Negotiating over payments for wetland ecosystem services

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Abstract. This paper proposes and examines the economic efficiency of novel payment schemes for the provision of wetland ecosystem services. By definition, payments for ecosystem services typically involve voluntary transactions between the beneficiaries and providers of ecosystem services. We develop a theoretical model that addresses the role that a third party—such as a social planner or government agency, acting in the interest of society—can play to ensure the optimal provision of ecosystem services. We consider different regulatory frameworks combining payments for ecosystem services with a subsidy that the third party grants to the beneficiaries or providers of ecosystem services. We compare the outcomes of the different policy mixes characterized by different levels of involvement of the third party. Of particular interest is the comparison between the outcomes of payments for ecosystem services subsidy arrangements in which the third party plays decentralized and centralized roles. Our results show, among other things, that the third party is indifferent between a negotiated payment for ecosystem services combined with a subsidy scheme and the constrained first-best payments for ecosystem services subsidy scheme, in the presence of transaction and administrative costs. However, beneficiaries and providers may have conflicting preferences over the two payments for ecosystem services schemes.

Résumé. Négociation des paiements pour services écosystémiques des zones humides. Cet article propose et examine l'efficience économique de systèmes de paiement novateurs pour le paiement de services écosystémiques des zones humides. Par définition, les paiements pour services écosystémiques consistent généralement en des transactions volontaires entre les bénéficiaires et les prestataires de services écosystémiques. Nous mettons au point un modèle théorique qui aborde le rôle qu'un tiers, comme un

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We thank the editor, three anonymous referees, Roy Brouwer and members of the Water Economics Research Group at the University of Waterloo for very helpful comments. We gratefully acknowledge financial support from the Social Sciences and Humanities Research Council (SSHRC) of Canada and from a Bordeaux–Waterloo joint grant. This paper was partly written when Nimubona was visiting the University of Bordeaux. He thanks the GREThA research centre for its hospitality.

Canadian Journal of Economics / *Revue canadienne d'économique* 2022 55(3)
August 2022. Printed in Canada / *août 2022. Imprimé au Canada*

ISSN: 0008-4085 / 22 / pp. 1507–1538 / DOI: 10.1111/caje.12605

planificateur social ou un organisme gouvernemental, agissant dans l'intérêt de la société, peut jouer afin de garantir la prestation optimale des services écosystémiques. Nous examinons différents cadres réglementaires combinant le paiement pour services écosystémiques à une subvention accordée par un tiers aux bénéficiaires ou aux prestataires de services écosystémiques. Nous comparons les résultats des différentes politiques, qui sont caractérisées par différents degrés de participation de la part du tiers. La comparaison entre les résultats des configurations de paiement pour services écosystémiques par subvention où le tiers joue un rôle décentralisé et les résultats de celles où il joue un rôle centralisé revêt un intérêt particulier. Nos résultats révèlent, entre autres, qu'en présence de coûts de transaction et d'administration, le tiers n'a pas de préférence entre un système où le paiement négocié pour services écosystémiques est combiné à une subvention et le système optimal contraint de paiement pour services écosystémiques. Cependant, les bénéficiaires et les prestataires pourraient avoir des préférences contradictoires entre les deux systèmes de paiement pour services écosystémiques.

JEL classification: Q15, Q24, Q26, Q28, Q57, Q58

1. Introduction

Wetlands are extremely fragile ecosystems that are important not only for the private goods (fish and reed) they produce but also for the unique and complex ecosystem functions and services they provide. These valuable ecosystem services (ESs), most of which are public in nature, include life-support services (water filtration and provision), cultural and recreational services that directly benefit human beings as well as hydro-ecological services (water flow regulation, climate and water quality regulation) that support and protect human activities indirectly. However, in Canada and globally, wetland ecosystems are highly threatened by both excessive human pressure and climate change.[1] In light of these threats, payments for ecosystem services (PES) have attracted attention as an appropriate mechanism to protect what remains of wetlands and to restore them wherever possible.

PES typically involve voluntary transactions between the beneficiaries and providers of ESs. The standard definition of PES highlights the objective to internalize what would otherwise be a positive externality (Pagiola and Platais 2007). It also emphasizes the bargaining interactions between at least one ES buyer and one ES provider, in accordance to the Coase theorem (Coase 1960, Wunder 2005, Engel et al. 2008). However, the necessary conditions for the Coase theorem do not pertain in the provision of most ESs,[2] and this fact casts serious doubt on the efficiency of PES as a new promising economic policy instrument. In particular, the order of magnitude of

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[1] In Canada, up to 70% of wetlands have been destroyed or degraded in urbanized watersheds (Branton and Robinson 2020). Globally, an estimated 64% to 71% of wetlands have been lost (Davidson 2014).

