Environmental and Resource Economics (2023) 84:475–506
https://doi.org/10.1007/s10640-022-00730-w

Negotiations over the Provision of Multiple Ecosystem Services

Alain-Désiré Nimubona[1,4] · **Ahmet Ozkardas**[2] · **Jean-Christophe Pereau**[3]

Accepted: 28 August 2022 / Published online: 6 October 2022

Abstract
This paper analyzes the provision of multiple ecosystem services (ES) by several providers (e.g. farmers) and the negotiation process over their payments by many beneficiaries, who are each interested in one specific type of ES. We determine the main factors that influence the beneficiaries and providers' preferences to negotiate individually or collectively. These factors are the number of providers, the marginal product of ecosystem acreage, and the cost/benefit ratio of ecosystem conservation through the payment for ecosystem services (PES). Using Nash-in-Nash bargaining, we show that four Nash equilibria can emerge. In equilibrium, beneficiaries and providers can both negotiate individually or collectively while facing opponents acting individually or collectively. We provide a welfare characterization of all the four equilibria that arise from the bargaining game. We show that the two equilibria in which beneficiaries negotiate collectively can implement the first-best.

Keywords Payments for Ecosystem Services (PES) · Multiple Purchasers · Collective PES · Bilateral Bargaining · Nash-in-Nash

JEL Classification Q15 · Q24 · Q26 · Q28 · Q57 · Q58

1 Introduction

Payments for ecosystem services (PES) have attracted attention as a convenient medium to protect and restore many ecosystems, such as forests, wetlands, watershed, biodiversity, etc. (Ferraro and Kiss 2002; Ferraro and Simpson 2002; Wunder 2005; Wunder et al. 2020). Initially, PES were defined as voluntary agreements between the buyers and sellers of a well-defined ecosystem service (ES) whereby a provider that secures ES provision is

✉ Alain-Désiré Nimubona
animubona@uwaterloo.ca

1 Department of Economics, University of Waterloo, Waterloo, Canada

2 Department of Economics, University of Waterloo, Waterloo, Canada

3 Bordeaux School of Economics (BSE) (UMR-CNRS 6060), Université de Bordeaux, Bordeaux, France

4 CIRANO, Montreal, Canada

rewarded (Wunder 2005).[1] The practice of PES shows that several negotiation configurations can occur throughout the implementation of PES schemes. With regard to the number and the strategies of participating agents**,** for example, PES programs are contracted out by beneficiaries and providers either using individually targeted strategies or through collective action involving groups of beneficiaries or/and providers.

While the literature focuses on the study of PES as individual contracts, collective PES programs may improve performance in the provision of ES (Kerr et al. 2014; Kaczan et al. 2017; Pfaff et al. 2019; Kotchen and Segerson 2020). The purpose of this paper is to encompass the different collective negotiation tactics that can be used on both the demand side and the supply side of ES provision into a bargaining model of PES. Our model comprises many providers and multiple beneficiaries, and we assume that each beneficiary is interested in one specific type of ES. This implies that the number of beneficiaries is the same as the number of ES provided by the ecosystem. This assumption is in line with Smith and Day (2018) and Smith et al. (2019) who only assume two beneficiaries and two ES.

In practice, PES schemes that involve multiple beneficiaries, which Smith and Day (2018) and Smith et al. (2019) refer to as multi-purchaser PES, have numerous advantages including the possibility of cost-sharing as well as an increased efficiency in the provision of multiple and simultaneous ES. A few examples of such multi-purchaser PES are the Bolivian watershed PES in Los Negros and the Costa Rican PSA (Pagos por Servicios Ambientales) scheme (Smith and Day 2018), as well as the UK's Countryside Stewardship agri-environment programme (Smith et al. 2019). However, these multiple-purchaser PES schemes are also associated with high incentives to free ride for the beneficiaries. Ultimately, an under-provision of ES will arise whenever some beneficiaries are free riders and enjoy the ES they are interested in at no cost. Among others, Nimubona and Pereau (2022) already show that this free-rider problem emerges in the provision of the ES because of the public good character of the latter, when considering only one ES and many beneficiaries and independently of the number of providers. With more than one ES and many beneficiaries interested in different ES, the free-rider problem becomes even worse.

We consider different negotiation scenarios, ranging from the negotiation between a group of providers, acting as an unique decision maker, facing individual beneficiaries to that of a group of beneficiaries facing several individual providers. We formalize our negotiation problem in the same setting as Matsushima and Shinohara (2019), who analyze the provision of public good through bilateral negotiations between the providers and the beneficiaries of the good. We differ from Matsushima and Shinohara (2019) by assuming that the public good provision, which corresponds to ecosystem conservation or restoration in our paper, benefits multiple agents in different ways, i.e. through the provision of many different types of ES. Moreover, we consider the presence of many providers. We want to answer the following questions: (i) Is it more profitable either for the providers or the beneficiaries of ES, or for both, to negotiate over PES individually or collectively with their counterparts? (ii) What is the impact of the public good dimension of the created ES in the bargaining game? (iii) What are the welfare properties of the equilibrium configurations? More specifically, under which

[1] This definition has been updated to include transparency and environmental additionality into the design of PES (Tacconi 2012). Wunder (2015) broadened the definition of PES to add that they can take the form of a transaction between providers and users that are subject to negotiated rules for the management of natural resources while highlighting their conditionality and voluntariness properties.

circumstances are the collective-level negotiations by beneficiaries and/or providers welfare-improving?

To answer the above questions, we derive the bargaining outcomes arising from each negotiation scenario. We use the Nash-in-Nash procedure whereby one negotiator is engaged in several negotiations that are separated and simultaneous (Collard-Wexler et al. 2019). We are able to fully characterize the conditions under which the beneficiaries and the providers will opt for individual or collective contracts. We find that the number of providers, the marginal product of ecosystem acreage, and the cost/benefit ratio of ecosystem conservation through the PES scheme influence the beneficiaries and providers' preferences to negotiate individually or collectively. We show that all four possible negotiation outcomes can be Nash equilibria, and we compare them with the social optimum. In the first equilibrium, both the beneficiaries and the providers negotiate individually over the PES. The second equilibrium is obtained when beneficiaries negotiate collectively while providers negotiate individually. The third equilibrium is the symmetric of the previous one. And finally, the fourth equilibrium arises when both the beneficiaries and the providers negotiate collectively.

When there are many (two or more) beneficiaries and providers, we find that the second equilibrium, whereby beneficiaries negotiate collectively while providers negotiate individually, is associated with the highest level of social welfare. In contrast, the third equilibrium, which is the symmetric of the second one, is always associated with the lowest social welfare. Our welfare analysis also suggests that a group of providers negotiating collectively always achieves a socially efficient provision of ES when it negotiates with a group of beneficiaries. Interestingly, providers negotiating individually also provide the socially efficient amount of ES when they are facing beneficiaries that negotiate collectively. Taken all together, these findings suggest that collective PES are effective at dealing with the free-rider problem associated with the presence of many beneficiaries and multiple simultaneous ES.

As discussed in the following literature review section, the earlier literature mostly presents collective PES as a means to use collective action to overcome transaction and monitoring costs associated with individual PES. Among other insights, our results show that collective PES, which imply group-level negotiations for both providers and beneficiaries, can arise as both a Nash-equilibrium and welfare optimum even without considering their well documented advantage in terms of reduced transaction and monitoring costs. We characterize conditions, in terms of the cost/benefit ratio of the provision of ES and the number of players, under which collective negotiations on the supply and/or demand side of ES provision will be a Nash equilibrium.

The remainder of our paper is structured as follows. In section 2, we review the literature and highlight the main contributions of our paper. Section 3 summarizes the key features of our model. Section 4 presents the different PES negotiation scenarios. In section 5, we present our results and highlight the possible outcomes that can emerge as Nash equilibria. We then turn in section 6 to provide a detailed discussion of our results and speculate about the implications of relaxing the simplifying assumptions that we consider in our model. Section 7 concludes our analysis. Finally, the appendix section provides proofs not included in the text.

2 Literature Review

In the economics literature, PES are referred to as Coasean negotiations (Coase 1960; Engel et al. 2008; Medema 2020). This is due to the fact that the ES incentivized through PES schemes are often public goods, and PES consist of voluntary transactions between ES users and providers. We apply the same line of reasoning in our formalization. Also, PES are described as following the beneficiary-pay principle thereby internalizing positive externalities, in contrast to the polluter-pay principle, which consists in the internalization of negative externalities. Our contribution to this literature is that we address multilateral negotiations in PES while highlighting the impact of the presence of externalities and the characteristics of ES as public goods. By formalizing PES as the result of bilateral and simultaneous bargaining, our paper differs from Crépin (2005) who defines PES either as take-it-or-leave-it contracts or uniform contracts.[2] Specifically, our paper relaxes this assumption of take-it-or-leave-it contracts by assuming that both the ecosystem acreage created and the PES are the result of a negotiation procedure. PES have also been formalized in the literature as contracts between ES beneficiaries and providers, using contract theory (Austen and Hanson 2007; Ferraro 2008; Mann et al. 2014).

What is more, with the exception of Nimubona and Pereau (2022), the existing literature focuses on the presence of one ES and two extreme bargaining cases: when there are (i) one beneficiary and many providers; or (ii) many beneficiaries and one provider. As in Nimubona and Pereau (2022), we consider a general model with many beneficiaries and many providers. Nimubona and Pereau (2022) also compare the effectiveness of government financed PES, which implies the presence of an intermediary such as a social planner in PES negotiations, and user-financed PES. They show that the presence of an intermediary in PES negotiations plays an active role in preventing free-riding, which arises when there are many beneficiaries involved in the negotiations. We also argue that there is free riding in our paper since there are many beneficiaries. However, instead of considering the involvement of an intermediary, we investigate the potential role of collective PES that rely on group-level contracts (versus individual PES) as a solution to the free-rider problem.

Furthermore, to add to the complexity of the free-rider problem in Nimubona and Pereau (2022), we consider the presence of more than one ES as each of the many beneficiaries is interested in a different ES. In this regard, our paper is close to Smith and Day (2018) and Smith et al. (2019). However, the experimental approach that the latter use does not explicitly model the ongoing negotiations, and it is restricted to the presence of two beneficiaries (and henceforth two ES) and only one provider. As such, their work amounts to analyzing the effectiveness of multiple-purchaser PES schemes. In contrast to Smith and Day (2018), we analyze the problem of collective action in a multi-purchaser framework as a standard negotiation problem. To be more clear, Smith and Day (2018) develop, in an appendix, a stylized non-cooperative model of two purchasers, but not in a context of negotiation as we do. Also, we do not restrict our analysis to only one price-taker provider facing two beneficiaries. Moreover, we do not consider any type of spatial dimension of ES provision and we do not exclude the possibility of stacking (Salzman 2009 ; Woodward 2011), which are important features in Smith et al. (2019).

[2] In a uniform contract, an authority offers a payment proportional to the ecosystem acreage created and allows providers to choose the acreage. In a take-it-or-leave-it contract, the authority sets both the ecosystem acreage and the transfer.

The paper by Smith and Day (2018) identifies binding pre-commitments to payments as the organizational structure under which multiple-purchaser PES schemes are effective at providing the efficient amount of ES, despite the free-rider problem associated with the presence of multiple beneficiaries. We extend the analytical setup in Smith and Day (2018) to allow for the presence of many competing agents on both the demand and supply sides of ES provision. In so doing, we are able to extend the collective action problem in Smith and Day (2018) to the supply side of the provision of ES. From this perspective, our paper also builds on the literature on collective PES (see, e.g., Kerr et al. 2014; Kaczan et al. 2017; Pfaff et al. 2019; Kotchen and Segerson 2020) whereby groups of beneficiaries contract with groups of providers.

While most of PES schemes in practice involve incentive payments to individual providers of ES, collective PES, which rely on group contracts, are more and more being used in situations where land is collectively owned and/or managed or as a way of reducing transaction and monitoring costs (Kerr et al. 2014; Kotchen and Segerson 2020). In fact, the existing literature distinguishes between collective PES involving a collective tenure or collective property rights upstream and those involving many landowners coordinating and grouping together while holding individually tenured land rights. In this paper, we focus our analysis on collective PES in which payments are made to collectives or communities of providers enjoying collective tenure.[3] Despite the fact that there has been a lot of discussion about the advantages and disadvantages of individual PES and collective PES, existing literature to date analyzes separately their effectiveness in terms of providing ES. What remains missing is some analytical comparison of individual PES and collective PES. We use our general framework to compare the effectiveness of individual and collective PES in the provision of multiple and simultaneous ES.

