering conservation costs, opportunity costs, and ESV (Le and Leshan 2020). This eco-compensation mechanism is a specific application of PES in China. The GFGP, one of the WNR's most critical eco-compensation programs, includes two phases: the first round of top-down GFGP (2000–2014) and the second round of bottom-up GFGP (2014-present). The differences in eco-compensation models between the two phases also lead to very different levels of community participation in eco-compensation.

The GFGP implemented in China in 1999 was the world's largest and most extensive PES project (Xu *et al.* 2006). The first round of GFGP started in 1999 and lasted 15 years until 2014. Since the official launch of the GFGP pilot in China in 1999, WNR has involved rural households since 2000. The first round of GFGP in WNR adopted a government-led top-down approach, i.e. the central government unified to formulate policies and decentralized tasks to the WNR Administration and township governments.

WNR's first round of GFGP was further subdivided into three phases: pilot, full-scale implementation, and consolidation. (i) Pilot phase. China pioneered the GFGP pilot in three provinces, Sichuan, Shaanxi, and Gansu, in 1999, after which some households in WNR joined this pilot in 2000. (ii) Full-scale implementation phase. China proposed GFGP as an essential initiative to boost domestic demand and increase farmers' income from October 2001 to January 2002, and further expanded the scale of GFGP. Consequently, most households in WNR also joined it (Transcript WNR03). (iii) Consolidation phase. After the original eight years of GFGP implementation, some households experienced livelihood difficulties. Therefore, China extended the GFGP for another cycle in 2007. Accordingly, the first round of WNR's GFGP was extended until 2014. In addition, the forms of eco-compensation in this round are also different (see Table 1).

Due to the various drawbacks of the first round of GFGP, the second round of GFGP from 2014-2020 was changed to a bottom-up approach for implementation. This means that based on households' voluntary declaration of GTGP tasks, the central government approves the scale of eco-compensation in each province and allocates subsidy funds to the province. Provincial governments are specifically responsible for implementing the GFGP in their jurisdictions and determining the eco-compensation standard independently. The second round of WNR's GFGP is the responsibility of the WNR Administration and township governments. The compensation will be distributed

Table 1. The forms of eco-compensation.

Stages of the GFGP	Year	The forms of eco-compensation
The first round of top-down GFGP	2000–2004	The eco-compensation received by participating households in the WNR's GFGP consisted of 150 kg/mu (2,250 kg/hm^2) of grain per year and a cash subsistence allowance of 20 CNY/mu (41.16 USD/hm^2) per year.
	2004–2007	WNR's GFGP changed the original compensation in the form of grain at 1.40 CNY/kg (0.19 USD/kg) to a full cash payment.
	2007–2014	WNR's GFGP compensation became cash compensation of 150 CNY/mu (308.70 USD/hm^2) per year and a subsistence allowance of 20 CNY/mu (41.16 USD/hm^2)
The second round of bottom-up GFGP	2014–2020	The compensation standard for this round of GFGP was 320 CNY/mu (658.56 USD/hm^2) per year.
	2020–2025	The compensation standard for this round of GFGP was 100 CNY/mu (205.8 USD/hm^2) per year.

to households according to the eco-compensation standard of Sichuan Province. The compensation standard for this round of GFGP was 1,600 CNY/mu (3,292.80 USD/hm^2) for five years and was distributed by the central government to provincial governments in three rounds. After its expiration in 2020, China decided to extend this round of GFGP for another five years and pay households cash at 100 CNY/mu (205.80 USD/hm^2) per year (see Table 1). However, this bottom-up eco-compensation only offers the possibility of community participation in PES, and is therefore not pure CB-PES in the strict sense.

2.3. Methods

This study adopted numerical simulation, content analysis, semi-structured interviews, and participant observation to explore incentive coordination in CB-PES. Since purely quantitative modeling relies on distilling critical information from the real world, this study attempts to use the empirical data obtained through content analysis, semi-structured interviews, and participant observation as the background information for examining incentive coordination in CB-PES. Moreover, purely quantitative modeling relies on complex and sophisticated quantitative methods with a range of subtle assumptions, often subject to a range of compromises in practice (Spicker 2018). Therefore, in order to explore the micro-mechanisms by which community participation in WNR affects PES, it is necessary to introduce qualitative methods into the analysis of numerical simulations.

This study first reviewed more than 20 publicly available government documents related to WNR, as well as related Chinese academic literature and media reports. The relevant government documents include those from executive authority (administrative regulations) and legislative bodies (acts). The Chinese academic literature analyzed came from the China Knowledge Network (www.cnki.net), a national Chinese literature database. At least 30 Chinese journal articles were analyzed in this study.

In addition, we conducted field research in WNR in July 2020. Semi-structured interviews with 17 government officials and 24 villagers in the region were conducted for this study based on verbal consent from the interviewees. Questions included experiences and perceptions of community participation in PES, measures they have taken in eco-compensation, and their views on incentive coordination in CB-PES. Interviewees were selected through a combination of convenience and purposeful (snowball) sampling, taking into account regional and sectoral representation. Interviews lasted between 30 and 60 min and were recorded, where permitted. Both authors of this study speak Mandarin, which allowed the interviewees to share their views and opinions in the way they felt best to express themselves. However, the authors' ethnic Chinese background may have affected the interpretation of the data in this study. Therefore, considering possible pre-existing biases or assumptions in data collection and analysis, this study also asked the interviewees about their professional backgrounds and perspectives.

Participant observation was also used in this study, in addition to interviews, to understand further the discursive practices and actual interactions of community participation in the WNR's GTGP. Participant observation sessions included participating in consultation meetings between communities and the WNR Administration, as well as visiting four villages in the WNR. Field notes were prepared for each participant observation meeting to the extent possible. Qualitative thematic analysis was employed in coding the interviews, field notes, and documents.

Differential game models and the corresponding numerical simulations have been widely used to analyze the conservation behaviors of stakeholders in PES because they can be used for continuous game studies with multiple players in a time-continuous system (Sheng and Webber 2021; Fernandez 2009). Therefore, this study used the above empirical data as background information to construct differential game models and numerically simulate the behavior of stakeholders under various scenarios, which ultimately explores the micro-mechanisms of community participation affecting PES in WNR.

3. Stakeholder strategies in different scenarios

This section examines stakeholders' behavior in no eco-compensation, eco-compensation, and incentive-coordinated CB-PES scenarios. The scenarios are denoted by the superscripts A, B, and C, respectively.