[2] The necessary conditions for the Coase theorem include, amongst others, the presence of well-defined and enforceable property rights and low transaction costs (Coase 1960).

transaction costs associated with bargaining solutions to environmental externalities is quite substantial (Falconer and Saunders 2002, Phan et al. 2017, Wunder and Alban 2008, Wunder et al. 2008).[3] Moreover, most of wetland ESs exhibit the characteristics of public goods.

The regulatory frameworks to incentivize wetland creation, therefore, require the involvement of an intermediary to ensure the implementation of PES mechanisms that balance the social benefits associated with wetland ESs against the costs incurred in wetland creation (Wunder et al. 2020). From this perspective, we develop a setting in which a third party—such as a social planner or government agency—acting in the interest of society is playing some active role in the design and implementation of a PES scheme to achieve the optimal provision of ESs.[4] This is in line with Vatn (2010), who emphasizes the fact that most of PES in practice involve an intermediary, acting as a dominant agent.[5] In accordance with the practice of PES implementation, we consider different regulatory frameworks combining PES with a subsidy that the third party grants to the beneficiaries or providers of ESs, as part of a novel policy instrument mix.[6] We compare the outcomes of these policy mixes characterized by different levels of involvement of the third party. Of particular interest is the comparison between the outcomes of arrangements in which the third party plays decentralized and centralized roles in the PES mechanisms.

The economics literature has also justified policy instrument mixes as a straightforward application of the second-best theory (see, e.g., Bennear and Stavins 2007, Bouma et al. 2019, Braathen 2007, Fankhauser et al. 2010, Johnstone 2003, Lehmann 2012). As argued by Engel et al. (2008), PES programs can also be seen as an environmental subsidy to ES providers combined with a user fee on ES beneficiaries. This corresponds to our

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[3] For example, Falconer and Saunders (2002) report a case in which the transaction costs associated with a wildlife enhancement PES scheme were 110% of the payment.

[4] Non-governmental organizations can also act as an intermediary in the PES process, as long as they are not the end users of the wetland ESs supplied. A good example is Ducks Unlimited Canada, which managed PES contracts for wetland conservation in the Canadian prairie provinces (Hill et al. 2011, Brown et al. 2011, Adamowicz and Olewiler 2015). We thank an anonymous referee for pointing this out.

[5] Vatn (2010) distinguishes between the concept of PES, which often requires a core role of an intermediary, and that of market for environmental services (MES).

[6] The practical relevance of combining PES with other policy instruments is supported by Pagiola and Platais (2007), who note that most of World Bank supported PES schemes are part of a broader policy instrument mix. Vatn (2010) also characterizes PES as mixes between Coase and Pigou.

benchmark case whereby a social planner chooses a mix of payment−subsidy to achieve the constrained first-best solution in the presence of administrative costs. We also refer to our benchmark case as a centralized regulatory approach. We compare the benchmark case with different decentralized regulatory scenarios wherein a PES is negotiated directly between the beneficiaries and providers while the social planner also intervenes in various ways to take into account other indirect beneficiaries. Engel et al. (2008) also refer to this centralized regulation structure as a government-financed PES program, in contrast to a user-financed PES program in which the beneficiaries bargain with and pay directly the providers of ESs. A key distinguishing feature of government-financed PES programs, which are the dominant mode worldwide (Wunder 2013), is that the payment by the beneficiaries is compulsory instead of voluntary. Many researchers (see, e.g., Brown et al. 2007, Schomers and Matzdorf 2013) argue that the relative dominance of government-financed PES programs over user-financed PES programs is caused mostly by the high transaction costs associated with the latter. However, Krutilla (1999) and Krutilla and Alexeev (2014) caution that significant, but sometimes neglected, administrative costs are also associated with government-financed PES programs. These administrative costs manifest themselves in the form of costs related to administration, monitoring and enforcement of centralized PES schemes as well as the costs of rent-seeking over environmental tax revenues (Medema 2020). We carefully consider these prevalent administrative costs, when comparing government-financed PES programs with user-financed PES programs.

What is the most efficient PES regulatory regime? We find that a decentralized regulatory approach, which combines a voluntary negotiated PES between beneficiaries and providers with a subsidy scheme, can achieve the same constrained first-best social optimum as a centralized regulatory approach, which consists of a compulsory price for ESs combined with a subsidy. Moreover, it does not matter whether the subsidy goes to the beneficiaries or to the providers. One other main result is that the beneficiaries and providers may have conflicting preferences over the role played by the third party. Both of these two agents may prefer a compulsory price for ESs, which assigns a more active role to the third party, over a voluntary negotiated PES, whenever their negotiation rents (or net payoffs from negotiation) are low. These negotiation rents depend on the rate of change of the marginal cost of wetland creation relative to that of marginal benefit for ES beneficiaries as well as the relative bargaining powers between the beneficiaries and the providers. Finally, we show that the social planner, acting as an intermediary in PES negotiations, plays an additional role when there are many beneficiaries involved in the negotiations. Even when there are no amenities, the social planner ensures the constrained first-best optimal provision of wetland ESs by preventing free-riding.