3 The Model

We consider a multiple-purchaser PES bargaining framework between n identical providers (e.g. farmers), denoted by P_i (with $i = 1, \ldots, n$) of m ecosystem services (ES), denoted by S_j (with $j = 1, .., m$), and m identical beneficiaries, denoted by B_j (with $j = 1, \ldots, m$). Each beneficiary B_j is interested to purchase one specific ES (S_1 for B_1,..., S_m for B_m), and respectively negotiates with the n providers to create an ecosystem acreage $Q_j = \sum_{i=1}^{n} q_{ij}$ where q_{ij} measures the ecosystem acreage (the area of wetland, forest, etc.) created (or conserved) by provider P_i and funded by B_j. We assume that each acre of ecosystem $Q_i = \sum_{j=1}^{m} q_{ij}$ created by P_i and funded by each of the m beneficiaries provides simultaneously the m ES, S_j with $S_j = \sum_{i=1}^{n} s_{i,j}$ where $s_{i,j}$ stands for the amount of ES supplied by P_i. We can think of these ES as any complementary ES, such as biodiversity conservation, recreational activities, water purification, etc. This modelling setup is a generalization of the setup in Smith and Day (2018), which involves the provision of two ES flows to two beneficiaries by one provider. From our general framework, we can also consider the extreme case of only one provider and/or only one beneficiary.

[3] According to Kerr et al. (2014) and Kotchen and Segerson (2020), PES schemes used to incentivize the conservation of forests, watershed, pastures, and ponds are more often than not of this type.

The total amount of ecosystem acreage created is $Q = \sum_{i=1}^{n} Q_i = \sum_{j=1}^{m} Q_j$, where $\sum_{i=1}^{n} Q_i$ is the total amount of ecosystem acreage created by the n providers and $\sum_{j=1}^{m} Q_j$ is the total amount of ecosystem acreage demanded by the m beneficiaries. In exchange of the created ecosystem acreage, beneficiaries have to pay each provider a leasing price p per acre of ecosystem conserved. The n providers create the total amount of ecosystem acreage Q but only charge each beneficiary B_j the share Q_j that is proportional to the quantity of S_j that B_j is enjoying. This amounts to assuming that the provision of ES can be proxied by the amount of ecosystem acreage created.[4] More specifically, the quantity of ES flow S_j depends linearly on the amount of ecosystem acreage created: $S_j = \alpha \sum_{j=1}^{m} Q_j$, where $\alpha > 0$ stands for the transformation rate between the ecosystem acreage and the quantity of ES or the marginal ES product of the ecosystem acreage. It is important to note that the quantity of S_j enjoyed by B_j also depends on the amount of the created ecosystem acreage sponsored by B_k with $k \neq j$, and vice-versa. In other words, the m ES delivered by the PES scheme have public good properties. The ES are enjoyed by multiple beneficiaries but each beneficiary has incentives to free-ride by reducing her own contribution and benefiting from the contribution of the other beneficiaries. Moreover, we assume that there is one type of soil quality, which implies that beneficiaries pay the same price p per acre of ecosystem created, independently of which type of ES they are interested in.

The utility of each provider P_i, denoted as U_{P_i}, corresponds to the leasing revenues minus the ecosystem creation costs consisting in the opportunity cost and the construction cost:

$$U_{P_i} = pQ_i - C(Q_i), \tag{1}$$

with $Q_i = \sum_{j=1}^{m} q_{ij}$. The cost function is assumed to be increasing and convex: $C' > 0$ and $C'' > 0$. The utility of each beneficiary B_j, which we denote as U_{B_j}, is defined as the benefit provided by S_j, the one ES she is interested in, minus the payment to the providers for the amount of ecosystem acreage demanded:

$$U_{B_j} = B(S_j) - pQ_j. \tag{2}$$

The benefit function $B(S_j)$ is assumed to be increasing and concave, $B' > 0$ and $B'' < 0$, implying decreasing marginal utility of ES. Equation (2) can be rewritten as

$$U_{B_j} = B(\alpha Q) - pQ_j, \tag{3}$$

with $Q = \sum_{j=1}^{m} Q_j$. In the sequel of the paper, we consider the following specification for the benefit and cost functions: $B(z) = az - \frac{b}{2}z^2$ and $C(z) = \frac{c}{2}z^2$. Therefore, $B'(z) = a - bz$ and $B'(z) = 0$ when $z = \frac{a}{b}$. We define $\gamma = \frac{c}{b}$ as a cost/benefit ratio.

Let us now define the payoff functions of the providers and the beneficiaries when they engage in collective-level negotiations. For providers, collective PES involve contracts negotiated by communities that hold land and resources under collective tenure. This corresponds to a situation where there is only one entity on the supply side of ES provision, i.e. $n = 1$. At this stage, we do not analyze how this entity will share the benefits and costs inside the community. The utility of the collective of providers is

[4] This assumption is in line with the fact that PES contracts are based in practice on land-use activities instead of the quantity of ES provided (Ferraro 2008).

Table 1 Normal form of the game

Beneficiaries / Providers	I	Co
I	$mU^I_{B_j};nU^I_{P_i}$	$mU^I_{B_j};U^{Co}_P$
Co	$U^{Co}_B;nU^I_{P_i}$	$U^{Co}_B;U^{Co}_P$

$$U_P = pQ - C(Q). \tag{4}$$

It is important to note that cases in which some but not all providers negotiate collectively while others are involved in individual negotiations with beneficiaries are interesting but not easy to incorporate in our model.[5] Adding this aspect is a natural extension of our work but, as we argue later in our discussion section, it is technically challenging and would require additional assumptions. As for the beneficiaries, their utility when they negotiate collectively is obtained by taking the sum of the m identical individual payoffs:

$$U_B = mB(\alpha Q) - pQ. \tag{5}$$

To complete the description of our model, it is helpful to highlight the features of the negotiation game. Each provider and each beneficiary have two strategies at their disposal: they can negotiate individually (denoted by I) or at the collective level (denoted by Co). Given these strategies, both the providers and the beneficiaries play a simultaneous game, the normal form of which is described in Table 1. The expressions in each cell represent the total payoffs the two types of agents receive from their interaction.

This simultaneous negotiation game gives rise to the following 4 different bargaining scenarios depending on whether beneficiaries and/or providers negotiate individual or collective agreements.

1. Scenario I, I:[6] each of the m beneficiaries B_j negotiates individually and simultaneously with each of the n providers P_i over two variables - Q_j, the amount of ecosystem acreage created; and p, the leasing price of the land, which delivers both S_j and S_k $k \neq j$, while B_k does the same over Q_k and p.
2. Scenario Co, I: the m beneficiaries form a group B, which negotiates separately and simultaneously with each of the n providers P_i over an amount of ecosystem acreage Q_i and a price p.
3. Scenario I, Co: the n providers form a group P, which negotiates separately and simultaneously with each B_j over an amount of ecosystem acreage Q_j and p.
4. Scenario Co, Co: the n providers form a group P, which negotiates with the group of the m beneficiaries B over an amount of ecosystem acreage Q and p.

The next section considers and analyzes the different negotiation outcomes resulting from these 4 scenarios.

[5] We thank an anonymous reviewer for pointing that out.

[6] The first letter refers to the beneficiaries' negotiation strategy and the second letter to the providers' strategy.

4 Negotiation Outcomes

When beneficiaries and providers are engaged in multiple simultaneous negotiations, we use the Nash-in-Nash bargaining solution consisting in a Nash equilibrium of several Nash bargaining solutions (Collard-Wexler et al. 2019). The difference between the different scenarios lies on the disagreement payoffs of the negotiators. In some cases, the disagreement payoffs can be the outcome of free riding; in other cases, they can be nil or correspond to the outcomes of the equilibrium agreements reached in other negotiations. In all negotiation scenarios, we assume the same bargaining power for all the players. Our objective is to focus on the impact of the scenarios.

4.1 Scenario *I,I* - Individual Negotiations for both Providers and Beneficiaries

In this scenario, each beneficiary B_j negotiates simultaneously and individually with each provider P_i. We consider this negotiation scenario as our benchmark scenario. In case of negotiation failure between one beneficiary and one provider, we assume that their disagreement payoffs are based on the equilibrium agreements reached with all the other agents they are negotiating with. The generic negotiation between P_i and B_j over q_{ij} and p is given by the maximization of the Nash product

$$\max_{p,q_{ij}} NBS_{P_i,B_j} = \left(U^a_{P_i} - U^d_{P_i}\right)(U^a_{B_j} - U^d_{B_j}), \tag{6}$$

where U^a and U^d stand for the utility in case of agreement and in case of disagreement, respectively. When an agreement is reached, we obtain

$$U^a_{P_i} = p\sum_{j=1}^{m} q_{ij} - C(\sum_{j=1}^{m} q_{ij}), \tag{7}$$

$$U^a_{B_j} = B(\alpha\sum_{j=1}^{m} Q_j) - pQ_j. \tag{8}$$

However a negotiation failure between P_i and B_j means that P_i will not create q_{ij}, but this failure does not impact the agreements reached by B_j with all the other providers and the one reached by P_i with the other beneficiaries B_k (with $k \neq j$) over q_{ik}. This implies that in case of disagreement we have

$$U^d_{P_i} = p\sum_{k\neq j}^{m} q_{ik} - C(\sum_{k\neq j}^{m} q_{ik}), \tag{9}$$

$$U^d_{B_j} = B((\alpha Q_j - q_{ij} + \sum_{k\neq j}^{m} Q_k)) - p\left(Q_j - q_{ij}\right). \tag{10}$$

Net payoffs are defined by

$$U^a_{P_i} - U^d_{P_i} = pq_{ij} - C(\sum_{j=1}^{m} q_{ij}) + C(\sum_{k\neq j}^{m} q_{ik}), \tag{11}$$

$$U^a_{B_j} - U^d_{B_j} = B(\alpha \sum_{j=1}^{m} Q_j) - B((\alpha Q_j - q_{ij} + \sum_{k\neq j}^{m} Q_k)) - pq_{ij}. \tag{12}$$

Substituting (11) and (12) in (6) and then differentiating with respect to p, we obtain

$$p = \frac{1}{2}\left(\frac{B(\alpha \sum_{j=1}^{m} Q_j) - B((\alpha Q_j - q_{ij} + \sum_{k\neq j}^{m} Q_k)}{q_{ij}} + \frac{C(\sum_{j=1}^{m} q_{ij}) - C(\sum_{k\neq j}^{m} q_{ik})}{q_{ij}} \right). \tag{13}$$

Substituting (13) in NBS_{P_i,B_j} given by (6) yields

$$NBS_{P_i,B_j} = \frac{1}{4}\left(B(\alpha \sum_{j=1}^{m} Q_j) - B((\alpha Q_j - q_{ij} + \sum_{k\neq j}^{m} Q_k) - C(\sum_{j=1}^{m} q_{ij}) + C(\sum_{k\neq j}^{m} q_{ik}) \right)^2. \tag{14}$$

The derivative of (14) with respect to q_{ij} then gives

$$\frac{\partial B\left(\alpha \sum_{j=1}^{m} Q_j\right)}{\partial q_{ij}} = \frac{\partial C\left(\sum_{j=1}^{m} q_{ij}\right)}{\partial q_{ij}}. \tag{15}$$

This expression holds for all the m beneficiaries in a symmetric way. We then compute the Nash-in-Nash solution as the Nash equilibrium of the m Nash Bargaining solutions. Using the specified benefit and cost functions, we obtain the following Lemma[7].