3.1. Model specification

The PES in the WNR contains two types of stakeholders: the WNR Administration (G) and landholders (L). The WNR Administration and landholders engage in various conservation behaviors to increase forest area and improve ES, which can be measured by their conservation effort $e_i(t)$ ($i = G, L$). According to the approach by Sheng (2020), the conservation costs of the WNR Administration and landholders are assumed to be related to their efforts at successive times $t \in [0, +\infty)$. The cost functions of the WNR Administration and landholders are set as follows:

$$c_i(t) = \frac{1}{2}\beta_i(e_i(t))^2, i = G,\ L \tag{1}$$

where $c_G(t)$ and $c_L(t)$ represent the conservation costs to the WNR Administration and landholders, respectively. $e_G(t)$ and $e_L(t)$ represent their conservation efforts. β_G, $\beta_L \in (0, +\infty)$ represent their conservation effort coefficients. In order to encourage conservation behavior by landholders, the WNR Administration will provide eco-compensation to landholders. It is assumed that the WNR Administration will provide eco-compensation based on the conservation costs of the landholders and that the eco-compensation rate is $\varphi(t) \in [0, 1]$.

Since it is closely related to forest area, ESV ($v(t)$) is a dynamic process influenced by the conservation efforts of the WNR Administration and landholders, as well as the previous forest area (Li *et al.* 2022). Consequently, $v(t)$ at the moment t is a time-varying differential equation as follows:

$$v(t)' = \frac{dv_t}{dt} = e_G(t) + e_L(t) - \delta v(t) \tag{2}$$

where $v(t)$ represents ESV, and $\delta \in (0, +\infty)$ represents the forest degradation rate. The total PES revenues are assumed to be influenced by a combination of the initial revenues, the conservation efforts of the administration and landholders, and the forest area. Thus, the total revenue function is as follows:

$$\pi(t) = \pi_0 + \mu_G e_G(t) + \mu_L e_L(t) + \tau v(t) \tag{3}$$

where $\mu_{G,}\ \mu_L \in (0, +\infty)$ represent the coefficients of the WNR Administration and landholders' efforts on total revenues. The total revenues are assumed to be distributed between the two in the proportions ω and $1 - \omega$, where $\omega \in [0, 1]$. It is supposed that both parties have the same discount rate $\rho \in [0, 1]$ and will seek to maximize their revenues. Consequently, the objective revenue functions of the WNR Administration and landholders are:

$$\begin{cases} \max_{e_L(t),\ \varphi(t)} \pi_G = \int_0^\infty e^{-\rho t}[\omega\pi(t) - c_G(t) - \varphi c_L(t)]dt \\ \max_{G(t)} \pi_L = \int_0^\infty e^{-\rho t}\left[(1-\omega)\pi(t) - (1-\varphi)c_L(t)\right]dt \end{cases} \tag{4}$$

Ultimately, three control variables ($e_G(t)$, $e_L(t)$, and $\varphi(t)$) and one state variable ($v(t)$) are included in Equations (1)–(4). In light of ESV and time, the WNR Administration and landholders can make feedback decisions.

3.2. Scenario A: no eco-compensation scenario

In the no eco-compensation scenario, the WNR Administration does not provide eco-compensation for conservation behavior provided by landholders, i.e. $\varphi(t) = 0$. In Scenario A, the WNR Administration and landholders determine their optimal effort strategies concurrently and independently because they are independent and equal partners.

Consequently, a Markov feedback Nash equilibrium with the following objective revenue functions represents the optimal combination of strategies for both parties:

$$\begin{cases} \max_{e_L(t),\ \varphi(t)} \pi_G^A = \int_0^\infty e^{-\rho t}\left[\omega\pi(\mathrm{t}) - c_G(t)\right]dt \\ \max_{G(t)} \pi_L^A = \int_0^\infty e^{-\rho t}\left[(1-\omega)\pi(\mathrm{t}) - c_L(t)\right]dt \end{cases} \tag{5}$$

where ${\pi_G}^A(t)$ and ${\pi_L}^A(t)$ denote the revenues of the WNR Administration and landholders, respectively, in Scenario A. The equilibrium conservation efforts of the WNR Administration and landholders in Scenario A are determined as follows after solving the aforementioned model (see Appendix A [online supplementary material]):

$$\begin{cases} e_G^A = \dfrac{\omega[\mu_G(\rho+\delta)+\tau]}{(\rho+\delta)\beta_G} \\ e_L^A = \dfrac{(1-\omega)[\mu_L(\rho+\delta)+\tau]}{(\rho+\delta)\beta_L} \end{cases} \tag{6}$$

where ${e_G}^A$ and ${e_L}^A$ represent the equilibrium conservation efforts of the WNR Administration and landholders, respectively, in Scenario A. At this point, the maximum revenues of the WNR Administration and landholders at the moment t are:

$$\begin{cases} \pi_G^A(t) = \dfrac{\omega\tau}{\rho+\delta}v(t) + \dfrac{\omega\left[\begin{array}{c} -(\delta\mu_L+\mu_L\rho+\tau)^2\omega+\left(\pi_0\ \ \beta_L+{\mu_L}^2\right)\rho^2+\left(\left(2\pi_0\ \ \beta_L+2{\mu_L}^2\right)\delta+2\tau\mu_L\right)\rho \\ +\left(\pi_0\ \ \beta_L+{\mu_L}^2\right)\tau^2+2\tau\mu_L\delta+\tau^2 \end{array}\right]}{\beta_L\rho(\rho+\delta)^2} \\ \quad + \dfrac{\omega^2(\delta\mu_G+\mu_G\rho+\tau)^2}{2\beta_G\beta_L\rho(\rho+\delta)^2} \\ \pi_L^A(t) = \dfrac{\tau(1-\omega)}{\rho+\delta}v(t) + \dfrac{(1-\omega)\left[\begin{array}{c} -(\delta\mu_L+\mu_L\rho+\tau)^2\omega+\left(2\pi_0\ \ \beta_L+{\mu_L}^2\right)\rho^2+\left(\left(4\pi_0\ \ \beta_L+2{\mu_L}^2\right)\delta+2\tau\mu_L\right)\rho \\ +\left(2\pi_0\ \ \beta_L+{\mu_L}^2\right)\delta^2+2\tau\mu_L\delta+\tau^2 \end{array}\right]}{2\beta_L\rho(\rho+\delta)^2} \\ \quad + \dfrac{(1-\omega)\omega(\delta\mu_G+\mu_G\rho+\tau)^2}{\beta_G\rho(\rho+\delta)^2} \end{cases} \tag{7}$$

In addition, the steady-state ESV and the dynamic of optimal ESV are:

$$\begin{cases} v^A = \dfrac{(1-\omega)(\delta\mu_L+\mu_L\rho+\tau)+\omega\beta_L(\delta\mu_G+\mu_G\rho+\tau)}{\delta(\rho+\delta)\beta_G\beta_L} \\ v^A(t) = v^A + (v_0 - v^A)e^{-\delta t} \end{cases} \tag{8}$$

where $v^A$and $v^A(t)$ represent the steady-state ESV and the dynamic of optimal ESV in Scenario A. Since $\partial v^A(t)/\partial t = -\delta(v_0 - v^A)e^{-\delta}$, the ESV gradually improves and converges to the steady-state ESV when the initial ESV(v_0) is lower than the ESV(v^A) at steady-state; conversely, the ESV decreases and converges to the steady-state ESV.