As mentioned above, PES are often modelled as a particular case of Coasean negotiations. Our formalization departs from the literature by considering a role for the third party, consistent with the practice of PES. Coase (1960) argues that bargaining with side payments between parties can solve environmental problems and that only transaction costs can prevent voluntary bargaining from attaining Pareto-efficient outcomes. Although Coase (1960) claims that this result holds generally, and not only for two players, most of the bargaining literature, using the alternating-offer model of Rubinstein (1982), has focused on the two-player case (Caparros and Pereau 2021). Other work on the incentives for wetland creation (Crépin 2005) considers only take-it-or-leave-it contracts. Crépin (2005) shows that the choice of take-it-or-leave-it contracts for wetland creation produces larger social benefits than those of a uniform contract but yields a different distribution between interest groups.[7] Our paper relaxes this assumption of take-it-or-leave-it contracts by assuming that both the wetland size and the PES are the result of a negotiation procedure.

Moreover, when applied to PES, addressing multilateral negotiations in the presence of upstream−downstream externalities and public goods is crucial. To capture these multilateral negotiations between beneficiaries and providers of ESs, we use the Nash-in-Nash bargaining solution (Collard-Wexler et al. 2019). The Nash-in-Nash procedure consists in a Nash equilibrium computed from the Nash bargaining solutions between the beneficiaries and providers. It implies simultaneous bilateral negotiations between the two types of players and highlights the importance of disagreement points of the players during the negotiations. In particular, when two players are engaged in multiple negotiations, we need to specify what will be the disagreement payoffs in case of a negotiation failure between the two players. The Nash-in-Nash bargaining suggests that the disagreement payoff of these two players is based on the equilibrium agreements reached in all the other negotiations, even if they don't take part in those agreements. Our aim is to develop a general framework that is able to encompass all the negotiation scenarios between beneficiaries and providers, from one-to-one to many-to-many negotiations, over two main variables: the wetland size and the payment.

PES can also be formalized as contracts between ES beneficiaries and providers, using contract theory (Austen and Hanson 2007, Ferraro 2008, Mann et al. 2014). In particular, Ferraro (2008) highlights information asymmetries that characterize the contractual relationships between ES beneficiaries and providers. Because of this asymmetric information, PES contracts, defined either as bilateral bargaining or take-it-or-leave-it contracts, give rise to inefficient outcomes (Crépin 2005, Ferraro 2008, Smith et al. 2019,

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[7] In the uniform contract, the authority offers a payment proportional to the surface of wetland created and allows farmers to choose the wetland size. In the take-it-or-leave-it contract, the authority sets both the wetland size and the transfer.

Medema 2020, etc.). To reduce informational rents associated with this asymmetry of information, conservation authorities could also use reverse auctions for PES contracts. Reverse auctions have already proven their effectiveness in environmental conservation in Europe, Australia and the United States (Reichelderfer and Boggess 1988, Latacz-Lohmann and Hodge 2003, Stoneham et al. 2003, White and Burton 2005, Selman et al. 2008). In Canada, only a few auctions have been implemented so far. Ducks Unlimited Canada has experimented with reverse auctions for wetland conservation in four sites in the Canadian prairies: Torlea in Alberta, Lake Alma and Yorkton in Saskatchewan and Killarney in Manitoba (Hill et al. 2011, Brown et al. 2011, Adamowicz and Olewiler 2015). On the basis of the assessment of the effectiveness of the pilot reverse auction conducted by Duck Unlimited Canada in the Assiniboine River Watershed of East Central Saskatchewan in 2009, Hill et al. (2011) suggest that reverse auctions can be an effective tool for wetland protection and restoration in Canada.

The remainder of our paper is structured as follows. Section 2 presents our model, characterizes the first-best and constrained first-best situations and derives the results of the PES Nash-in-Nash negotiation in the general case with many providers and many beneficiaries. In section 3, we then turn to the comparison of the outcomes of our different wetland PES arrangements as well as the comparison of the general case with three other special cases observed empirically: (i) one beneficiary and one provider, (ii) many providers and one beneficiary and (iii) many beneficiaries and one provider. Section 4 concludes our analysis. Finally, the appendix section provides proofs not included in the text.