Lemma 1 *The Nash-in-Nash Bargaining solution between the n providers P_i (with $i = 1, \dots, n$) and the m beneficiaries B_j (with $j = 1, \dots, m$) yields the PES scheme*

$$\left(Q^{I,I}, p^{I,I}\right) = \left(\frac{n\alpha}{\alpha^2 n + \gamma}\frac{a}{b}, \frac{\alpha\left(\alpha^2 + (4m-1)\gamma\right)}{4m\left(n\alpha^2 + \gamma\right)} a \right),$$

and the corresponding utility levels for P_i and B_j are respectively

$$\begin{aligned} U^{I,I}_{P_i} &= \frac{1}{4}\frac{\alpha^2\left(\alpha^2 + (2m-1)\gamma\right)}{m\left(n\alpha^2+\gamma\right)^2}\frac{a^2}{b}, \\ U^{I,I}_{B_j} &= \frac{1}{4}\frac{n\alpha^2\left(\left(2nm^2-1\right)\alpha^2 + (4m(m-1)+1)\gamma\right)}{m^2\left(n\alpha^2+\gamma\right)^2}\frac{a^2}{b}. \end{aligned}$$

Therefore, the total payoffs of the providers and the beneficiaries are $U^{I,I}_P = nU^{I,I}_{P_i}$ and $U^{I,I}_B = mU^{I,I}_{B_j}$, while total welfare is $W^{I,I} = nU^{I,I}_{P_i} + mU^{I,I}_{B_j}$. Since all the players have the same bargaining power, it can be shown that the negotiation implies an equal sharing of the net payoffs: $U^a_{B_k} - U^d_{B_k} = U^a_{P_i} - U^d_{P_i} = \frac{1}{4}\frac{a^2}{bm^2}\frac{\alpha^2(\alpha^2+\gamma)}{(n\alpha^2+\gamma)^2}$.

[7] The proof of Lemma 1 as well as all the other proofs are in the appendix section.

4.2 Scenario *Co,I* - Collective Negotiation for Beneficiaries and Individual Negotiations for Providers

In this negotiation scenario, all beneficiaries form a group B that negotiates simultaneously and separately with each of the n individual providers P_i. In other words, the beneficiaries opt for a collective agreement while the providers favours individual agreements. Hence, in case of negotiation failure with one provider, the disagreement payoff of the group of beneficiaries will be based on the equilibrium agreements reached with all the other providers, but the disagreement payoff of any unsuccessful provider will be nil. The generic negotiation between the group of beneficiaries B and each provider P_i over q_i and p is given by the maximization of the Nash product

$$\max_{p,q_i} NBS_{P_i,B} = \left(U^a_{P_i} - U^d_{P_i}\right)\left(U^a_B - U^d_B\right), \tag{16}$$

where U^a and U^d stand for the utility in the cases of agreement and disagreement, respectively.

When an agreement is reached, we obtain

$$U^a_{P_i} = pq_i - C\left(q_i\right), \tag{17}$$

$$U^a_B = mB(\alpha Q) - pQ. \tag{18}$$

However, in case of a negotiation failure, we have

$$U^d_{P_i} = 0, \tag{19}$$

$$U^d_B = mB\left(\alpha\left(Q - q_i\right)\right) - p\left(Q - q_i\right). \tag{20}$$

Net payoffs are defined by

$$U^a_{P_i} - U^d_{P_i} = pq_i - C\left(q_i\right), \tag{21}$$

$$U^a_B - U^d_B = m\left(B(\alpha Q) - B\left(\alpha\left(Q - q_i\right)\right)\right) - pq_i. \tag{22}$$

The first order condition with respect to the leasing price $\frac{\partial NBS_{P_i,B}}{\partial p} = 0$ yields

$$p = \frac{1}{2}\left(\frac{m\left(B(\alpha Q) - B\left(\alpha\left(Q - q_i\right)\right)\right)}{q_i} + \frac{C\left(q_i\right)}{q_i}\right). \tag{23}$$

Substituting (23) in $NBS_{P_i,B}$ yields

$$NBS_{P_i,B} = \frac{1}{4}\left(m\left(B(\alpha Q) - B\left(\alpha\left(Q - q_i\right)\right)\right) - C\left(q_i\right)\right)^2. \tag{24}$$

The first order condition with respect to the amount of ecosystem acreage created, i.e. $\frac{\partial NBS_{P_i,B}}{\partial q_{12,i}} = 0$, gives

$$m\frac{\partial B(\alpha Q)}{\partial q_i} = \frac{\partial C\left(q_i\right)}{\partial q_i}. \tag{25}$$

It is then easy to derive the negotiated PES scheme and the utilities of the beneficiaries and providers, as given in the following Lemma.

Lemma 2 *The Nash-in-Nash Bargaining solution between each provider P_i (with $i = 1, \dots, n$) and the group of beneficiaries B yields the PES scheme*

$$\left(Q^{Co,I}, p^{Co,I}\right) = \left(\frac{mn\alpha}{\gamma + mn\alpha^2}\frac{a}{b}, \frac{m\alpha\left(m\alpha^2 + 3\gamma\right)}{4\left(mn\alpha^2 + \gamma\right)}a\right),$$

and the corresponding utility levels for P_i and B are respectively

$$U_{P_i}^{Co,I} = \frac{1}{4}\frac{m^2\alpha^2\left(m\alpha^2 + \gamma\right)}{\left(mn\alpha^2 + \gamma\right)^2}\frac{a^2}{b},$$
$$U_B^{Co,I} = \frac{1}{4}\frac{m^2n\alpha^2\left(\gamma + (2n-1)m\alpha^2\right)}{\left(mn\alpha^2 + \gamma\right)^2}\frac{a^2}{b}.$$

Therefore, the total payoff of the n providers is $U_P^{Co,I} = nU_{P_i}^{Co,I}$, and total welfare is given by $W^{Co,I} = nU_{P_i}^{Co,I} + U_B^{Co,I}$. As it is the case in the previous scenario, the negotiation implies an equal sharing of the net payoffs, i.e. $U_B^a - U_B^d = U_{P_i}^a - U_{P_i}^d = \frac{a^2m^2\alpha^2(m\alpha^2+\gamma)}{4b\left(mn\alpha^2+\gamma\right)^2}$.

4.3 Scenario *I,Co* - Individual Negotiations for Beneficiaries and Collective Negotiation for Providers

In this negotiation scenario, the m individual beneficiaries B_j negotiate simultaneously and separately with a group P of all providers. The generic negotiation between P and each B_j over Q_j and p is given by the maximization of the Nash product

$$\max_{p,Q_j} NBS_{P,B_j} = \left(U_P^a - U_P^d\right)\left(U_{B_j}^a - U_{B_j}^d\right). \tag{26}$$

In case of an agreement, we have

$$U_P^a = p\sum_{j=1}^{m} Q_j - C(\sum_{j=1}^{m} Q_j), \tag{27}$$

$$U_{B_j}^a = B(\alpha\sum_{j=1}^{m} Q_j) - pQ_j. \tag{28}$$

However, in case of a disagreement between B_j and P, the disagreement utility of B_j is her free-riding payoff, and the disagreement utility of P depends on the agreement reached with B_k (with $k \neq j$), i.e.

$$U_P^d = p\sum_{k\neq j}^{m} Q_k - C(\sum_{k\neq j}^{m} Q_k), \tag{29}$$

$$U_{B_j}^d = B(\alpha\sum_{k\neq j}^{m} Q_k). \tag{30}$$

Therefore, the net payoffs of P and B_j are, respectively

$$U_P^a - U_P^d = pQ_j - C(\sum_{j=1}^{m} Q_j) + C(\sum_{k\neq j}^{m} Q_k), \tag{31}$$

$$U_{B_j}^a - U_{B_j}^d = B(\alpha\sum_{j=1}^{m} Q_j) - B(\alpha\sum_{k\neq j}^{m} Q_k) - pQ_j. \tag{32}$$

We obtain a similar negotiation problem with the other B_k (with $k \neq j$) and the group of providers P. The first order condition with respect to p gives

$$p = \frac{1}{2}\left(\frac{B\left(\alpha\sum_{j=1}^{m} Q_j\right) - B\left(\alpha\sum_{k\neq j}^{m} Q_k\right)}{Q_j} + \frac{C(\sum_{j=1}^{m} Q_j) - C(\sum_{k\neq j}^{m} Q_k)}{Q_j}\right). \tag{33}$$

Substituting (33) into NBS_{P,B_j} gives

$$NBS_{P,B_j} = \frac{1}{4}\left(B\left(\alpha\sum_{j=1}^{m} Q_j\right) - B\left(\alpha\sum_{k\neq j}^{m} Q_k\right) - C(\sum_{j=1}^{m} Q_j) + C(\sum_{k\neq j}^{m} Q_k)\right)^2. \tag{34}$$

The first order condition with respect to Q_j gives

$$\frac{\partial B\left(\alpha\sum_{j=1}^{m} Q_j\right)}{\partial Q_j} = \frac{\partial C\left(\sum_{j=1}^{m} Q_j\right)}{\partial Q_j}. \tag{35}$$

Using the specified functions, we obtain the following Lemma.

Lemma 3 *The Nash-in-Nash Bargaining solution between the group of providers P with each beneficiary B_j (with $j = 1, \ldots, m$) yields the PES scheme*

$$\left(Q^{I,Co}, p^{I,Co}\right) = \left(\frac{\alpha}{\alpha^2+\gamma}\frac{a}{b}, \frac{1}{4}\frac{\alpha\left(\alpha^2+(4m-1)\gamma\right)}{m\left(\alpha^2+\gamma\right)}a\right),$$

and the corresponding utility levels for P and B_j are

$$U_P^{I,Co} = \frac{1}{4}\frac{\alpha^2\left(\alpha^2 + (2m-1)\gamma\right)}{m\left(\alpha^2+\gamma\right)^2}\frac{a^2}{b},$$
$$U_{B_j}^{I,Co} = \frac{1}{4}\frac{\alpha^2\left(\left(2m^2-1\right)\alpha^2 + (4m(m-1)+1)\gamma\right)}{m^2\left(\alpha^2+\gamma\right)^2}\frac{a^2}{b}.$$

Therefore, the total payoff of all the m beneficiaries is $U_B^{I,Co} = mU_{B_j}^{I,Co}$, and total welfare is given by $W^{I,Co} = mU_{B_j}^{I,Co} + U_P^{I,Co}$. It can again be shown that the negotiation implies an equal sharing of the net payoffs: $U_{B_k}^a - U_{B_k}^d = U_P^a - U_P^d = \frac{1}{4}\frac{a^2}{bm^2}\frac{\alpha^2}{\alpha^2+\gamma}$.

4.4 Scenario *Co,Co* - Collective Negotiations for both Providers and Beneficiaries

The last scenario refers to a bilateral negotiation between two groups - the group P of providers and the group B of beneficiaries, given by the maximization of the Nash product

$$\max_{p,Q} NBS_{P,B} = \left(U_P^a - U_P^d\right)\left(U_B^a - U_B^d\right). \tag{36}$$

In case of an agreement, we have

$$U_P^a = pQ - C(Q), \tag{37}$$

$$U_B^a = mB(\alpha Q) - pQ. \tag{38}$$

But in case of a disagreement, both groups get zero payoffs: $U_P^b = U_B^d = 0$. The first order condition with respect to p gives

$$p = \frac{1}{2}\left(\frac{mB(\alpha Q)}{Q} + \frac{C(Q)}{Q}\right). \tag{39}$$

Substituting (39) into $NBS_{P,B}$ gives

$$NBS_{P,B} = \frac{1}{4}(mB(\alpha Q) - C(Q))^2. \tag{40}$$

The first order condition with respect to Q gives

$$m\frac{\partial B(\alpha Q)}{\partial Q} = \frac{\partial C(Q)}{\partial Q}. \tag{41}$$

It is then possible to derive the negotiated PES scheme and the utilities of the beneficiaries and providers, as shown in the following Lemma.

Lemma 4 *The Nash-in-Nash Bargaining solution between the group of providers P and the group of beneficiaries B yields the PES scheme*

$$\left(Q^{Co,Co}, p^{Co,Co}\right) = \left(\frac{\alpha m}{m\alpha^2+\gamma}\frac{a}{b}, \frac{1}{4}\frac{m\alpha\left(m\alpha^2+3\gamma\right)}{m\alpha^2+\gamma}a\right),$$

and the corresponding utility levels for P and B are

Table 2 Total amount of ecosystem acreage created Q

Beneficiaries / Providers	I	Co
I	$Q^{I,I} = \frac{n\alpha}{\alpha^2 n+\gamma}\frac{a}{b}$	$Q^{I,Co} = \frac{\alpha}{\alpha^2+\gamma}\frac{a}{b}$
Co	$Q^{Co,I} = \frac{mn\alpha}{\gamma+mn\alpha^2}\frac{a}{b}$	$Q^{Co,Co} = \frac{\alpha m}{m\alpha^2+\gamma}\frac{a}{b}$

$$U_P^{Co,Co} = U_B^{Co,Co} = \frac{1}{4}\frac{\alpha^2 m^2}{m\alpha^2+\gamma}\frac{a^2}{b}.$$

Therefore, total welfare is $W^{Co,Co} = U_P^{Co,Co} + U_B^{Co,Co}$. In this last scenario, it is easy to show that each group gets the same net payoff since the disagreement payoff is nil for both groups.