3.3. Scenario B: eco-compensation scenario

In the eco-compensation scenario, the WNR Administration pays for the landholders' ES, which is reflected in the fact that the WNR Administration compensates landholders for the conservation costs in proportion to $\varphi(t)$. Since the WNR Administration determines the compensation rate first, and landholders decide whether to participate in the GFGP based on the compensation, the WNR Administration becomes the leader in Scenario B. This means that the WNR Administration will first develop its conservation strategy and decide on its optimal conservation efforts. Landholders, as followers, will develop their own conservation strategies and determine their optimal conservation efforts based on the WNR Administration's strategy. Consequently, a

Stackelberg master-slave game equilibrium with the following objective revenue functions is the optimal combination of strategies for both parties:

$$\begin{cases} \max_{e_L(t),\ \varphi(t)} \pi_G^B = \int_0^\infty e^{-\rho t}\left[\omega\pi(\mathrm{t}) - c_G(t) - \varphi(t)c_L(t)\right]dt \\ \max_{G(t)} \pi_L^B = \int_0^\infty e^{-\rho t}\left[(1-\omega)\pi(\mathrm{t}) - (1-\varphi(t))c_L(t)\right]dt \end{cases} \tag{9}$$

where $\pi_G{}^B(t)$ and $\pi_L{}^B(t)$ denote the revenues of the WNR Administration and landholders in Scenario B, respectively. The equilibrium conservation efforts and the equilibrium eco-compensation rate of the WNR Administration and landholders are determined as follows after solving the aforementioned model (see Appendix B [online supplementary material]):

$$\begin{cases} e_G^B = \dfrac{\omega[\mu_G(\rho+\delta)+\tau]}{(\rho+\delta)\beta_G} \\ e_L^B = \begin{cases} \dfrac{(1-\omega)[\mu_L(\rho+\delta)+\tau]}{(\rho+\delta)\beta_L}, & \text{when } 0 \le \omega \le \dfrac{1}{3} \\ \dfrac{(\omega+1)[\mu_L(\rho+\delta)+\tau]}{2(\rho+\delta)\beta_L}, & \text{when } \dfrac{1}{3} < \omega \le 1 \end{cases} \\ \varphi^B = \begin{cases} 0, & \text{when } 0 \le \omega \le \dfrac{1}{3} \\ \dfrac{3\omega-1}{\omega+1}, & \text{when } \dfrac{1}{3} < \omega \le 1 \end{cases} \end{cases} \tag{10}$$

where $e_G{}^B$ and $e_L{}^B$ represent the equilibrium conservation efforts of the WNR Administration and landholders in Scenario B, and φ^B represents the equilibrium eco-compensation rate. When $0 \le \omega \le 1/3$, the WNR Administration does not provide eco-compensation to landholders. At this point, the conservation efforts of the WNR Administration and landholders in Scenario B are the same as in Scenario A. Ultimately, the maximum revenues of the WNR Administration and landholders at the moment t in Scenario B are:

$$\begin{cases} \pi_G^B(t) = \dfrac{\tau\omega}{\rho+\delta}v(t) + \dfrac{\left[(\delta\mu_L+\rho\mu_L+\tau)^2\omega^2+(\delta\mu_L+\rho\mu_L+\tau)^2\right]\beta_G}{8\beta_G\beta_L\rho(\rho+\delta)^2} + \dfrac{\omega^2(\delta\mu_G+\rho\mu_G+\tau)^2}{2\beta_G\beta_L\rho(\rho+\delta)^2} \\ \quad + \dfrac{\left[\left(8\pi_0\beta_L+2\mu_L{}^2\right)\rho^2+\left(\left(16\pi_0\beta_L+4\mu_L{}^2\right)\delta+4\tau\mu_L\right)\rho+\left(8\pi_0\beta_L+2\mu_L{}^2\right)\delta^2+4\tau\delta\mu_L+2\tau^2\right]\omega\beta_G}{8\beta_G\beta_L\rho(\rho+\delta)^2} \\ \pi_L^B(t) = \dfrac{\tau(1-\omega)}{\rho+\delta}v(t) + \dfrac{\left[(\delta\mu_L+\rho\mu_L+\tau)^2\beta_G+4\beta_\mathrm{L}(\delta\mu_G+\rho\mu_G+\tau)^2\right]\omega(1-\omega)}{4\beta_G\beta_L\rho(\rho+\delta)^2} \\ \quad + \dfrac{\left[\left(4\left(\pi_0(\rho+\delta)^2\beta_L\right)+(\delta\mu_L+\rho\mu_L+\tau)^2\right)\beta_G\right](1-\omega)}{4\beta_G\beta_L\rho(\rho+\delta)^2} \end{cases} \tag{11}$$

Finally, the steady-state ESV and the dynamic of optimal ESV are:

$$\begin{cases} v^B = \begin{cases} \dfrac{(1-\omega)(\delta\mu_L+\rho\mu_L+\tau)\beta_G+\omega\beta_L(\delta\mu_G+\rho\mu_G+\tau)}{\delta\beta_G\beta_L(\rho+\delta)}, & \text{when } 0\le\omega\le\dfrac{1}{3} \\ \dfrac{(\omega+1)(\delta\mu_L+\rho\mu_L+\tau)\beta_G+2\omega\beta_L(\delta\mu_G+\rho\mu_G+\tau)}{2\delta\beta_G\beta_L(\rho+\delta)}, & \text{when } \dfrac{1}{3}<\omega\le 1 \end{cases} \\ v^B(t)=v^B+(v_0-v^B)e^{-\delta t} \end{cases} \tag{12}$$

where v^B and $v^B(t)$ represent the steady-state ESV and the dynamic of optimal ESV in Scenario B.