2. Model

We consider a theoretical framework with three types of agents: (i) direct identical beneficiaries, denoted by B_i with $i = 1, ..., n$, who enjoy some wetland ecosystem services (ESs) that depend on the size of the wetland created, (ii) identical providers of ESs (i.e., farmers), denoted by P_j with $j = 1, ..., m$, and (iii) a social planner (SP). We assume that all agents have perfect knowledge of the relevant information required to make optimal decisions.[8] These wetland ESs include recreation services, water conservation, research and cultural services. They provide some benefit, which we denote by $B(Q)$, where Q corresponds to the size of the wetland created, to the direct beneficiaries.[9] We consider a concave benefit function: $B(Q) = aQ - \frac{b}{2}Q^2$, with

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[8] Ferraro (2008) identifies two potential sources of information asymmetries in the design of PES, i.e., hidden information (adverse selection) and hidden action (moral hazard). We discuss in the conclusion how relaxing the assumption of perfect information would alter our results.

[9] Contrary to Crépin (2005), our benefit function $B(Q)$ is not an environmental surplus. It refers to the ecosystem benefits associated with the creation of

$B'(Q) = a - bQ \gtreqless 0$ for $Q \lesseqgtr a/b$ and $B''(Q) = -b < 0$. The coefficient a can be interpreted as the beneficiaries' maximum willingness to pay for wetland ESs, while the coefficient b is the rate of change of the marginal benefit of wetland creation.

Our assumption that the provision of ESs can be proxied by the size of wetland created is based on the practice of PES schemes, which suggests that PES contracts are often based on land-use activities (or lack of activities) rather than the quantity of ecosystem services provided (Ferraro 2008). In fact, ecosystem analyses have shown that the size of the wetland has a positive effect on the delivery of ESs (Mitsch and Gosselink 2015, Tiner 2017, Finlayson et al. 2018). Moreover, in a recent meta-analysis of valuation research on China's wetlands, Zhou et al. (2020) estimate a concave function between the value of ESs and the wetland area for material production, recreational services, research and cultural services, soil conservation, water conservation, climate regulation, carbon sequestration and oxygen release, biodiversity and habitat conservation, option value, existence value and bequest value. In contrast, a convex function appears to be more relevant for the values of flood control and environmental purification.

Nevertheless, through wetland creation, farmers also deliver additional benefits to society -such as biodiversity and habitat conservation, climate regulation, flood control and environmental purification. The additional benefits accrue in the form of amenities represented by $A(Q)$ in our model. These amenities clearly have the characteristics of public goods and, they might also benefit direct beneficiaries, albeit rather indirectly. However, the latter are willing to contribute towards the provision of wetland ESs only insofar as they add to their direct utility. Therefore, whenever these amenities provide beneficiaries with some utility, we assume that they are already factored into $B(Q)$. Put in another way, $A(Q)$ represents the benefits from wetland creation not already included in $B(Q)$. To account for the fact, mentioned above, that the relationship between the wetland size and the value of ESs can be different for different types of ESs (Zhou et al. 2020), we assume that $A(Q)$, the amenity function, is convex: $A(Q) = \frac{e}{2}Q^2$, with $A'(Q) = eQ > 0$ and $A''(Q) = e > 0$, where e represents the rate of change of the marginal amenity benefit.[10]

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wetlands. Crépin (2005) does not distinguish the beneficiaries of wetland ESs from the social planner. The latter acts on behalf of the beneficiaries and maximizes a welfare function including the environmental surplus defined as the net environmental benefit (the environmental benefit less the environmental cost) of wetland creation.

[10] Note that the amenity function can also be concave. We have analyzed the robustness of our main results by assuming a concave amenity function $A(Q)$ of the same form as the benefit function $B(Q)$. Our analysis confirmed that a concave amenity function does not change the qualitative results of the paper.

To provide the wetland ES, each farmer incurs a cost, denoted by $C(q_j)$, which we assume to be dependant only on q_j—the wetland size he creates. According to Crépin (2005), wetland creation costs consist of fixed cost, the construction cost and the opportunity cost of wetland creation; the latter is the only cost component in our model. We assume the following cost function: $C(q_j) = \frac{c}{2}q_j^2$, where $c > 0$ represents the rate of change of the marginal cost of wetland creation. Under this assumption, the creation of a larger wetland yields a higher opportunity cost ($C' = cq_j > 0$) and the marginal cost is likely to increase if the wetland size increases because land available for alternative usage is more scarce ($C'' > 0$). s The social planner acts as an intermediary between the direct beneficiaries and providers of ESs, and her objective is to insure the creation of a wetland of optimal size. For this purpose, the social planner includes in her objective function the additional social benefits associated with the presence of amenities. In fact, her basic objective function corresponds to

$$W = A(Q) + \sum_{i=1}^{n} B(Q) - \sum_{j=1}^{m} C(q_j). \tag{1}$$

This completes the description of our basic model, which we use in order to compare different wetland PES arrangements. To further highlight the impact of the number of providers and beneficiaries, we consider a general case with n identical beneficiaries and m identical providers.[11] In this way, our model allows for four different scenarios observed empirically that are: (i) one beneficiary and one provider, (ii) m providers and one beneficiary, (iii) n beneficiaries and one provider and (iv) n beneficiaries and m providers.