5 Results

In this section, we first determine which negotiation scenarios will be better for the beneficiaries and the providers. It is worthwhile to note that beneficiaries prefer a larger amount of ecosystem acreage created and a lower leasing price, while providers prefer a higher price. Therefore, the lower is the leasing price and/or the larger is the amount of ecosystem acreage created under a specific negotiation scenario, the higher is the corresponding utility for the beneficiaries. In the same vein, the utility of providers under a specific scenario with a high price should be high. Second, we use the results from this comparison of negotiation scenarios to derive the Nash equilibria of the bargaining game between the m beneficiaries and n providers.

5.1 Comparing the Negotiation Scenarios

First, let us analyze under which conditions the amount of ecosystem acreage created will be the largest and what will be the payoff outcomes of the simultaneous game between the beneficiaries and the providers. As mentioned above, we consider that players on both the demand and supply side of ES provision have the choice between two strategies: they can negotiate individually (I) or at the collective level (Co).

Our results from the comparison of the different negotiation scenarios based on the amount of ecosystem acreage created are depicted in Table 2 and summarized in Proposition 1.

Proposition 1 *Other things equal, the amounts of ecosystem acreage created from our four negotiation scenarios compare as follows:*

- for $n = 1$ and $\forall m$, $Q^{I,I} = Q^{I,Co}$ and $Q^{Co,I} = Q^{Co,Co}$;
- for $m = 1$ and $\forall n$, $Q^{Co,I} = Q^{I,I}$ and $Q^{Co,Co} = Q^{I,Co}$;
- for $n > m$, $Q^{Co,I} > Q^{I,I} > Q^{Co,Co} > Q^{I,Co}$;
- for $n = m$, $Q^{Co,I} > Q^{I,I} = Q^{Co,Co} > Q^{I,Co}$;
- for $n < m$, $Q^{Co,I} > Q^{Co,Co} > Q^{I,I} > Q^{I,Co}$.

Table 3 Land leasing price p

Beneficiaries / Providers	I	Co
I	$p^{I,I} = \frac{\alpha(\alpha^2+(4m-1)\gamma)}{4m(n\alpha^2+\gamma)}a$	$p^{I,Co} = \frac{1}{4}\frac{\alpha(\alpha^2+(4m-1)\gamma)}{m(\alpha^2+\gamma)}a$
Co	$p^{Co,I} = \frac{m\alpha(m\alpha^2+3\gamma)}{4(mn\alpha^2+\gamma)}a$	$p^{Co,Co} = \frac{1}{4}\frac{m\alpha(m\alpha^2+3\gamma)}{m\alpha^2+\gamma}a$

Table 4 Total utilities

B / P	I	Co
I	$U_B^{I,I} = \frac{mn\alpha^2((2nm^2-1)\alpha^2+(4m(m-1)+1)\gamma)a^2}{4bm^2(n\alpha^2+\gamma)^2}$	$U_B^{I,Co} = \frac{m\alpha^2((2m^2-1)\alpha^2+(4m(m-1)+1)\gamma)a^2}{4bm^2(\alpha^2+\gamma)^2}$
	$U_P^{I,I} = \frac{n\alpha^2(\alpha^2+(2m-1)\gamma)}{4m(n\alpha^2+\gamma)^2}\frac{a^2}{b}$	$U_P^{I,Co} = \frac{\alpha^2(\alpha^2+(2m-1)\gamma)a^2}{4m(\alpha^2+\gamma)^2 b}$
Co	$U_B^{Co,I} = \frac{m^2n\alpha^2(\gamma+(2n-1)m\alpha^2)a^2}{4b(mn\alpha^2+\gamma)^2}$	$U_B^{Co,Co} = \frac{\alpha^2m^2a^2}{4b(m\alpha^2+\gamma)}$
	$U_P^{Co,I} = \frac{nm^2\alpha^2(m\alpha^2+\gamma)a^2}{4b(mn\alpha^2+\gamma)^2}$	$U_P^{Co,Co} = \frac{m^2\alpha^2a^2}{4b(m\alpha^2+\gamma)}$

To put Proposition 1 in words, the amount of ecosystem acreage created is the largest when beneficiaries collectively negotiate individual agreements simultaneously with each of the n providers (scenario Co, I). On the contrary, the amount of ecosystem acreage created is the smallest when providers form a collective bargaining unit that negotiates simultaneously individual agreements with each of the beneficiaries (scenario I, Co). The interpretation of these results is quite intuitive: with respect to our benchmark scenario, i.e. scenario I, I in which both the beneficiaries and the providers negotiate individual agreements, beneficiaries (providers) increase their bargaining power when they negotiate at the collective level while providers (beneficiaries) still negotiate individual agreements. Intuitively, when beneficiaries become more powerful than providers, they use this opportunity to secure a larger amount of ecosystem acreage created. Conversely, a decrease in beneficiaries' bargaining power when providers negotiate collectively translates into a decrease in the amount of ecosystem acreage created. Between the above two extreme scenarios (i.e. Co, I and I, Co), we can show that the comparison between $Q^{I,I}$and $Q^{Co,Co}$ depends on the respective numbers of beneficiaries and providers. As we assume that the number of ES is equal to the number of beneficiaries, the most relevant configuration is to assume that the number of providers exceeds the number of beneficiaries, $n > m$, in which case $Q^{Co,I} > Q^{I,I} > Q^{Co,Co} > Q^{I,Co}$. Of course, it is not surprising that $Q^{I,I} = Q^{I,Co}$ and $Q^{Co,I} = Q^{Co,Co}$ when $n = 1$, and $Q^{Co,I} = Q^{I,I}$ and $Q^{Co,Co} = Q^{I,Co}$ when $m = 1$.

From the comparison of our results for the land leasing prices, we obtain Table 3 and Proposition 2.

Proposition 2 *Other things equal, the land leasing prices resulting from our four negotiation scenarios compare as follows*:

- for $n = 1$ and $\forall m$, $p^{Co,Co} = p^{Co,I}$ and $p^{I,Co} = p^{I,I}$;

- for $m = 1$ and $\forall n$, $p^{Co,I} = p^{I,I}$ and $p^{Co,Co} = p^{I,Co}$;
- for $n \geqslant 2$ and $m \geqslant 2$, $p^{Co,Co} > p^{I,Co} > p^{I,I}$ and $p^{Co,Co} > p^{Co,I}$; moreover $p^{Co,I} > p^{I,I}$ if $\gamma < (1+m)\alpha^2$.

When there are many (two or more) beneficiaries and providers, Proposition 2 shows that the highest leasing price is always $p^{Co,Co}$, which is obtained when both the beneficiaries and the providers negotiate a collective agreement. As for when the lowest leasing price is obtained, it depends on the value of the cost/benefit ratio γ. For relatively low values of γ, i.e. $\gamma < (1+m)\alpha^2$, the lowest price is obtained when both the beneficiaries and the providers negotiate individual agreements ($p^{I,I}$). For relatively high values of γ, i.e. $\gamma > (1+m)\alpha^2$, the lowest price might be obtained when beneficiaries negotiate as a group with individual providers ($p^{Co,I}$). Also, we unsurprisingly find that $p^{Co,Co} = p^{Co,I}$ and $p^{I,Co} = p^{I,I}$ when $n = 1$, and $p^{Co,I} = p^{I,I}$ and $p^{Co,Co} = p^{I,Co}$ when $m = 1$.

Table 4 and Lemma 5 follow from the comparison of the equilibrium levels of total of utilities, based on the number of providers (n), the number of beneficiaries (m), the marginal product of ecosystem acreage (α), and the cost/benefit ratio of ecosystem acreage creation (γ).[8]

Lemma 5 *Other things equal, the beneficiary total utilities derived from our four negotiation scenarios compare as follows*:

- for $n = 1$ and $\forall m$, $U_B^{Co,Co} = U_B^{Co,I}$ and $U_B^{I,I} = U_B^{I,Co}$;
- for $m = 1$ and $\forall n$, $U_B^{Co,Co} = U_B^{I,Co}$ and $U_B^{I,I} = U_B^{Co,I}$;
- for $n \geqslant 2$, $U_B^{I,I} > U_B^{I,Co}$ and $U_B^{Co,I} > U_B^{Co,Co}$;
- for $m \geqslant 2$, $U_B^{I,I} > U_B^{Co,I}$ if $\gamma < (m+1)\alpha^2$ or if $\gamma > (m+1)\alpha^2$ and $n < \widetilde{n}$ with $\widetilde{n} = \gamma \frac{\left((m-1)^2\gamma - (m^2+m+1)\alpha^2\right) - \sqrt{m\left(\left(m^3-4m^2+5m-1\right)\gamma^2 + \left(4m^2-2m^3-m+1\right)\alpha^2\gamma + m\alpha^4\right)}}{m\alpha^2\left((m+1)\alpha^2-\gamma\right)}$, where $\widetilde{n}$ is decreasing in γ and increasing in α; but if $\gamma > (m+1)\alpha^2$ and $n > \widetilde{n}$ then $U_B^{I,I} < U_B^{Co,I}$.
- for $m = 2$, $U_B^{I,Co} > U_B^{Co,Co}$; but for $m > 2$, $U_B^{I,Co} > U_B^{Co,Co}$ if $\gamma < \widetilde{\gamma}$ with $\widetilde{\gamma} = \frac{(2m^2+1)\alpha^2 + \sqrt{\alpha^4\left(8m^4-8m^3-4m^2+4m+1\right)}}{2\left(m^2-3m+1\right)}$ and if $\gamma > \widetilde{\gamma}$ then $U_B^{I,Co} < U_B^{Co,Co}$.

Also, we find the following results for the providers:

- for $n = 1$ and $\forall m$, $U_P^{Co,Co} = U_P^{Co,I}$ and $U_P^{I,I} = U_P^{I,Co}$;
- for $m = 1$ and $\forall n$, $U_P^{Co,Co} = U_P^{I,Co}$ and $U_P^{I,I} = U_P^{Co,I}$;
- $m \geqslant 2$, $U_P^{Co,Co} > U_P^{I,Co}$;
- $n \geqslant 2$, $U_P^{Co,I} > U_P^{Co,Co}$ if $\gamma > m\sqrt{n}\alpha^2$, but if $\gamma < m\sqrt{n}\alpha^2$ then $U_P^{Co,Co} > U_P^{Co,I}$;
- $n \geqslant 2$, $U_P^{I,I} > U_P^{I,Co}$ if $\gamma > \sqrt{n}\alpha^2$; but if $\gamma < \sqrt{n}\alpha^2$ then $U_P^{I,Co} > U_P^{I,I}$.

One can interpret Lemma (5) as follows. When two or more beneficiaries face two or more providers that negotiate individually, the former have no incentives to negotiate collectively and always prefer to negotiate individually ($U_B^{I,I} > U_B^{Co,I}$) for relatively low values of the cost/benefit ratio ($\gamma < (m+1)\alpha^2$) or as long as the the number of providers is

[8] In Table 4, B and P stand respectively for Beneficiaries and Providers.

relatively small ($n < \widetilde{n}$). Moreover, when there are only two beneficiaries ($m = 2$), these beneficiaries have no incentive to negotiate collectively and prefer to negotiate individually when they face a group of providers negotiating collectively ($U_B^{I,Co} > U_B^{Co,Co}$). When there are more than two beneficiaries, this happens only for relatively low values of the cost/benefit ratio ($\gamma < (m+1)\alpha^2$). Unsurprisingly, we find that $U_B^{Co,Co} = U_B^{Co,I}$ and $U_B^{I,I} = U_B^{I,Co}$ when $n = 1$, while $U_B^{Co,Co} = U_B^{I,Co}$ and $U_B^{I,I} = U_B^{Co,I}$ when $m = 1$. As far as providers are concerned, on one hand, they always get a higher payoff when they negotiate collectively as a group with a group of beneficiaries than with individual beneficiaries ($U_P^{Co,Co} > U_P^{I,Co}$). On another hand, when facing a group of beneficiaries, providers prefer to negotiate individually ($U_P^{Co,I} > U_P^{Co,Co}$) for relatively high values of the cost/benefit ratio ($\gamma > m\alpha^2\sqrt{n}$). Finally, providers get a higher payoff by negotiating individually when they must negotiate with individual beneficiaries ($U_P^{I,I} > U_P^{I,Co}$) for relatively high values of the cost/benefit ratio ($\gamma > \alpha^2\sqrt{n}$), but they prefer to negotiate at the collective level otherwise.