3.4. *Scenario C: incentive-coordinated CB-PES scenario*

In the incentive-coordinated CB-PES scenario, the WNR Administration and landholders need to align their interests through community participation. This means that an elected community committee needs to be established to act as an intermediary between the WNR Administration and landholders to participate in task allocation, implementation, reporting, and monitoring in PES (Chen *et al.* 2020). Therefore, the WNR Administration and the community committee representing the interests of the landholders can negotiate coordinated conservation efforts to maximize the total revenues to society. Therefore, the total objective revenue function of the WNR Administration and landholders is:

$$\max_{e_U(t),\, e_L(t)} \pi^C(t) = \int_0^{\infty} e^{-\rho t}\left[\pi(\mathrm{t}) - c_G(t) - c_L(t)\right]dt \tag{13}$$

where $\pi^C(t)$ represents the total revenues in Scenario C. After solving the above model (see Appendix C [online supplementary material]), the equilibrium conservation efforts of the WNR Administration and landholders are obtained as follows:

$$\begin{cases} e_G^C = \dfrac{\omega[\mu_G(\rho+\delta)+\tau]}{(\rho+\delta)\beta_G} \\ e_L^C = \dfrac{\mu_L(\rho+\delta)+\tau}{\beta_L(\rho+\delta)} \end{cases} \tag{14}$$

where $e_G{}^C$ and $e_L{}^C$ represent the equilibrium conservation efforts of the WNR Administration and landholders in Scenario C. At this point, the maximum total revenues at moment t in Scenario C are:

$$\pi^C(t) = \frac{\tau}{\rho+\delta}v(t) + \frac{\left[2\pi_0(\rho+\delta)^2\beta_L + (\delta\mu_L+\rho\mu_L+\tau)^2\right]\beta_G + \beta_L(\delta\mu_G+\rho\mu_G+\tau)^2}{2\beta_G\beta_L\rho(\rho+\delta)^2} \tag{15}$$

Finally, the steady-state ESV and the dynamic of optimal ESV are:

$$\begin{cases} v^C = \dfrac{(\delta\mu_L+\rho\mu_L+\tau)\beta_G+\beta_L(\delta\mu_G+\rho\mu_G+\tau)}{\delta\beta_G\beta_L(\rho+\delta)} \\ v^C(t) = v^C + (v_0 - v^C)e^{-\delta t} \end{cases} \tag{16}$$

where v^C and $v^C(t)$ represent the steady-state ESV and the dynamic of optimal ESV in Scenario C.

4. Results

4.1. Comparison of scenarios

First, the equilibrium conservation efforts of the WNR Administration and landholders in the three scenarios are compared. Equations (6), (10), and (14) can be used to determine the following:

$$e_G^A = e_G^B = \frac{\omega[\mu_G(\rho+\delta)+\tau]}{(\rho+\delta)\beta_G} < e_G^C = \frac{\omega[\mu_G(\rho+\delta)+\tau]}{(\rho+\delta)\beta_G} \tag{17}$$

This result demonstrates that the WNR Administration's equilibrium conservation efforts are highest in Scenario C, while it is the same in Scenarios A and B. When 1/3 $< \omega \le 1$, the following can be obtained:

$$\begin{cases} e_L^B - e_L^A = \dfrac{(3\omega-1)(\delta\mu_L+\rho\mu_L+\tau)}{2\beta_L(\rho+\delta)} > 0 \\ e_L^C - e_L^B = \dfrac{(1-\omega)(\delta\mu_L+\rho\mu_L+\tau)}{2\beta_L(\rho+\delta)} > 0 \end{cases} \tag{18}$$

When $0 \le \omega \le 1/3$, the conservation efforts of the WNR Administration and landholders in Scenario B are the same as those in Scenario A. The above results show that the landholders' conservation efforts are also highest in Scenario C and lowest in Scenario A.

Second, we will compare the revenues of WNR Administration and landholders in Scenarios A and B. When $1/3 \le \omega \le 1$, the following can be obtained in accordance with Equations (7) and (11):

$$\begin{cases} \pi_G^B(t)-\pi_G^A(t)=\dfrac{(3\omega-1)(\delta\mu_L+\rho\mu_L+\tau)\left[\mu_L(3\omega-1)\delta^2+(\rho\mu_L+\tau)(3\omega-1)\delta+4\omega\tau\rho\right]}{8\delta\beta_L\rho(\rho+\delta)^2}>0 \\ \pi_L^B(t)-\pi_L^A(t)=\dfrac{(1-\omega)(3\omega-1)(\delta\mu_L+\rho\mu_L+\tau)\left(\mu_L\delta^2+\delta\mu_L\rho+\delta\tau+2\tau\rho\right)}{4\delta\beta_L\rho(\rho+\delta)^2}>0 \end{cases} \tag{19}$$

The results show that when $1/3 \le \omega \le 1$, the revenues of both the WNR Administration and landholders are higher in scenario B than in scenario A. Therefore, compared to Scenario A, the revenues of both parties in scenario B achieve a Pareto improvement compared to Scenario A.

Third, we will compare the total revenues of the WNR Administration and landholders in Scenarios A and B. When $1/3 \le \omega \le 1$, the following can be obtained in accordance with Equations (7) and (11):

$$\begin{cases} \pi^B(t)-\pi^A(t) = \left(\pi_G^B(t)+\pi_L^B(t)\right) - \left(\pi_G^A(t)+\pi_L^A(t)\right) \\ \quad = \dfrac{(3\omega-1)(\delta\mu_L+\rho\mu_L+\tau)\left[\mu_L\delta^2(\omega+1)+(\rho\mu_L+\tau)(\omega+1)+4\tau\rho\right]}{8\delta\beta_L\rho(\rho+\delta)^2} > 0 \\ \pi^C(t)-\pi^B(t) = \pi^C(t) - \left(\pi_U^B(t)+\pi_L^B(t)\right) = \dfrac{(\eta\theta)^2}{2\mu_L\rho(\rho+\delta)^2} + \dfrac{[\eta\beta(\rho+\delta)+\eta\theta]^2}{8\mu_U\rho(\rho+\delta)^2} > 0 \end{cases} \tag{20}$$

The results show that the total revenue is highest in Scenario C and lowest in Scenario A when $1/3 \le \omega \le 1$.

Finally, after comparing the steady-state ESVs in the three scenarios, the following can be obtained according to Equations (8), (12), and (16):

$$\begin{cases} v^B - v^A = \begin{cases} 0, & \text{when } 0 \le \omega \le \dfrac{1}{3} \\ \dfrac{(3\omega - 1)(\delta\mu_L + \rho\mu_L + \tau)}{2\delta\beta_L(\rho+\delta)} > 0, & \text{when } \dfrac{1}{3} < \omega \le 1 \end{cases} \\ v^C - v^B = \begin{cases} \dfrac{(1-\omega)(\delta\mu_G + \rho\mu_G + \tau)\beta_L + \omega\beta_G(\delta\mu_L + \rho\mu_L + \tau)}{\delta\beta_G\beta_L(\rho+\delta)} > 0, & \text{when } 0 \le \omega \le \dfrac{1}{3} \\ \dfrac{(1-\omega)\left[(\mu_L + \rho\mu_L + \tau)\beta_G + 2(\delta\mu_G + \rho\mu_G + \tau)\beta_L\right]}{2\delta\beta_G\beta_L(\rho+\delta)} > 0, & \text{when } \dfrac{1}{3} < \omega \le 1 \end{cases} \end{cases} \tag{21}$$

The above results show that ESV is highest in Scenario C, lowest in Scenario A, and between the ESVs of these two scenarios in Scenario B.