2.1. Social optimum

Let us first derive the social optimal or first-best wetland size, which the social planner seeks to induce farmers to produce. The total wetland size created by the m identical providers is $Q = mq$. The social optimum size is obtained by solving the following social welfare maximization problem:

$$\max_{Q} W = A(Q) + nB(Q) - mC\left(\frac{Q}{m}\right) \tag{2}$$

The first-order condition for this maximization problem is

$$A'(Q) + nB'(Q) - mC'\left(\frac{Q}{m}\right) = 0. \tag{3}$$

Given our specific functions defined above, condition (3) implies that the socially optimal total wetland size, which we index with the superscript SO, is

$$Q^{SO} = \frac{nma}{c + m(bn - e)}, \tag{4}$$

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[11] We thank the editor and an anonymous referee for pointing us in this direction.

and the corresponding optimal created wetland per provider is

$$q^{SO} = \frac{an}{c + m(bn - e)}. \tag{5}$$

Note that the optimal wetland size per provider decreases (increases) when the number of providers, m, increases, if the rate of change of the marginal benefit associated with amenity services, e, is lower (greater) than the rate of change of the marginal direct benefit times the number of beneficiaries, bn. Moreover, a rise in the number of beneficiaries, n, increases (decreases) the optimal wetland size per provider if the rate of change of the marginal cost of wetland creation, c, is greater (greater) than the rate of change of the marginal benefit associated with amenity services times the number of providers, em.[12] However, when there are no amenity services associated with wetlands (i.e., $e = 0$), the social optimal wetland size always decreases with m and increases with n. We can easily show that the optimal wetland size per provider increases with the maximum willingness to pay for ESs, a, and e, but decreases with c and the rate of change of the marginal direct benefit, b.

The farmers will, without a doubt, provide too little wetland ESs with respect to those corresponding to the socially optimal wetland size. To correct for this and achieve the socially optimum target, the social planner can rely on a variety of policy instrument mixes. In the following sections, we consider specific alternative ways through which the social planner can provide incentives to farmers to provide the socially optimal amount of wetland ESs.

2.2. Beneficiaries pay a compulsory fee and subsidies go to providers

We start with the case in which the social planner assumes a centralized role by setting simultaneously a **compulsory fee** (p) that the beneficiaries of wetland ESs ought to pay to the social planner and a **subsidy** (s) that the latter ought to grant to the providers for each unit of wetland created. A good example of such a centralized regulation structure (or government-financed PES program) in Canada is Greencover Canada's Land Conversion progrqam, which was run by the federal government from 2003 to 2009 (Renzetti and Dupont 2015, Knight 2010).[13] Worldwide, the largest and, arguably, most successful government-financed PES programs are the

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[12] This is due only to the convexity of $A(Q)$ and the concavity of $B(Q)$. The following comparative static result can be obtained: $\frac{\partial q_j^{so}}{\partial m} = \frac{an(e-bn)}{(c+m(bn-e))^2} \gtrless 0$ and $\frac{\partial q_j^{so}}{\partial n} = \frac{a(c-em)}{(c+m(bn-e))^2} \gtrless 0$.

[13] Greencover Canada's Land Conversion was replaced with Growing Forward 2, a five-year policy framework involving cost-sharing programs (Renzetti and Dupont 2015).

Conservation Reserve Program and the Wetlands Reserve Program in the United States (Murray 2016).[14]

First, let us suppose that the revenues from the compulsory fee and the subsidy are handled without any administrative costs. Each beneficiary B_i demands q_i units of wetland in order to maximize the following utility function:

$$U_{B_i} = B(Q) - pq_i,\ i = 1, ..., n \tag{6}$$

Using the specified benefit function, the behaviour of the beneficiaries is captured by the following first-order condition:

$$B'(q_{-i} + q_i) = a - b(q_{-i} + q_i) = a - bQ^B = p,\ i = 1, ..., n, \tag{7}$$

where q_{-i} is the total demand by the other beneficiaries and Q^B is the beneficiaries' total demand. In turn, each provider P_j supplies q_j units of wetland to maximize the following utility function:

$$U_{P_j} = sq_j - C(q_j),\ j = 1, ..., m \tag{8}$$

Using the specified cost function, the behaviour of the providers is captured by the following first-order condition:

$$s = C'(q_j) = cq_j,\ j = 1, ..., m \tag{9}$$

Summing up over all providers j yields

$$s = \frac{c}{m}\sum_{j=1}^{m} q_j = \frac{c}{m}Q^P, \tag{10}$$

where Q^P is the total wetland supply by all providers.