When the number of providers is large, beneficiaries have a higher bargaining power due to a higher disagreement payoff. In case of negotiation failure with one provider, they know that they are able to secure an agreement with all the other providers. Besides, with respect to the benchmark case of *I*, *I*, the formation of a group by beneficiaries entails a “loss" for the providers because their disagreement payoff is nil in case of failure, and this decreases their bargaining power. In the *I*, *I* case, providers continue to reach an agreement with one beneficiary following a failure with the other beneficiary. With respect to the benchmark scenario *I*, *I*, when providers negotiate at the collective level, the “loss" is now on the beneficiaries side because their disagreement payoff decreases.[9] Moreover, as already pointed out, when both the beneficiaries and providers engage in collective-level negotiations, their bargaining power is the same, and as a consequence they get the same payoff.

5.2 Outcomes of the Negotiation Game

Using the above comparison of the different negotiation scenarios, it is helpful, then, to derive and characterize Nash equilibria that arise from the game. For this purpose, we assume that the players have to decide simultaneously which strategies to adopt as described by the normal form of the game in Table 1. Based on Table 4, the outcomes of the game are given by the following proposition.

Proposition 3 *Each one of our negotiation scenarios can arise as a Nash Equilibrium* (*NE*) *of the negotiation game*:

- scenario *I*, *I* is a NE when $\gamma \in]\sqrt{n}\alpha^2, (1+m)\alpha^2[$ or when $\gamma > \max(\sqrt{n}\alpha^2, (1+m)\alpha^2)$ with $n \le \widetilde{n}$, and

[9] In the scenario *I*, *I*, for example, a beneficiary B_j gets a disagreement payoff equal to $U_{B_j}^d = B\left(\alpha\left(Q_j - q_{ji} + \sum_{k\neq j}^m Q_k\right)\right) - p\left(Q_j - q_{ji}\right)$, but in the scenario *I*, *Co* her disagreement payoff is $U_{B_j}^d = B\left(\alpha\sum_{k\neq j}^m Q_k\right)$.

Table 5 Total Welfare

Beneficiaries / Providers	I	Co
I	$W^{I,I}=\frac{1}{2}\frac{n\alpha^2\left(mn\alpha^2+(2m-1)\gamma\right)}{\left(n\alpha^2+\gamma\right)^2}\frac{a^2}{b}$	$W^{I,Co}=\frac{1}{2}\frac{\alpha^2\left(m\alpha^2+(2m-1)\gamma\right)}{\left(\alpha^2+\gamma\right)^2}\frac{a^2}{b}$
Co	$W^{Co,I}=\frac{1}{2}\frac{m^2n\alpha^2}{mn\alpha^2+\gamma}\frac{a^2}{b}$	$W^{Co,Co}=\frac{1}{2}\frac{m^2\alpha^2}{m\alpha^2+\gamma}\frac{a^2}{b}$

$$\widetilde{n}=\gamma\frac{\left((m-1)^2\gamma-\left(m^2+m+1\right)\alpha^2\right)-\sqrt{m\left(\left(m^3-4m^2+5m-1\right)\gamma^2+\left(4m^2-2m^3-m+1\right)\alpha^2\gamma+m\alpha^4\right)}}{m\alpha^2\left((m+1)\alpha^2-\gamma\right)};$$

- scenario Co, I is a NE when $\gamma>\max(m\sqrt{n}\alpha^2,(1+m)\alpha^2)$ with $n>\widetilde{n}$;
- scenario I, Co is a NE when $\gamma<\sqrt{n}\alpha^2$ for $m=2$ and when $\gamma<\min(\sqrt{n}\alpha^2;\widetilde{\gamma}\alpha^2)$ for $m>2$ with $\widetilde{\gamma}=\frac{\left(2m^2+1\right)\alpha^2+\sqrt{\alpha^4\left(8m^4-8m^3-4m^2+4m+1\right)}}{2\left(m^2-3m+1\right)}$;
- scenario Co, Co is a Nash equilibrium when $\gamma\in]\widetilde{\gamma}\alpha^2,m\sqrt{n}\alpha^2[$ but only for $m>2$.

Proposition (3) suggests that according to the value of the cost-benefit ratio γ, four Nash Equilibria can be the outcome of the negotiation game. In particular, the scenario I, Co is a NE for relatively low values of γ ($\gamma<\sqrt{n}\alpha^2$) when there are only two beneficiaries ($m=2$) or for $\gamma<\min(\sqrt{n}\alpha^2;\widetilde{\gamma}\alpha^2)$ when there are more than two beneficiaries ($m>2$). This Nash equilibrium appears more likely to occur when the number of providers (n) is relatively large and/or when the marginal product of ecosystem acreage (α) is high. In this case, the amount of ecosystem acreage created is small as per Proposition (1), and providers have a strong incentive to negotiate at the collective level while beneficiaries prefer to negotiate individually. In contrast, when the number of providers is small ($n<\widetilde{n}$) and for relatively high values of γ ($\gamma>m\sqrt{n}\alpha^2$), the scenario I, I arises as a NE. However, when γ is large while the number of providers is large ($n>\widetilde{n}$), the scenario Co, I becomes a NE. In this case, the amount of ecosystem acreage created is large as per Proposition (1), and beneficiaries prefer to negotiate collectively. Interestingly, when there are only two beneficiaries and two ES ($m=2$), the scenario Co, Co, in which both the beneficiaries and the providers negotiate at the collective level is the only scenario that can never arise as a NE. As long as $m>2$, such a NE can occur for specific values of γ ($\gamma\in]\widetilde{\gamma}\alpha^2,m\sqrt{n}\alpha^2[$).

6 Discussion

In this section, we provide further explanation of our main results, with a focus on social welfare analysis, as well as more discussion for policy implications. We also offer some speculations as to the implications of relaxing our main simplifying assumptions.

6.1 Social Welfare and Policy Implications

Before deriving the socially optimal amount of ecosystem acreage, we first compare the social welfare levels corresponding to each of our four negotiation scenarios. Table 5 and Proposition (4) summarize the results from this comparison.

Proposition 4 *Other things equal, the total welfare levels associated with our four negotiation scenarios compare as follows*:

- for $n = 1$ and $\forall m$, $W^{I,I} = W^{I,Co} > W^{Co,I} = W^{Co,Co}$;
- for $m = 1$ and $\forall n$, $W^{I,I} = W^{Co,I} > W^{Co,Co} = W^{I,Co}$;
- for $n \geqslant 2$ and $m \geqslant 2$, $W^{Co,I} > W^{I,I} > W^{Co,Co} > W^{I,Co}$ if $\gamma > \widehat{\gamma}$ with $\widehat{\gamma} = \frac{mn(n-1)}{m^2-n(2m-1)}\alpha^2$; but if $\gamma < \widehat{\gamma}$ then $W^{Co,I} > W^{Co,Co} > W^{I,I} > W^{I,Co}$.

Proposition (4) says that, when there are two or more providers and two or more beneficiaries ($n \geqslant 2$ and $m \geqslant 2$), total welfare is the highest when beneficiaries negotiate collectively as a group simultaneous and individual agreements with each of the n providers (scenario Co, I). In contrast, total welfare is the lowest when beneficiaries negotiate individually while providers negotiate collectively as a group (scenario I, Co). Proposition (4) also suggests the following welfare analysis results. First, total welfare is always greater when there are two or more beneficiaries that negotiate collectively as a group with two or more individual providers (scenario Co, I) than when both the n beneficiaries and the m providers, with $n \geqslant 2$ and $m \geqslant 2$, negotiate at the collective level (scenario Co, Co). Second, total welfare is always greater when there are both two or more beneficiaries and providers ($n \geqslant 2$ and $m \geqslant 2$) that both negotiate at the collective level (scenario Co, Co) than when providers negotiate collectively as a group with individual beneficiaries (scenario I, Co). Third, welfare when both beneficiaries and providers negotiate at the individual level (scenario I, I) will be greater than welfare when both negotiate at the collective level (scenario Co, Co) for higher number of providers relative to beneficiaries ($n > m$). Fourth, when there is only one provider ($n = 1$), in which case $W^{I,I} = W^{I,Co}$ and $W^{Co,I} = W^{Co,Co}$, then total welfare is the highest when beneficiaries negotiate individually. Finally, when there is only one beneficiary ($m = 1$), in which case $W^{I,I} = W^{Co,I}$ and $W^{Co,Co} = W^{I,Co}$, total welfare is also the highest when providers negotiate individually.

It is straightforward to see from Propositions (3) and (4) that the scenario Co, I is the Nash Equilibrium that gives rise to the highest total welfare when $n \geqslant 2$ and $m \geqslant 2$, while the scenario I, Co is the worst Nash Equilibrium in terms of welfare. In line with the existing theory on collective bargaining in environmental economics,[10] our results suggest that beneficiaries negotiating at the collective level are less prone to the free-rider problem, and therefore negotiating as a group can be profitable in terms of maximizing the amount of ecosystem acreage created, the ensuing provision of ES, as well as social welfare.

From a public policy standpoint, the results derived above have the following ramifications. In practice, collective PES that imply group-level negotiations for both providers and beneficiaries, are viewed as a means to use collective action to overcome transaction and monitoring costs associated with individual PES. Our findings suggest, however, that collective PES can be more efficient than individual PES in terms of providing ES, even without considering the presence of transaction costs. In particular, collective PES schemes relying on group-level contracts emerge from our analysis as an effective solution to dealing with free-riding issues that arise from the provision of multiple and simultaneous ES by many providers to many beneficiaries.

[10] See, for example, Barret (1994) and Carraro and Siniscalco (1993) in the context of climate change negotiation.

Before concluding our social welfare analysis, let us compare the outcomes of our negotiation scenarios with the social optimum. For this purpose, we derive the social optimal or first-best amount of ecosystem acreage, which a social planner would seek to induce providers to create. Here, we assume that the social planner acts as an intermediary between the beneficiaries and providers of ES, and her objective is to insure optimal ecosystem acreage creation by providers. We first consider the case where providers decide individually about the amount of ecosystem acreage created. The social planner's objective function corresponds to:

$$W^I = \sum_{j=1}^{m} B(S_j^I) - \sum_{i=1}^{n} C\left(Q_i^I\right). \tag{42}$$

The total ecosystem acreage created by the n identical providers is $Q^I = nQ_i^I$. Therefore, the social optimum amount of ecosystem acreage created is obtained by solving the following social welfare maximization problem:

$$\max_{Q^I} W^I = \sum_{j=1}^{m} B(\alpha\left(Q^I\right)) - nC\left(\frac{Q^I}{n}\right). \tag{43}$$

The first-order condition for this maximization problem is:

$$m\alpha B'(\alpha Q^{I^*}) - C'\left(\frac{Q^{I^*}}{n}\right) = 0. \tag{44}$$

Given our specific functions defined above, (44) implies that the socially optimal total amount of ecosystem acreage created by individual providers, which we index with the superscript I^*, is:

$$Q^{I^*} = \frac{mn\alpha}{\alpha^2 mn + \gamma}\frac{a}{b}. \tag{45}$$

We can now derive the corresponding first-best social welfare by substituting (45) into (42):

$$W^{I^*} = \frac{1}{2}\frac{m^2 n\alpha^2}{mn\alpha^2 + \gamma}\frac{a^2}{b}. \tag{46}$$

As mentioned above, a collective-level negotiation by providers corresponds to a situation where there is only one entity on the supply side of ES provision, i.e. $n = 1$. Therefore, we can derive from (45) and (46) respectively the socially optimal total amount of ecosystem acreage created and the corresponding first-best social welfare, when providers negotiate collectively:

$$Q^{Co^*} = \frac{m\alpha}{\alpha^2 m + \gamma}\frac{a}{b}; \tag{47}$$

$$W^{Co^*} = \frac{1}{2}\frac{m^2\alpha^2}{m\alpha^2 + \gamma}\frac{a^2}{b}. \tag{48}$$

We can now compare the social optimum amounts of ecosystem acreage created (Eqs. 45 and 47) and the corresponding first-best social welfare (Eq. 46 and 48) with the outcomes from our negotiation scenarios (Tables 1 and 4). From this comparison, it is easy to see that $Q^{I^*} = Q^{Co,I}$ and $W^{I^*} = W^{Co,I}$, while $Q^{Co^*} = Q^{Co,Co}$ and $W^{Co^*} = W^{Co,Co}$. This finding constitutes our last proposition

Proposition 5 *The following two negotiation scenarios can implement the first-best*:

- scenario Co, I in which multiple beneficiaries negotiate collectively with individual providers;
- scenario Co, Co in which both the beneficiaries and providers negotiate at the collective level.