4.2. Numerical simulation

Due to data accessibility, 2001 was chosen as the base period for this study to examine the conservation behavior of the WNR Administration and landholders under the three scenarios. According to the land-use remote sensing data from the Resource and Environment Science and Data Center (https://www.resdc.cn/Default.aspx), the linearly interpolated forest degradation rate (δ) is set to 0.2724, measured by the percentage of forest area change to the initial forest area in the WNR. The cost coefficient of the WNR Administration (β_G) is set to 0.1486, measured by the ratio of GFGP investment to GFGP area in the WNR. Similarly, according to the Chinese Wolong Household Research Survey from the Inter-University Consortium for Political and Social Research (https://www.icpsr.umich.edu/web/pages/), the cost coefficient of the landholders (β_L) is set to 1.9718, measured by the ratio of the opportunity costs of the landholders' participation in GFGP to the area of the GFGP. The initial revenues (π_0) are set to 9,084, measured by the GDP per capita of WNR.

The coefficient of the WNR Administration's conservation efforts on total revenues (μ_G) is set at 0.4574, measured by the ratio of WNR's GDP to GFGP investment. Similarly, the coefficient of the landholders' conservation efforts on total revenues (μ_L) is set at 1.5867, measured by the ratio of the landholders' income to the opportunity costs of participating in GFGP. The coefficient of ESV on total revenues (τ) is set to 0.5088, measured by the ratio of WNR's GDP to the forest area.

Based on the compensation to opportunity costs ratio, the eco-compensation rate (φ) is set to 0.1805. According to Equation (10), the optimal distribution rate (ω) can be calculated as 0.4187. Finally, according to Sheng and Webber (2021), the discount rate (ρ) is set to 0.1. The specific numerical specification is summarized in Table 2.

The equilibrium conservation efforts of the WNR Administration and landholders can be determined for the three scenarios using Table 2 and Equations (6), (9), and (12) (see Figure 2).

According to Figure 2, the equilibrium conservation efforts of the WNR Administration and landholders are highest in Scenario C and lowest in Scenario A.

Table 2. Numerical specification.

Notation	Description	Unit	Value
δ	Forest degradation rate	%	0.2724
β_G	The cost coefficient of the WNR Administration	RMB/m^2	0.1486
β_L	The cost coefficient of the landholders	RMB/m^2	1.9718
π_0	Initial revenues	RMB/person	9084
μ_G	The coefficient of the WNR Administration's conservation efforts on total revenues		0.4574
μ_L	The coefficient of the landholders' conservation efforts on total revenues		1.5867
τ	The coefficient of ESV on total revenues	RMB/m^2	0.5088
φ	Eco-compensation rate		0.4000
ω	Distribution rate		0.4187
ρ	Discount rate		0.1000

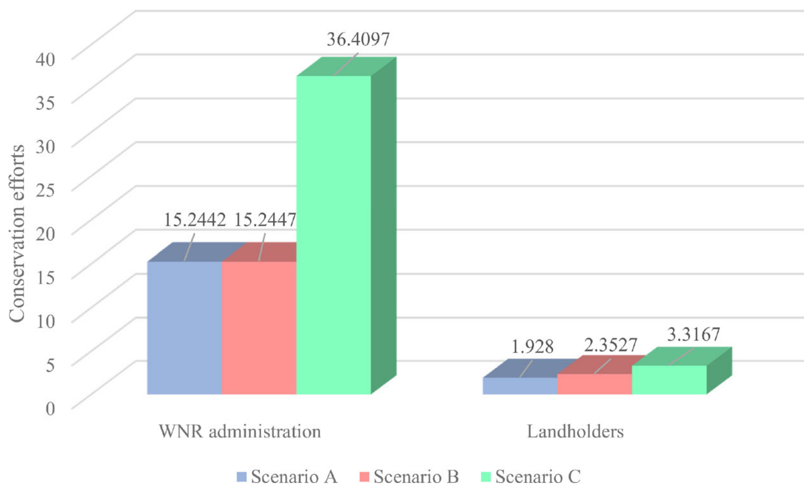

Figure 2. The conservation efforts in the three scenarios.

The equilibrium conservation efforts of the WNR Administration are the same in Scenarios A and B. Compared to Scenarios A and B, the conservation efforts of the WNR Administration in Scenario C increased by 139%, while the conservation efforts of the landholders increased by 72.03% and 40.97%, respectively. It suggests that by adopting an incentive-coordinated CB-PES, the WNR Administration and landholders would increase conservation efforts, thereby improving the ESV of GFGP. The conservation efforts of the landholders in Scenario B increased by 22.03% compared to Scenario A, suggesting that eco-compensation can also improve the conservation effort of the landholders.

In addition, the optimal eco-compensation rate in Scenario B is $\varphi^B = (3\omega\text{-}1)/(\omega+1)$. As $d\varphi/d\omega = 4/(\omega+1)^2 > 0$, the optimal eco-compensation rate (φ) increases as ω increases. This means that the more revenues the WNR Administration distributes in the eco-compensation scenario, the more it shares the conservation costs of the landholders.

According to Table 2, we can obtain the dynamics of stakeholders' revenues (see Figure 3) and the dynamics of total revenues (see Figure 4).

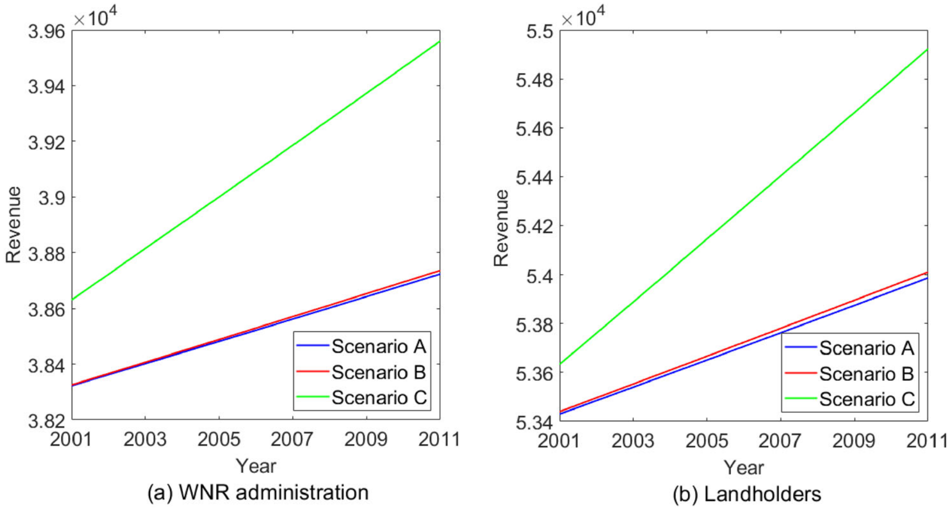

Figure 3. The dynamics of stakeholders' revenues.