To achieve the first-best outcome, the social planner anticipates the behaviours of the beneficiaries and the providers and sets the levels of p and s so as to equalize both Q^B and Q^P to Q^{SO}. We obtain the following proposition.

Proposition 1. *The implementation of the PES-subsidy scheme of the form*

$$\left(p^{SO}; s^{SO}\right) = \left(\frac{a(c - me)}{c + m(bn - e)}; \frac{nac}{c + m(bn - e)}\right)$$

achieves the first-best wetland size and yields the following beneficiaries' surplus, providers' profits and total welfare:

$$U_{B_i}^{SO} = \frac{1}{2}a^2\frac{m\left(2(c - me)(n - 1) + bmn^2\right)}{(c + m(bn - e))^2},\ U_B^{SO} = nU_{B_i}^{SO}$$

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[14] Another example of a government-financed PES program is Mexico's Payments for Hydrological Environmental Services (PSAH) program. For more details about the PSAH, see Munoz-Pina et al. (2008).

$$U_{P_j}^{SO} = \frac{c}{2}\left(\frac{an}{c+m(bn-e)}\right)^2, \ U_P^{SO} = mU_{P_j}^{SO}$$

$$W^{SO} = \frac{1}{2}\frac{a^2mn^2}{c+m(bn-e)}.$$

The result established in proposition 1 is intuitive. It is straightforward to see that the subsidy received by the providers is greater than the fee paid by the beneficiaries (i.e., $s^{SO} > p^{SO}$), even when there are no amenities (i.e., $e = 0$). Also, we can analyze the influence of changes in the parameters of the model on the compulsory fee (p^{SO}), the optimal subsidy level (s^{SO}), the optimal wetland size created (Q^{SO}), the equilibrium payoffs of each beneficiary and provider ($U_{B_i}^{SO}$, $U_{P_j}^{SO}$), and social welfare (W^{SO}). The main results are summarized in table 1, where the signs indicate the effect of a change in the parameter at the top of the column on the row variable. The compulsory fee may increase or decrease with respect to the maximum willingness to pay for ESs (a), the marginal benefit (b) and the number of beneficiaries (n) but always increases with the marginal cost (c) and always decreases with the marginal amenity benefit (e) and the number of providers (m). When n increases, the compulsory fee decreases under the condition $c > me$, while the subsidy the providers get increases under the same condition. Also, the subsidy always increases with a and e and always decreases with b. Under the condition $bn > e$, the subsidy increases with c and decreases with m. As a consequence, the payoff of a beneficiary increases with a, e and m but decreases with b and c. In turn, the payoff of a provider always increases with a and e but decreases with b and c. Finally, welfare always increases with a, e, n and m but decreases with b and c.

To implement this PES-subsidy combination scheme, however, additional administrative (or public transfer) costs will be incurred (Krutilla 1999, Krutilla and Alexeev 2014), which might preclude the achievement of the first-best welfare outcome. In particular, Wunder et al. (2008) argue that

TABLE 1
Summary of comparative statics results

	a	b	c	e	n	m
Q^{SO}	$+$	$-$	$-$	$+$	$\pm$ if $c \gtrless me$	$+$
p^{SO}	$\pm$ if $c \gtrless me$	$\mp$ if $c \gtrless me$	$+$	$-$	$\mp$ if $c \gtrless me$	$-$
s^{SO}	$+$	$-$	$\pm$ if $bn \gtrless e$	$+$	$\pm$ if $c \gtrless me$	$\mp$ if $bn \gtrless e$
$U_{B_i}^{SO}$	$+$	$-$	$-$	$+$	$\pm$ if $c \gtrless me$	$+$
$U_{P_j}^{SO}$	$+$	$-$	$-$	$+$	$\pm$ if $c \gtrless me$	$\mp$ if $bn \gtrless e$
W^{SO}	$+$	$-$	$-$	$+$	$+$	$+$

government-financed PES are associated with administrative costs due to budget fights within governments and difficulties in payment targeting.[15] These administrative costs include costs related to administration, monitoring and enforcement of centralized PES schemes as well as the costs of rent-seeking over environmental tax revenues (Medema 2020). The significance of costs associated with government intervention has already been shown in the context of environmental policymaking. In particular, Krutilla and Krause (2011) and MacKenzie and Ohndorf (2012) argue that administrative costs could exceed the efficiency benefits of environmental policy.