Our last proposition confirms the interpretation of our main results above that collective PES schemes, in which beneficiaries negotiate collectively, are efficient at providing multiple ES to many beneficiaries. The policy message of this proposition and the above is that government intervention might be needed during the implementation of PES schemes to attain optimal social and ecosystem conservation outcomes. Among other types of government intervention, encouraging collective negotiations on the supply and/or demand side of ES provision seems like a promising avenue to achieve that.

6.2 Potential Implications of Relaxing Some of our Simplifying Assumptions

To derive our results, our model makes a number of simplifying assumptions. We now discuss the key features of these assumptions and speculate about potential implications of relaxing some of them. However, understanding the full consequences of these features will require additional research.

First, we assume that transaction costs are nil, but the latter might depend on the number of providers. For example, one could think that providers acting collectively can reduce transaction costs, which might be substantial in the presence of a large number of providers negotiating individually (Kerr et al. 2014; Kaczan et al. 2017). We can refer to the model in Nimubona and Pereau (2022) to extrapolate how transaction costs will affect our results. Intuitively, one can argue that transaction costs will reduce the amount of ecosystem acreage created. Note that the presence of transaction costs in our model can be interpreted as an increase in γ , the cost/benefit ratio. Moreover, one can argue that transaction costs are higher with individual PES than collective PES. The results from our model already show that the scenario where both beneficiaries and providers negotiate collectively can emerge as a Nash equilibrium that implements the first-best. Therefore, adding this assumption will increase the likelihood that this scenario emerges as a Nash equilibrium. Furthermore, with high transaction costs, the outcomes of all negotiation scenarios will likely be different from the social optimum, as in Coase (1960).

Second, multiple-purchaser PES are more complex in practice than our model suggests. For example, multiple-purchaser PES involve more often than not spatial aspects and complementarity between multiple ES (Smith and Day 2018; Smith et al. 2019). Indeed, we can rely on Smith et al. (2019) to discuss about the spatial considerations associated with multiple ES flows. Note that there are two potential spatial aspects associated with multiple-purchaser PES: (i) spatially interdependent ES on the supply side of the provision of ES; and (ii) spatially interdependent benefits on the demand side. Intuitively, when ES are located close to each other, more incentives for collective PES arise. For spatially interdependent benefits, the beneficiary who is located closer to the source of ES flow of her interest enjoys more benefits than the ones located further away. In the context of our model, this would correspond to including heterogeneity with different values of α for different beneficiaries. One can argue that the comparison of the different values of α for different beneficiaries will play a key role in the characterization of the Nash equilibria.

Third, our paper does not consider any form of asymmetric information. According to Ferraro (2008), it is realistic to assume the existence of asymmetric information regarding the benefits from and/or the costs of ecosystem acreage creation, which may yield inefficient outcomes (Ferraro 2008, p 814, Footnote 4). These inefficiencies may take the form of delay or failure in negotiations. In this perspective, it is also important to consider heterogeneous players and the potential for hidden information, and this intuitively leaves more room for government intervention in maximizing the efficiency of collective PES.

Last but not least, we assume that collective-level negotiations are such that all agents on the demand or supply side of the provision of ES commit to negotiating collectively with their counterparts. However, one can argue that some but not all agents might negotiate collectively while others are involved in individual contracts as shown in Clark and Pereau (2021). In the context of our model, the partial bargaining scenario in Clark and Pereau (2021) would correspond to a situation where there is only one player on either side of the negotiation table, i.e. when either one beneficiary or one provider is involved in all the negotiation contracts with their opponents on the other side of the negotiation. To determine the optimal number of agents on either the supply or demand side of ES provision that will participate in a collective PES agreement, we would require both internal and external stability conditions in the sense of D'Aspremont et al. (1983), as defined in the economic theory of cartel stability. Clark and Pereau (2021) show that the maximum size of a stable bargaining group is three players, as it is the case in the context of public goods (see e.g., Barrett, 1994; Carraro and Siniscalco, 1993; Finus 2008; Nordhaus 2015; Hannam et al. 2017; etc.). A model considering the formation of several bargaining groups in a context of many providers and many beneficiaries is beyond the scope of this paper and we leave it for future research.

7 Conclusion

This paper has analyzed negotiations over payments for ecosystem services (PES) when ecosystem restoration benefits many agents (the beneficiaries), each of whom is looking to increase the delivery of a different ecosystem service (ES). We assumed that the multiple ES of interest are delivered simultaneously through each acre of ecosystem land created by multiple providers (e.g. farmers). This implies that the actions of each beneficiary to increase the delivery of the ES of her interest also provide the many other ES. In particular, we highlighted the implications of the public nature of these ES. On the supply side, providers have no incentive to provide the ES before the implementation of the PES scheme. Moreover, the demand side of the market that emerges from the PES scheme is the subject of a prisoner's dilemma problem that mitigates against collective action (Smith and Day 2018).

When the multiple beneficiaries negotiate with many providers over PES, their interactions can take different forms. We investigated two interaction strategies: individual negotiations and collective negotiations. Under the first strategy, beneficiaries (providers) do not consider their counterpart actions when making their decisions, and they negotiate individually with providers (beneficiaries) with the objective of maximizing their individual utility. Under the second strategy, beneficiaries (providers) cooperate and pool their resources to create ecosystem acreage. One important feature of the second strategy is that it gives rise to a monopsony (monopoly) when beneficiaries (providers) negotiate as a group. We considered how four different negotiation scenarios, based on these two different interaction strategies, affect the provision of ES. Using a Nash-in-Nash procedure, consisting in a Nash equilibrium computed from the solutions of the Nash bargaining between beneficiaries and providers, we found that each of our four negotiation scenarios that can arise from the negotiation game can be a Nash equilibrium. In equilibrium, both beneficiaries and providers can notably negotiate at the collective level. Moreover, the two negotiation scenarios in which beneficiaries negotiate collectively can implement the first-best. This suggests that collective PES involving group-level contracts are an effective solution to dealing with free-riding issues that arise from the provision of multiple and simultaneous ES by many providers to many beneficiaries.

Appendix

Proof of Lemma (1)

Using the specified benefit and cost functions, the first order condition (15) for all providers P_i, with $i = 1, \dots, n$, can be rewritten as

$$a\alpha - b\alpha^2 \sum_{j=1}^{m} Q_j = c \sum_{j=1}^{m} q_{ij}.$$

Since $Q = \sum_{j=1}^{m} Q_j$ and assuming that the n providers are identical, which implies that $\sum_{j=1}^{m} q_{ij} = \frac{Q}{n}$, we have

$$a\alpha n - b\alpha^2 nQ = cQ,$$

giving

$$Q^{I,I} = \frac{n\alpha}{\alpha^2 n + \gamma} \frac{a}{b}, \tag{49}$$

with $\gamma = \frac{c}{b}$. Since both beneficiaries and providers are identical we have $Q^{I,I} = mQ_j^{I,I}$ and $Q^{I,I} = nQ_i^{I,I}$.

Substituting (49) in equation (13) gives the negotiated leasing price

$$p^{I,I} = \frac{1}{2}\left(\frac{B\left(\alpha Q^{I,I}\right) - B\left(\alpha\left(Q^{I,I} - \frac{1}{n}Q_j^{I,I}\right)\right)}{\frac{1}{n}Q_j^{I,I}} + \frac{C\left(\frac{1}{n}Q^{I,I}\right) - C\left(\frac{1}{n}Q^{I,I} - \frac{1}{n}Q_j^{I,I}\right)}{\frac{1}{n}Q_j^{I,I}} \right).$$

Using the specified benefit and cost functions, we obtain

$$p^{I,I} = \frac{\alpha\left(\alpha^2 + (4m-1)\gamma\right)}{4m\left(n\alpha^2 + \gamma\right)} a. \tag{50}$$

We derive the expressions of the utilities of each provider and each beneficiary by substituting (49) and (50) into (7) and (8), respectively

$$\begin{aligned}
U_{P_i}^{I,I} &= \frac{1}{n} p^{I,I} Q^{I,I} - C\left(\frac{Q^{I,I}}{n}\right) = \frac{1}{4} \frac{\alpha^2\left(\alpha^2 + (2m-1)\gamma\right)}{m\left(n\alpha^2 + \gamma\right)^2} \frac{a^2}{b}, \\
U_{B_j}^{I,I} &= B(\alpha Q^{I,I}) - \frac{1}{m} p^{I,I} Q^{I,I} = \frac{1}{4} \frac{n\alpha^2\left(\left(2nm^2 - 1\right)\alpha^2 + (4m(m-1)+1)\gamma\right)}{m^2\left(n\alpha^2 + \gamma\right)^2} \frac{a^2}{b}.
\end{aligned}$$

From the above expressions, it is straightforward to get the expression of total welfare:

$$W^{I,I} = nU_{P_i}^{I,I} + mU_{B_j}^{I,I} = \frac{1}{2} \frac{n\alpha^2\left(mn\alpha^2 + (2m-1)\gamma\right)}{\left(n\alpha^2 + \gamma\right)^2} \frac{a^2}{b}.$$

Proof of Lemma (2)

Using the benefit and cost specifications, the first order condition (25) can be rewritten as

$$m\left(\alpha a - \alpha^2 bQ\right) = cq_i.$$

Since providers are identical, i.e. $q_i = \frac{Q}{n}$, the above equation immediately gives the following expression for the amount of ecosystem acreage created

$$Q^{Co,I} = \frac{mn\alpha}{\gamma + mn\alpha^2} \frac{a}{b}. \tag{51}$$

The expression for the negotiated price is obtained by substituting (51) into (23):

$$p = \frac{1}{2}\left(\frac{m\left(B\left(\alpha Q^{Co,I}\right) - B\left(\alpha\left(Q^{Co,I} - \frac{1}{n}Q^{Co,I}\right)\right)\right)}{\frac{1}{n}Q^{Co,I}} + \frac{C\left(\frac{1}{n}Q^{Co,I}\right)}{\frac{1}{n}Q^{Co,I}}\right),$$

which gives

$$p^{Co,I} = \frac{m\alpha\left(m\alpha^2 + 3\gamma\right)}{4\left(mn\alpha^2 + \gamma\right)} a. \tag{52}$$

We immediately get the expressions of the utility of each provider P_i and the group of beneficiaries B by substituting the expressions of (51) and (52) into (17) and (18), respectively

$$U_{P_i}^{Co,I} = \frac{1}{n}p^{Co,I}Q^{Co,I} - C(\frac{1}{n}Q^{Co,I}) = \frac{1}{4}\frac{m^2\alpha^2\left(m\alpha^2+\gamma\right)}{\left(mn\alpha^2+\gamma\right)^2}\frac{a^2}{b},$$

$$U_B^{Co,I} = mB\left(\alpha Q^{Co,I}\right) - p^{Co,I}Q^{Co,I} = \frac{1}{4}\frac{m^2n\alpha^2\left(\gamma+(2n-1)m\alpha^2\right)}{\left(mn\alpha^2+\gamma\right)^2}\frac{a^2}{b}.$$

Finally, total welfare is given by

$$W^{Co,I} = U_B^{Co,I} + nU_{P_i}^{Co,I} = \frac{1}{2}\frac{m^2n\alpha^2}{mn\alpha^2+\gamma}\frac{a^2}{b}.$$