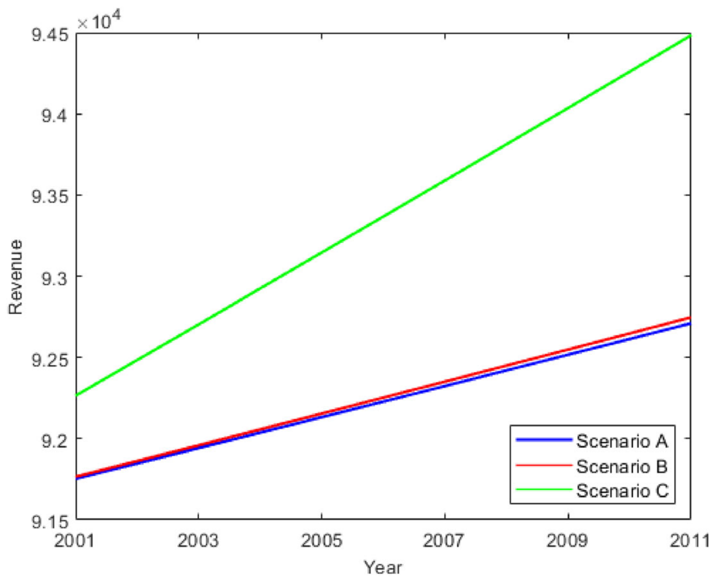

Figure 4. The dynamics of total revenues.

According to Figure 3, the revenues of both the WNR Administration and landholders increase over time in all scenarios. The revenues of both parties are lowest in scenario A and highest in scenario C. Both parties have slightly higher revenues in Scenario B than in Scenario A. This suggests that eco-compensation can bring a slight increase in revenues for both, but it is far from the level of revenues in the incentive-coordinated CB-PES scenario.

According to Figure 4, total revenues also increase over time for all three scenarios. The increase in total revenues is greater in Scenario C than in Scenario B and Scenario A. This suggests that eco-compensation can achieve a Pareto improvement

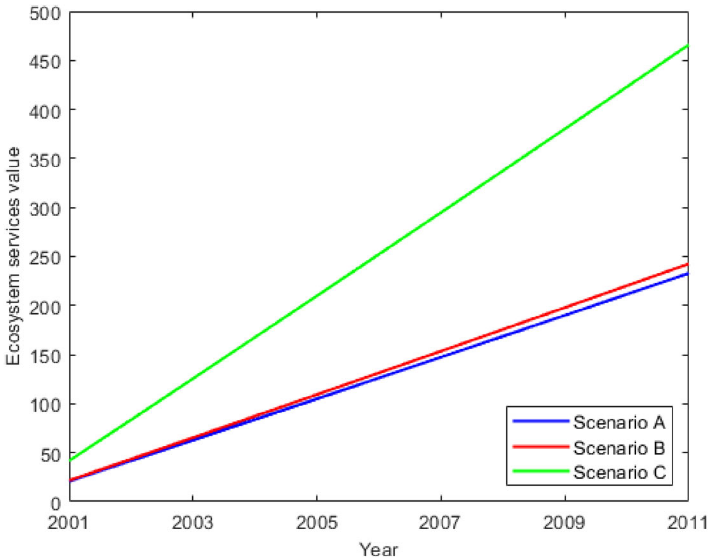

Figure 5. The dynamics of ESV under the three scenarios.

compared to the no eco-compensation scenario, while incentive-coordinated CB-PES can achieve Pareto optimality.

Finally, the dynamics of ESV in the three scenarios can also be obtained from the parameter values in Table 2 (see Figure 5).

According to Figure 5, the ESV also improves over time for the three scenarios. The ESVs in the eco-compensation and incentive-coordinated CB-PES scenarios in 2011 were 1.04 times and two times higher than those in the no eco-compensation scenario. This suggests that eco-compensation slightly improves the ESV, while incentive-coordinated CB-PES substantially improves the ESV.

In summary, stakeholder revenue is higher in the incentive-coordinated CB-PES scenario than in both the eco-compensation and no eco-compensation scenarios, and the scenario has the greatest ESV. However, realizing this ideal state depends on coordinating the conservation efforts of the various stakeholders in the CB-PES. The community committee needs to negotiate mutually acceptable conservation efforts with the WNR Administration that maximize the total benefit to the community while ensuring that both parties gain more than in other scenarios.

4.3. Sensitivity analysis at steady-state

The discount rate (ρ) in the analysis above is set to 0.1. This study employs sensitivity analysis to examine the effect of the discount rate on ESV at steady-state in order to make sure that the results are robust. The discount rate affects the landholders' GFGP participation rates, which, in turn, affects stakeholders' conservation efforts and revenues. Due to $\rho \in [0, 1]$, the discount rate (ρ) is set to 0–1 with a step size of 0. 1. Figure 6 displays the effects of variations in the discount rate on the steady-state ESV in the three scenarios.

Figure 6 shows that the ESVs in all three scenarios continuously fall as the discount rate rises when $0 \leq \rho \leq 0.1$. When $0.1 < \rho \leq 1$, the ESVs in all three scenarios

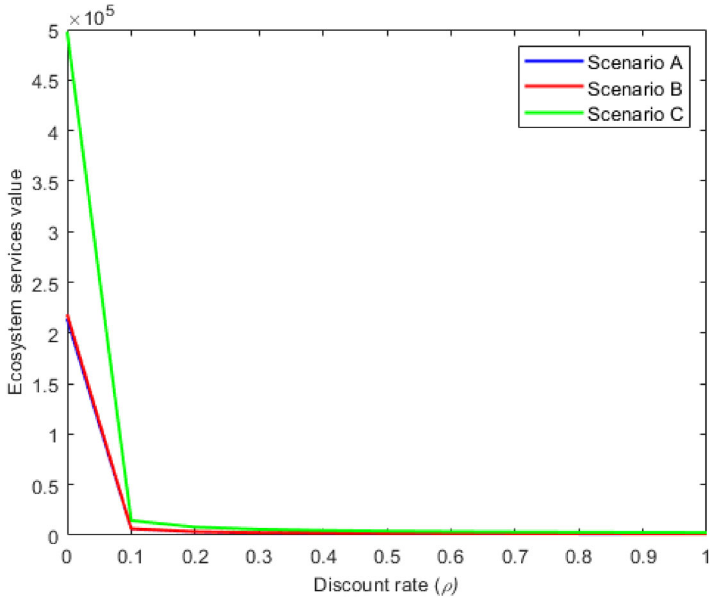

Figure 6. The effect of discount rate on ESV.

gradually tend to zero as the discount rate rises. This demonstrates that a rise in the discount rate makes the WNR Administration and landholders focus more on short-term revenues and less on investments in nature conservation, which worsens the steady-state ESV. Thus, the discount rate has an inverse relationship with the steady-state ESVs for all three scenarios. Furthermore, the ESVs in the three scenarios when $\rho = 0$ are 33.12 times, 33.83 times, and 33.83 times higher than those when $\rho = 0.1$, respectively. This suggests that the ESVs in all three scenarios are very sensitive to the discount rate. Therefore, a change in the discount rate significantly alters the ESV in the WNR regardless of the scenario.