In the presence of administrative costs, the social planner might be interested in implementing a constrained first-best PES-subsidy scheme, which maximizes the following welfare function:

$$W = A(Q) + \sum_{i=1}^{n} U_{B_i} + \sum_{j=1}^{m} U_{P_j} - (s+\delta)Q + (p-\mu)Q, \tag{11}$$

where coefficients μ and δ measure the administrative costs associated with the management of the PES and subsidy instruments, respectively. Therefore, the first-best PES-subsidy scheme $\left(p^{SO}; s^{SO}\right)$ achieves a total welfare surplus, which we index with the superscript PS, equal to

$$\begin{aligned} W^{PS} &= A(Q^{SO}) + nB(Q^{SO}) - mC\left(\frac{Q^{SO}}{m}\right) - (\delta+\mu)Q^{SO} \\ &= \frac{amn(an - 2(\mu+\delta))}{2(c + m(bn-e))}. \end{aligned} \tag{12}$$

Unsurprisingly, $W^{PS} < W^{SO}$ in the presence of public transfer costs, and the gap between the two measures of social welfare increases with the number of providers, the number of beneficiaries (when $c > me$) and the beneficiaries' maximum willingness to pay for wetland ESs but decreases with the marginal benefit and cost coefficients.

Considering the presence of public transfer costs gives the following proposition.

Proposition 2. *In the presence of administrative costs, the following constrained first-best PES-subsidy scheme, which we index with the superscript CFB,*

$$\left(p^{CFB}; s^{CFB}\right) = \left(\frac{a(c-me) + bm(\mu+\delta)}{c + m(bn-e)}; \frac{c(an - (\mu+\delta))}{c + m(bn-e)}\right)$$

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[15] On the reverse side, however, government-financed PES are associated with lower transaction costs than user-financed PES when the number of participants is large and may benefit from economies of scope.

achieves the following wetland size:

$$Q^{CFB} = \frac{m(an - (\mu + \delta))}{c + m(bn - e)}$$

and yields the following beneficiaries' surplus, providers' profits and total welfare:

$$\begin{aligned}
U_{B_i}^{CFB} &= \frac{1}{2}\frac{m}{n}\frac{(an - (\mu + \delta))\left(bm(\mu + \delta)(n - 2) + 2a(n - 1)(c - me) + abmn^2\right)}{(c + m(bn - e))^2} \\
U_B^{CFB} &= nU_{B_i}^{CFB} \\
U_{P_j}^{CFB} &= \frac{c}{2}\left(\frac{an - (\mu + \delta)}{c + m(bn - e)}\right)^2, \; U_P^{CFB} = mU_{P_j}^{CFB} \\
W^{CFB} &= \frac{1}{2}m\frac{(an - (\mu + \delta))^2}{c + m(bn - e)}
\end{aligned}$$

The result in proposition 2 is also intuitive. It is worthwhile to note that Q^{CFB}, p^{CFB} and s^{CFB} respectively correspond to Q^{SO}, p^{SO} and s^{SO} for $\mu = \delta = 0$. It can also be shown that $U_{B_i}^{CFB} < U_{B_i}^{SO}$ and $U_{P_i}^{CFB} < U_{P_i}^{SO}$. As for total welfare, we can show that $W^{CFB} < W^{SO}$ but $W^{CFB} > W^{PS}$. In fact, it is straightforward to see that $W^{SO} - W^{CFB} = \frac{1}{2}m(\mu + \delta)\frac{an - \mu - \delta}{c + m(bn - e)} > 0$ and $W^{CFB} - W^{PS} = \frac{1}{2}m\frac{(\mu + \delta)^2}{c + m(bn - e)} > 0$. Here, we assume that the sum of the maximum willingness to pay for all the beneficiaries exceeds the sum of the administrative costs, i.e., $an > (\mu + \delta)$, which ensures a positive size of wetland and positive payoffs.

2.3. PES Nash-in-Nash negotiation

Now, let us assume that the beneficiaries and providers negotiate a wetland PES agreement over the size of created wetland and the associated payment. This form of PES program, in which the buyers of wetland ESs are their direct beneficiaries, is referred to as a user-financed PES program and is the closest to the Coasian environment (Medema 2020). According to Salzman et al. (2018), a direct beneficiary of wetland ESs can be a private entity, an NGO or even a public actor, as long as they are the end users of the given ESs. User-financed wetland PES programs are not common, but the Vittel watershed scheme in France (Depres et al. 2008) is a good example.[16] We assume that the participants in this PES negotiation bear transaction costs μ, which are comparable to the administrative costs in the previous section. This

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[16] There are other few examples for watershed services and carbon sequestration in Ecuador (Wunder and Albán 2008), watershed and biodiversity services in Bolivia (Asquith, Vargas, and Wunder 2008), watershed services in Nicaragua and Guatemala (Corbera, Kosoy, and Martinez Tuna 2007), and wildlife conservation in Cambodia (Clements et al. 2010) and Tanzania (Nelson et al. 2010).

assumption is in the spirit of a recommendation by Medema (2020) that the role played by transaction costs in user-financed PES programs be balanced with that of administrative costs associated by direct government involvement in PES programs, when comparing these two forms of PES programs. The literature (see, e.g., Wunder et al. 2008, Vatn 2010) already suggests that government involvement can improve the efficiency of PES schemes by reducing transaction costs. However, having low transaction costs is not sufficient for efficiency. Therefore, to identify other sources of efficiency, we assume that the administrative costs associated with government intervention are equal to the transaction costs borne by participants in a negotiated PES scheme.