Proof of Lemma (3)

Using the first order condition (35) and the specified benefit and cost functions, we have

$$a\alpha - b\alpha^2\sum_{j=1}^{m}Q_j = c\sum_{j=1}^{m}Q_j,$$

which yields

$$Q^{I,Co} = \sum_{j=1}^{m}Q_j^{I,Co} = \frac{\alpha}{\alpha^2+\gamma}\frac{a}{b}. \tag{53}$$

Noting that $\sum_{k\neq j}Q_k = \sum_j Q_j - Q_j$, the expression of the negotiated price (33) can be rewritten as

$$p = \frac{1}{2}\left(\frac{B\left(\alpha Q^{I,Co}\right) - B\left(\alpha\left(Q^{I,Co}-Q_j\right)\right)}{Q_j} + \frac{C\left(Q^{I,Co}\right) - C\left(Q^{I,Co}-Q_j\right)}{Q_j}\right).$$

Given that all the m beneficiaries are identical, we also have $Q_j = \frac{1}{m}Q^{I,Co}$, and the above expression is equivalent to

$$p = \frac{1}{2}\left(\frac{B\left(\alpha Q^{I,Co}\right) - B\left(\alpha\left(Q^{I,Co}-\frac{1}{m}Q^{I,Co}\right)\right)}{\frac{1}{m}Q^{I,Co}} + \frac{C\left(Q^{I,Co}\right) - C\left(Q^{I,Co}-\frac{1}{m}Q^{I,Co}\right)}{\frac{1}{m}Q^{I,Co}}\right). \tag{54}$$

Substituting (53) into (54) gives

$$p^{I,Co} = \frac{1}{4}\frac{\alpha\left(\alpha^2+(4m-1)\gamma\right)}{m\left(\alpha^2+\gamma\right)}a. \tag{55}$$

We immediately get the expressions of the utility of the group of providers P and each beneficiary B_j by substituting the expressions of (53) and (55) into (27) and (28), respectively

$$U_P^{I,Co} = p^{I,Co}Q^{I,Co} - C(Q^{I,Co}) = \frac{1}{4}\frac{\alpha^2\left(\alpha^2+(2m-1)\gamma\right)}{m\left(\alpha^2+\gamma\right)^2}\frac{a^2}{b},$$

$$U_{B_j}^{I,Co} = B\left(\alpha Q^{I,Co}\right) - \frac{1}{m}p^{I,Co}Q^{I,Co} = \frac{1}{4}\frac{\alpha^2\left(\left(2m^2-1\right)\alpha^2+(4m(m-1)+1)\gamma\right)}{m^2\left(\alpha^2+\gamma\right)^2}\frac{a^2}{b}.$$

Finally, total welfare is given by

$$W^{I,Co} = mU_{B_j}^{I,Co} + U_P^{I,Co} = \frac{1}{2}\frac{\alpha^2\left(m\alpha^2+(2m-1)\gamma\right)}{\left(\alpha^2+\gamma\right)^2}\frac{a^2}{b}.$$

Proof of Lemma (4)

Using the first order condition (41) and the specified cost and benefit functions, we have

$$m\left(a\alpha - b\alpha^2 Q\right) = cQ,$$

which gives the following expression of the amount of ecosystem acreage created

$$Q^{Co,Co} = \frac{\alpha m}{m\alpha^2+\gamma}\frac{a}{b}. \tag{56}$$

The following expression of the negotiated price is obtained by substituting (56) into (39)

$$p^{Co,Co} = \frac{1}{2}\left(\frac{mB\left(\alpha Q^{Co,Co}\right)}{Q^{Co,Co}} + \frac{C(Q^{Co,Co})}{Q^{Co,Co}}\right) = \frac{1}{4}\frac{m\alpha\left(m\alpha^2+3\gamma\right)}{m\alpha^2+\gamma}a. \tag{57}$$

We can then derive the expressions of the utility of the group of providers P and the group of beneficiaries B by substituting the expressions of (56) and (57) into (37) and (38), respectively

$$U_B^{Co,Co} = mB\left(\alpha Q^{Co,Co}\right) - p^{Co,Co}Q^{Co,Co} = \frac{1}{4}\frac{\alpha^2 m^2}{m\alpha^2+\gamma}\frac{a^2}{b},$$

$$U_P^{Co,Co} = p^{Co,Co}Q^{Co,Co} - C(Q^{Co,Co}) = \frac{1}{4}\frac{a^2}{b}\frac{m^2\alpha^2}{m\alpha^2+\gamma}.$$

Finally, total welfare is given by

$$W^{Co,Co} = U_B^{Co,Co} + U_P^{Co,Co} = \frac{1}{4}\frac{\alpha^2 m^2}{m\alpha^2+\gamma}\frac{a^2}{b} + \frac{1}{4}\frac{a^2}{b}\frac{m^2\alpha^2}{m\alpha^2+\gamma}.$$

Proof of Proposition (1)

From Table 2, we obtain the following expressions of the variations of the amount of ecosystem acreage created across our four different negotiation scenarios:

- $Q^{Co,I} - Q^{I,I} = \frac{a}{b} n\alpha \frac{\gamma}{(n\alpha^2+\gamma)(mn\alpha^2+\gamma)}(m-1)$;
- $Q^{I,I} - Q^{Co,Co} = \frac{a}{b} \alpha \frac{\gamma}{(m\alpha^2+\gamma)(n\alpha^2+\gamma)}(n-m)$;
- $Q^{Co,Co} - Q^{I,Co} = \frac{a}{b} \alpha \frac{\gamma}{(m\alpha^2+\gamma)(\alpha^2+\gamma)}(m-1)$;
- $Q^{Co,I} - Q^{Co,Co} = \frac{a}{b} m\alpha \frac{\gamma}{(m\alpha^2+\gamma)(mn\alpha^2+\gamma)}(n-1)$;
- $Q^{Co,I} - Q^{I,Co} = \frac{a}{b} \alpha \frac{\gamma}{mn\alpha^2+\gamma} \frac{mn-1}{\alpha^2+\gamma}$;
- $Q^{I,I} - Q^{I,Co} = \frac{a}{b} \alpha \frac{\gamma}{(n\alpha^2+\gamma)(\alpha^2+\gamma)}(n-1)$.

Using the above expressions, it is straightforward to derive the different points of Proposition (1).

Proof of Proposition (2)

From Table 2, we obtain the following expressions of the variations of the negotiated leasing price across our four different negotiation scenarios:

- $p^{Co,Co} - p^{Co,I} = \frac{1}{4} am^2 \frac{\alpha^3}{(m\alpha^2+\gamma)(mn\alpha^2+\gamma)} \left(m\alpha^2 + 3\gamma\right)(n-1)$;
- $p^{I,Co} - p^{II} = \frac{1}{4} \frac{a}{m} \frac{\alpha^3}{(n\alpha^2+\gamma)(\alpha^2+\gamma)}(n-1)\left(\alpha^2 + (4m-1)\gamma\right)$;
- $p^{Co,Co} - p^{I,Co} = \frac{1}{4} \frac{a}{m} \frac{\alpha}{(m\alpha^2+\gamma)(\alpha^2+\gamma)}(m-1)\left(m^2\alpha^4 + m\alpha^4 + m^2\alpha^2\gamma + (3m-1)\gamma^2 + \alpha^2\gamma\right)$;
- $p^{Co,I} - p^{I,I} = \frac{1}{4} \frac{a}{m} \frac{\alpha}{(n\alpha^2+\gamma)(mn\alpha^2+\gamma)}(m-1)\left((3m-1)\gamma^2 + \alpha^2\left(1 + m^2 + m(1-n)\right)\gamma + m^2n\alpha^4 + mn\alpha^4\right)$;
- $p^{Co,I} - p^{I,Co} = \frac{1}{4} \frac{a}{m} \frac{\alpha\left((3m^2-4m+1)\gamma^2+\alpha^2\left(3m^2+m^3-1-4m^2n+mn\right)\gamma+m\alpha^4\left(m^2-n\right)\right)}{(mn\alpha^2+\gamma)(\alpha^2+\gamma)}$.

Using the above expressions, it is straightforward to derive the different points of Proposition (2).

Proof of Lemma (5)

To prove the first part of Lemma (5), we first compare the utility levels of the beneficiaries in our four negotiation scenarios.

We can show that the following results always hold:

- for $n \geqslant 2$, $U_B^{I,I} > U_B^{I,Co}$ because $U_B^{I,I} - U_B^{I,Co} = \frac{1}{4} \frac{a^2}{bm} \frac{\alpha^2(n-1)\left((4(m-1)+1)\gamma^3+n\alpha^6+\left(2m^2n\alpha^2+2m^2\alpha^2-\alpha^2\right)\gamma^2+(4m-1)n\alpha^4\gamma\right)}{\left(n\alpha^2+\gamma\right)^2\left(\alpha^2+\gamma\right)^2} > 0$; moreover, it is immediate to see that $U_B^{I,I} = U_B^{I,Co}$ for $n = 1$.
- for $n \geqslant 2$, $U_B^{Co,I} > U_B^{Co,Co}$ since $U_B^{Co,I} - U_B^{Co,Co} = \frac{1}{4} \frac{a^2}{b} \frac{m^2\alpha^2(n-1)\left(nm^2\alpha^4+2nm\alpha^2\gamma+\gamma^2\right)}{(m\alpha^2+\gamma)\left(mn\alpha^2+\gamma\right)^2} > 0$; moreover, it is immediate to see that $U_B^{Co,I} = U_B^{Co,Co}$ for $n = 1$.

However, the other comparisons of interest are more complex. First, we compute the difference between $U_B^{I,I}$ and $U_B^{Co,I}$ as follows:

$$U_B^{I,I} - U_B^{Co,I} = \frac{n\alpha^2(m-1)\left(\alpha^4 m^2\left((m+1)\alpha^2-\gamma\right)n^2 + 2m\alpha^2\gamma\left(\left(m^2+m+1\right)\alpha^2 + \left(2m-m^2-1\right)\gamma\right)n + \Gamma\right)}{4m\left(n\alpha^2+\gamma\right)^2\left(mn\alpha^2+\gamma\right)^2}\frac{a^2}{b},$$

with $\Gamma = \left(\left(m^3+m^2+m+1\right)\alpha^2 + \left(3m-m^2-1\right)\gamma\right)\gamma^2$.

- For $m = 1$, it is immediate to show that $U_B^{I,I} = U_B^{Co,I}$.
- For $m \geqslant 2$, it can be shown that for $\gamma \in [0, (m+1)\alpha^2]$ the numerator of the above expression is positive for all positive values of n and α. This implies that for low values of coefficient γ, beneficiaries prefer to negotiate individually when providers are also negotiating individually, $U_B^{I,I} > U_B^{Co,I}$. But when $\gamma > (m+1)\alpha^2$,the discriminant of the quadratic equation in n is always positive $\forall \gamma, \alpha > 0$:

$$\Delta = 4m^3\alpha^4\gamma^2\left(\left(m^3-4m^2+5m-1\right)\gamma^2 + \left(4m^2\alpha^2-2m^3\alpha^2-m\alpha^2+\alpha^2\right)\gamma + m\alpha^4\right) > 0$$

This implies that the numerator is positive when $n < \widetilde{n}$ with $\widetilde{n} = \frac{2m\alpha^2\gamma\left(\left(m^2+1-2m\right)\gamma-\left(m^2+m+1\right)\alpha^2\right)-\sqrt{\Delta}}{2m^2\alpha^4\left((m+1)\alpha^2-\gamma\right)} > 0$ (and $\gamma > 3\alpha^2$), meaning that beneficiaries prefer to negotiate individually when providers are also negotiating individually, i.e. $U_B^{I,I} > U_B^{Co,I}$. In contrast, when $\gamma > (m+1)\alpha^2$ and $n > \widetilde{n}(\gamma,\alpha)$, then beneficiaries prefer to negotiate collectively while providers negotiate individually, $U_B^{I,I} < U_B^{Co,I}$. Moreover, it can be shown that under the condition $\gamma > (m+1)\alpha^2$, the derivative of $\widetilde{n}$ with respect to α and γ are $\frac{\partial\widetilde{n}}{\partial\gamma} < 0$ and $\frac{\partial\widetilde{n}}{\partial\alpha} > 0$, implying that $\widetilde{n} = \widetilde{n}(\overset{-}{\gamma}, \overset{+}{\alpha})$.