In brief, these results can be summarized as follows: (i) incentive-coordinated CB-PES maximize the revenue of WNR Administration and landholders as well as total revenue, while eco-compensation improves the revenue of both parties to a lesser extent; (ii) compared to the no eco-compensation scenario, eco-compensation slightly improves WNR's environmental benefits, while incentive-coordinated CB-PES substantially improve environmental benefits; (iii) an essential prerequisite for achieving incentive-coordinated CB-PES is that the WNR Administration and landholders negotiate coordinated conservation efforts that maximize the economic outcomes and environmental benefits of PES, so that their respective economic outcomes are also better than the no eco-compensation and eco-compensation scenarios.

5. Discussion

In order to explore the micro-mechanisms by which community participation affects PES, this study developed a PES theoretical model considering ESV. In addition, this study also describes the dynamic conservation behavior of stakeholders in various scenarios using the case of rural communities in China's WNR. The findings show that when the WNR Administration receives more than one-third of the revenue distribution, both the WNR Administration and landholders in the eco-compensation scenario have higher revenues than in the no eco-compensation scenario. In the incentive-coordinated CB-PES scenario, both parties achieve Pareto optimality regarding total revenues and ESV. However, the micro-mechanisms of community participation in influencing PES under this scenario require that the WNR Administration and the community committee representing the interests of the landholders determine the optimal conservation efforts through consultation in order to seek to maximize the total benefits to society. In addition, this study obtains a benefit distribution scheme that guarantees individual rationality in the no eco-compensation scenario. The overall rationality is ensured by introducing a dynamic revenue distribution mechanism in this scheme, which enables the cooperative relationship between the WNR Administration and landholders to stabilize over time.

The transition from top-down to bottom-up eco-compensation in WNR offers the possibility of community participation in PES. The first round of government-led GFGP resulted in limited community participation in WNR, which triggered many drawbacks. Since the first round of WNR's GFGP was completely government-led, communities could not participate in the policy formulation of GFGP. Although the GFGP was theoretically based on voluntary participation, many households insisted they were forced to join (Bennett 2008). The lack of consideration of community and household willingness led to an indifference to forest conservation among households participating in WNR's GFGP (Transcript WNR01). In addition, since the state completely dominates this round of GFGP, households' revenues in the WNR are completely dependent on the state's decisions, leading to continuous protests by farmers for increased compensation (Transcript WNR03). Moreover, the state determines the WNR's GFGP entirely, resulting in the inclusion of some lands unsuitable for GFGP (Delang 2019). Finally, the GFGP's eco-compensation standards are uniform across the country, resulting in WNR's externalities for giant panda conservation not being considered, causing conflicts and contradictions between communities and the WNR Administration (Transcript WNR01). The second round of GFGP changed the previous government-led eco-compensation model, which made community participation in WNR possible. In fact, village committees elected by the villagers have been established in all six villages of the WNR. A critical function of these village committees is to consult with the WNR Administration and township governments on ecosystem conservation activities and eco-compensation distribution. Village committees and households are no longer asked what kind of trees to plant (economic or ecological forests) in the second phase of the GFGP (Delang 2019). The WNR Administration and township governments only provide advisory services to village committees and households, such as advising whether the selected plants suit the local soil and climate. In addition, WNR's village committees have gradually adopted various ways to participate in the GFGP, leading to the emergence of the budding CB-PES. First, the village committees negotiated with the government for specific eco-compensation standards based on WNR's local socioeconomic conditions (Transcript WNR05). Second, the WNR's village committees organized cooperatives to improve the income of the participating households, such as the honey cooperative in WNR's Zhuanjinglou village (Transcript WNR04). Finally, the village committees also negotiated with the WNR Administration to recruit local residents to serve as rangers, thereby increasing their revenues (Transcript WNR11). This series of practices shows that the second round of bottom-up GFGP empowers WNR's community participation through decentralization, which offers potential for incentive coordination in CB-PES.

Compared to traditional PES, CB-PES can deploy a range of incentive-coordinated techniques and practices, ultimately improving economic outcomes for stakeholders and environmental benefits for society. This study confirms that stakeholder revenue is higher in the incentive-coordinated CB-PES scenario than in both the eco-compensation and no eco-compensation scenarios, and the scenario has the greatest ESV. In a traditional PES, communities are only involved in the ES provision rather than the policymaking process of PES, and this limited involvement may not increase the willingness of communities to participate (Wunder 2007; Cremaschi, Lasco, and Delfino 2013; Xuan *et al.* 2012). Moreover, limited community participation can exacerbate the gap between rich and poor, trigger intra-community conflict, and provoke concerns about encroachment on community land (Corbera, Kosoy, and Tuna 2007; Lansing 2015). Incentive coordination techniques that CB-PES can deploy, including negotiation, establishing workshops, and forming communities of interest, allow communities to participate in PES in the form of planning, consultation, governance, and monitoring, thus helping to alleviate internal conflicts of interest in PES and removing obstacles to PES implementation (Denham 2017; Rawlins and Westby 2013). For instance, a villager in Wolong town claimed, "The vast majority of our residents here are Jiarong Tibetans and Qiang, so Tibetan Buddhism is very important to us. Fortunately, after the village committee communicated with the WNR Administration, our sacred mountain and sacred tree were basically protected" (Transcript WNR09). Open and respectful communication in CB-PES helps landholders to build trust and facilitate negotiations with local communities (McGrath, Carrasco, and Leimona 2017). As a result, stakeholders can negotiate sufficiently to develop cost-effective land use practices (McGrath, Carrasco, and Leimona 2017), supporting livelihoods and environmental conservation goals (Davis and Goldman 2019). In addition, the coordination techniques of the workshops can enable collaboration between the WNR Administration and rural communities (Schröter *et al.* 2018). Regular communication between policymakers and community participants is needed in PES research and planning, which helps PES gain long-term support (Thornton and Scheer 2012). Workshops provide community participants with the opportunity to better understand their natural resource use and thus are essential for community participation in natural resource management (Levine and Feinholz 2015). An official from the WNR Administration said, "We regularly communicate with village committees on conservation work every month, and encourage local communities to participate in conservation through ranger agreements. For example, through consultation with local communities, we hired 142 residents as rangers in the towns of Wolong and Genda to improve their income in 2019" (Transcript WNR02). Finally, community-based incentive coordination brings stakeholders together to form a consortium of interests (Bhatta *et al.* 2018; Schröter *et al.* 2018). This allows policymakers to integrate stakeholders' motivations, interests, and values into PES to expand ES provision (Gissi and Garramone 2018), thereby achieving optimal economic outcomes for stakeholders.