Second, we compute the difference between $U_B^{I,Co}$ and $U_B^{Co,Co}$ as follows:

$$U_B^{I,Co} - U_B^{Co,Co} = \frac{1}{4}\frac{\alpha^2(m-1)\left(\left(3m-m^2-1\right)\gamma^2 + \left(2m^2+1\right)\alpha^2\gamma + (m+1)m\alpha^4\right)}{m\left(m\alpha^2+\gamma\right)\left(\alpha^2+\gamma\right)^2}\frac{a^2}{b}.$$

- For $m = 1$, it is immediate to show that $U_B^{I,Co} = U_B^{Co,Co}$.
- For $m = 2$, the numerator of the above expression is positive, which immediately implies that $U_B^{I,Co} > U_B^{Co,Co}$.
- For $m > 2$, the discriminant of the quadratic equation in γ is is always positive: $\Delta = \alpha^4\left(8m^4 - 8m^3 - 4m^2 + 4m + 1\right) > 0$. This gives the critical value $\widetilde{\gamma} = \frac{\left(2m^2+1\right)\alpha^2+\sqrt{\Delta}}{2\left(m^2-3m+1\right)}$, such that if $\gamma < \widetilde{\gamma}$ then $U_B^{I,Co} > U_B^{Co,Co}$ and if $\gamma > \widetilde{\gamma}$ then $U_B^{I,Co} < U_B^{Co,Co}$.

To prove the second part of Lemma (5), we use the same logic to compare the utility levels of the providers.

The following result always holds:

- for $m \geqslant 2, U_P^{Co,Co} > U_P^{I,Co}$ since $U_P^{CC} - U_P^{SC} = \frac{1}{4}\frac{a^2}{bm}\frac{\alpha^2(m-1)\left(m^2\alpha^4+m\alpha^4+2m^2\alpha^2\gamma+\alpha^2\gamma+m^2\gamma^2+m\gamma^2-\gamma^2\right)}{\left(m\alpha^2+\gamma\right)\left(\alpha^2+\gamma\right)^2} > 0$; moreover $U_P^{Co,Co} = U_P^{I,Co}$ for $m = 1$

The following payoff comparisons are more complex. First, we compute the difference between $U_P^{Co,Co}$ and $U_P^{Co,I}$ as follows:

$$U_P^{Co,Co} - U_P^{Co,I} = \frac{1}{4}\frac{a^2}{b}m^2\alpha^2 \frac{\left(nm^2\alpha^4 - \gamma^2\right)}{\left(m\alpha^2 + \gamma\right)\left(mn\alpha^2 + \gamma\right)^2}(n-1).$$

- For $n = 1$, it is immediate to see that $U_P^{Co,Co} = U_P^{Co,I}$.
- For $n \geqslant 2$, the expression above is positive if $nm^2\alpha^4 - \gamma^2 > 0$, i.e. if $\gamma < m\alpha^2\sqrt{n}$. Then, $U_P^{Co,Co} > U_P^{Co,I}$ for $\gamma < m\alpha^2\sqrt{n}$ and $U_P^{Co,Co} < U_P^{Co,I}$ for $\gamma > m\alpha^2\sqrt{n}$.

Second, we compute the difference between $U_P^{I,I}$ and $U_P^{I,Co}$ as follows:

$$U_P^{I,I} - U_P^{I,Co} = \frac{1}{4}\frac{a^2}{bm}\frac{\alpha^2(n-1)\left(\alpha^2 + (2m-1)\gamma\right)\left(\gamma^2 - n\alpha^4\right)}{\left(n\alpha^2 + \gamma\right)^2\left(\alpha^2 + \gamma\right)^2}.$$

- For $n = 1$, it is immediate to see that $U_P^{I,I} = U_P^{I,Co}$.
- For $n \geqslant 2$, the expression above is positive if $\gamma^2 - n\alpha^4 > 0$, i.e. if $\gamma > \alpha^2\sqrt{n}$. Then, $U_P^{I,I} > U_P^{I,Co}$ for $\gamma > \alpha^2\sqrt{n}$ and $U_P^{I,I} < U_P^{I,Co}$ for $\gamma < \alpha^2\sqrt{n}$.

Proof of Proposition (3)

The results from our comparison of the provider and beneficiary equilibrium utility levels in Table 3 and Lemma (5) are paramount in order to derive and characterize Nash equilibria.

The proof that Scenario *I,I* can be a Nash equilibrium (NE) proceeds as follows:

- We can show that if the beneficiaries negotiate individual agreements, then the best reply of the providers is also to negotiate individual agreements when $\gamma > \alpha^2\sqrt{n}$.
- In turn, if the providers negotiate individual agreements, then the best reply of the beneficiaries is also to negotiate individual agreements when $\gamma < (1+m)\alpha^2$ or $\gamma > (1+m)\alpha^2$ with $n < \widetilde{n}$.
- Therefore, Scenario *I,I* is a NE when conditions $\gamma > \alpha^2\sqrt{n}$ and $\gamma < (1+m)\alpha^2$ hold simultaneously (case (i)). Case (i) can also be rewritten as follows : $\gamma \in]\sqrt{n}\alpha^2, (1+m)\alpha^2[$, which implies $n < (1+m)^2$. Alternatively, conditions $\gamma > \alpha^2\sqrt{n}$ and $\gamma > (1+m)\alpha^2$ with $n < \widetilde{n}$ must hold simultaneously, which is equivalent to $\gamma > \max(\alpha^2\sqrt{n}, (1+m)\alpha^2)$ with with $n < \widetilde{n}$ (case (ii)).

The proof that Scenario *Co,I* can be a Nash equilibrium (NE) proceeds as follows:

- We can show that if the beneficiaries negotiate a collective agreement, then the best reply of the providers is to negotiate individual agreements when $\gamma > m\alpha^2\sqrt{n}$.
- We can also show that if the providers negotiate individual agreements, then the best reply of the beneficiaries is to negotiate a collective agreement when $\gamma > (1+m)\alpha^2$ and $n > \widetilde{n}$.

- Therefore, we can combine conditions $\gamma > m\alpha^2\sqrt{n}$ and $\gamma > (1+m)\alpha^2$ and conclude that scenario *Co,I* is a NE when $\gamma > \max(m\sqrt{n}\alpha^2, (1+m)\alpha^2)$ with $n > \widetilde{n}$.

The proof that Scenario *I,Co* can be a Nash equilibrium (NE) proceeds as follows:

- First, we can show that if the beneficiaries negotiate individual agreements, the best reply of the providers is to negotiate a collective agreement when $\gamma < \alpha^2\sqrt{n}$.
- Second, we can show that if the providers negotiate a collective agreement, then the best reply of the beneficiaries is always to negotiate individual agreements when $m = 2$, and when $\gamma < \widetilde{\gamma}$ for $m > 2$.
- Therefore, we can combine the above points and conclude that when $m = 2$, the only effective condition for Scenario *I,Co* to be a Nash equilibrium is $\gamma < \sqrt{n}\alpha^2$ and this condition becomes less restrictive when the numbers of providers increases. This suggests that in presence of a large number of providers, the latter have a strong incentive to negotiate at the collective level when facing individual beneficiaries. However when $m > 2$, the condition for Scenario *I,Co* to be a Nash equilibrium becomes $\gamma < \min(\sqrt{n}\alpha^2; \widetilde{\gamma}\alpha^2)$.

The proof that Scenario *Co,Co* can be a Nash equilibrium (NE) proceeds as follows:

- First, we can show that if the beneficiaries negotiate a collective agreement, the best reply of the providers is to negotiate a collective agreement when $\gamma < m\alpha^2\sqrt{n}$.
- Second, we can also show that if the providers negotiate a collective agreement, then the best reply of the beneficiaries is to negotiate a collective agreement only for $m > 2$ and when $\gamma > \widetilde{\gamma}$.
- When $m = 2$, Scenario *Co,Co* cannot be a NE because if the beneficiaries negotiate a collective agreement then the best reply of the providers is also to negotiate a collective agreement when $\gamma < m\alpha^2\sqrt{n}$, but the reciprocal is not true. In fact, if the providers negotiate a collective agreement when there are only two beneficiaries, the best reply of these beneficiaries is to negotiate individual agreements.
- Combining the above points, we conclude that Scenario *Co,Co* can only be a NE when $m > 2$ and under the condition that $\gamma \in]\widetilde{\gamma}\alpha^2, m\sqrt{n}\alpha^2[$, which also yields $n > \left(\frac{\widetilde{\gamma}}{m}\right)^2$.

Proof of Proposition (4)

It is straightforward to show that:

- $W^{I,I} > W^{I,Co}$ for $m \geqslant 2$ and $n \geqslant 2$, since $W^{I,I} - W^{I,Co} = \frac{1}{2}\frac{a^2}{b}\alpha^2\frac{\gamma(n-1)\left((2m-1)\gamma^2+n\alpha^4+m\alpha^2\gamma+mn\alpha^2\gamma\right)}{\left(n\alpha^2+\gamma\right)^2\left(\alpha^2+\gamma\right)^2} > 0$; however $W^{I,I} = W^{I,Co}$ for for $n = 1$;
- $W^{Co,I} > W^{I,I}$ for $m \geqslant 2$ and $n \geqslant 2$, since $W^{Co,I} - W^{I,I} = \frac{1}{2}\frac{a^2}{b}n\alpha^2\frac{\gamma^2(m-1)^2}{\left(n\alpha^2+\gamma\right)^2\left(mn\alpha^2+\gamma\right)} > 0$; however $W^{I,I} = W^{I,Co}$ for for $m = 1$;
- $W^{Co,I} > W^{Co,Co}$ for $m \geqslant 2$ and $n \geqslant 2$, since $W^{Co,I} - W^{Co,Co} = \frac{1}{2}\frac{a^2}{b}m^2\alpha^2\frac{\gamma(n-1)}{\left(m\alpha^2+\gamma\right)\left(mn\alpha^2+\gamma\right)} > 0$; however $W^{I,I} = W^{I,Co}$ for for $n = 1$;
- $W^{Co,Co} > W^{I,Co}$ for $m \geqslant 2$ and $n \geqslant 2$, since $W^{Co,Co} - W^{I,Co} = \frac{1}{2}\frac{a^2}{b}\alpha^2\frac{\gamma^2(m-1)^2}{\left(m\alpha^2+\gamma\right)\left(\alpha^2+\gamma\right)^2} > 0$; however $W^{I,I} = W^{I,Co}$ for for $m = 1$.

However the comparison between $W^{Co,Co}$ and $W^{I,I}$ is more complex. From $W^{I,I} - W^{Co,Co} = \frac{1}{2}\frac{a^2}{b}\alpha^2\frac{\gamma\left(\left(n(2m-1)-m^2\right)\gamma+(n-1)mn\alpha^2\right)}{\left(m\alpha^2+\gamma\right)\left(n\alpha^2+\gamma\right)^2}$, we can show that $W^{I,I} > W^{Co,Co}$ for $\left(n(2m-1)-m^2\right)\gamma + (n-1)mn\alpha^2 > 0$ or $\gamma > \frac{(n-1)mn\alpha^2}{m^2-n(2m-1)}$.

Proof of Proposition (5)

The expression of social welfare W^I is given by

$$W^I = m\left(a\alpha Q^I - \frac{b}{2}\left(\alpha Q^I\right)^2\right) - n\frac{c}{2}\left(\frac{Q^I}{n}\right)^2$$

The derivative $\frac{\partial W^I}{\partial Q^I} = 0$ yields

$$mm\left(a\alpha - b\alpha^2 Q^I\right) - \frac{c}{n}Q^I = 0$$

Since $c = \gamma b$, we obtain

$$Q^{I^*} = \frac{mn\alpha}{\alpha^2 mn + \gamma}\frac{a}{b}$$

and after substitution in W^I we obtain $W^{I^*} = m\left(a\alpha Q^{I^*} - \frac{b}{2}\left(\alpha Q^{I^*}\right)^2\right) - n\frac{c}{2}\left(\frac{Q^{I^*}}{n}\right)^2 = \frac{1}{2}\frac{\alpha^2 m^2 n}{mn\alpha^2+\gamma}\frac{a^2}{b}$.

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