Furthermore, CB-PES that aim to achieve incentive coordination rely on participatory intermediary governance. Existing eco-compensation in China excludes potential stakeholders (e.g. civil society, non-profit actors, and NGOs) from acting as intermediaries due to their reliance on governmental and quasi-governmental actors (Chen *et al.* 2020), which leads to increased public and private transaction costs and low economic and environmental benefits (Schröter *et al.* 2018; Zhang, Zinda, and Li 2017). In the participatory intermediary governance model, the community committee, as community governing bodies and representatives of members' interests, acts as a participant and a governor (Chen *et al.* 2020). As a cooperative intermediary linking the PES administration and landholders, the community committee can align the environmental goals of the administration with the interests of local communities, thus achieving community-based incentive coordination. Communities in PES planning can help the administration to clarify objectives and activities expected to be implemented (Rawlins and Westby 2013), as well as prioritize areas for implementation (Corbera, Kosoy, and Tuna 2007), thus achieving CB-PES incentive coordination. In the case of WNR, village committees, as autonomous organizations of the local community, gradually tried to act as an intermediary for the CB-PES. For instance, in 2018, the village committee of WNR's Zhuanjinglou Village initiated the establishment of a community honey cooperative in consultation with the WNR Administration in an attempt to improve Aboriginal incomes by incorporating beekeeping programs into PES (Transcript WNR04). Moreover, in the participatory intermediary governance model, community intermediaries are also able to achieve incentive coordination between ES purchasers and providers due to being granted the right to allocate payments (Sommerville, Jones, *et al.* 2010) and the power to monitor ES providers (Corbera, Kosoy, and Tuna 2007). For instance, one villager in Gengda town declared, "The village committee distributes the eco-compensation revenues of each of our households. In addition, the village committee also coordinates the recruitment of rangers" (Transcript WNR11). Thus, achieving incentive-coordinated CB-PES in the future may depend on how community committees, local experts, social entrepreneurs, and NGOs are transformed into participatory intermediaries.

Designing community-based incentive coordination mechanisms in PES remains challenging, as it also depends on coordinated conservation efforts to optimize the economic outcomes and environmental benefits of PES. As the WNR's case illustrates, the community committee needs to negotiate mutually acceptable conservation efforts with the WNR Administration that maximize the total benefit to the community while ensuring that both parties gain more than other scenarios. The effectiveness of CB-PES implementation often depends on constructing coordinated conservation efforts. For instance, in China's CB-PES project in Jingyuan County, the lack of effective coordination between the community and the PES administration has resulted in a governance model with high cooperation between the administration and the community but low participation by the landholders, which undermines the environmental benefits of PES (C. Chen *et al.* 2020). In contrast, China's CB-PES project in Ringshui County has developed a governance model with high cooperation and participation due to effective coordination (C. Chen *et al.* 2020). In the case of WNR, although village committees would be involved in the distribution of eco-compensation, they were excluded when it came to developing the WNR's tourism industry. A village committee director claimed that "local governments and tourism enterprises dominate the tourism industry in the newly established GPNP, and local residents are not involved in providing tourism services or managing tourism projects. Local residents can only give advice to our village committee. Still, community residents are generally largely uninvolved in managing tourism, and it is difficult to benefit from it" (Transcript WNR07). These facts show that community-based incentive coordination mechanisms are simply not possible in PES when stakeholders cannot reach a consensus on conservation efforts, ultimately harming all stakeholders' interests. Furthermore, PES is not only a tool for better coordinating social interests within an externally imposed value system, but should also be understood as a social construction mediated by the local socioeconomic context (Corbera, Brown, and Adger 2007). Therefore, community-based incentive coordination needs to be adapted to the local socioeconomic context in order to find coordinated conservation efforts. These socioeconomic contexts include, but are not limited to, property rights systems, capacities of local institutions, and institutional relationships within communities (Oldekop *et al.* 2016; Dougill *et al.* 2012). Although challenging, designing community-based incentive coordination is nevertheless feasible. A framework for incentive coordination in CB-PES is offered by the PES theoretical model considering ESV, which helps policymakers to develop and formulate a feasible community-based incentive coordination mechanism.

6. Conclusions

This study scrutinizes, using a differential game approach and the case of rural communities in China's WNR, the role of community-based incentive coordination in PES. It critically examines how community participation affects stakeholders' conservation behavior and the optimal way to proceed in PES. In summary, the CB-PES can deploy a range of incentive-coordinated techniques and practices, ultimately improving economic outcomes for stakeholders and environmental benefits for society. In addition, CB-PES that aim to achieve incentive coordination rely on participatory intermediary governance. Finally, designing community-based incentive coordination mechanisms in PES remains challenging, as it also depends on coordinated conservation efforts to optimize the economic outcomes and environmental benefits of PES.

The findings about the function of community-based incentive coordination in PES highlight the limitations of the prior work. Despite a growing literature critically examining the connection between community participation and PES outcomes (C. Chen *et al.* 2020), the economic and environmental impacts of community participation in PES remain unclear to date, and even less research has problematized the community-based incentive coordination in PES. The PES theoretical model considering ESV may provide a feasible methodology for studying community-based incentive coordination. Furthermore, by focusing on incentive coordination in CB-PES in a non-liberal, non-western context, this study provides new insights into CB-PES in China.

Finally, this study also provides new insights for improving CB-PES. As our study on rural communities in the WNR highlights, participatory intermediary governance, the interests of stakeholders, including but not limited to community committees, local experts, social entrepreneurs, and NGOs, should be included in future CB-PES programs aimed at creating incentive coordination. Furthermore, an understanding of the local socioeconomic context is necessary to find coordinated conservation efforts to achieve sustainable CB-PES.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Supplemental data

Supplemental data for this article can be accessed here.

Funding

This work was supported by the National Natural Science Foundation of China [grant number 72074119].

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