The social planner acts as a core intermediate in this negotiation. Her specific role is either to subsidize the beneficiaries (for an effective financing of wetland creation) or the providers (to achieve the social optimum size of wetland creation). As in the previous section, the management of the subsidy system is associated with administrative costs δ. We consider different PES arrangements corresponding to different bargaining settings with different types of intermediation.

We use the Nash-in-Nash solution concept consisting in a Nash equilibrium computed from the Nash bargaining solutions between the beneficiaries and the providers. Such a procedure and its non-cooperative foundations have been analyzed by Collard-Wexler et al. (2019), who show that this game has imperfect information. Indeed, within a given period, players do not see agreement offers that do not involve them. Moreover, the solution concept is a pure-strategy weak perfect Bayesian equilibrium with passive beliefs. These beliefs cause players to believe, upon receiving an off-the-equilibrium-path offer, that all unobserved actions remain equilibrium actions (Collard-Wexler et al. 2019). As a consequence, the disagreement payoff of each beneficiary is based on the agreements reached in all the other negotiations between the beneficiaries and the providers.

We consider a negotiation framework between many beneficiaries and many providers, which is general enough to encompass different types of PES agreements observed empirically in terms of the number of negotiating agents: one beneficiary and one provider ($n = m = 1$), one beneficiary and m providers, n beneficiaries and one provider, and as many beneficiaries as providers ($n = m$). In this last configuration, we restrict the set of agreements to bilateral pairwise agreements, implying that each provider can sign an agreement with only one beneficiary, and vice versa. Moreover, our specific negotiation framework does not consider potential configurations when $n \neq m$ with $n, m > 1$.[17] These configurations require assigning a payoff for each pair of beneficiaries and providers in all the potential agreements (Collard-Wexler et al. 2019, Caparros and Pereau 2013). While considering such agreements

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[17] This technical assumption excludes both cases where either $1 < n < m$ or $n > m > 1$. We thank an anonymous referee for pointing it out.

is intriguing and might provide a better understanding of factors at play, it is beyond the scope of this paper and we leave it for future research.

2.3.1. Beneficiaries receive a subsidy and pay a PES

We focus on a generic negotiation between a beneficiary, B_i, and a provider, P_j, over two variables: (i) the wetland size funded by beneficiary i and created by provider j, q_{ij}, and (ii) the associated payment, $\tilde{p}$. Let us also assume that B_i receives a subsidy $\tilde{s}$ from the social planner to achieve the socially optimal outcome. The objective functions of an individual beneficiary, an individual provider and the social planner are respectively as follows:

$$U_{B_i} = B(Q) - (\tilde{p} + \mu)q_{ij} + \tilde{s}q_{ij} \tag{13}$$

$$U_{P_j} = \tilde{p}q_{ij} - C(q_{ij}) \tag{14}$$

$$W = A(Q) + \sum_{i=1}^{n} U_{B_i} + \sum_{j=1}^{m} U_{P_i} - (\tilde{s} + \delta)Q \tag{15}$$

The result of this negotiation is given by the Nash bargaining solution, defined as the set of bilateral bargaining outcomes that maximize the product of the net payoffs of one beneficiary i and one provider j with average weights of β and $1 - \beta$, where $0 \leq \beta \leq 1$ measures the bargaining power of the beneficiaries. Because providers are identical, they also have the same bargaining power, $1 - \beta$. Specifically, the Nash bargaining solution is given by

$$NBS_{i,j} = \arg\max_{\tilde{p}, q_{ij}} \left(U^a_{B_i} - U^d_{B_i}\right)^{\beta} \left(U^a_{P_j} - U^d_{P_j}\right)^{1-\beta}, \tag{16}$$

where the net payoff is the difference between the agreement outcome (denoted by the superscript a) and the disagreement outcome (denoted by the superscript d). Specifically, in case of agreement, payoffs are

$$U^a_{B_i} = B(Q) - (\tilde{p} + \mu)q_{ij} + \tilde{s}q_{ij}, \tag{17}$$

$$U^a_{P_j} = pq_{ij} - C(q_{ij}), \tag{18}$$

while in case of disagreement, we respectively have

$$U^d_{B_i} = B(Q - q_{ij}), \tag{19}$$

$$U^d_{P_j} = 0. \tag{20}$$

Note from equations (17) and (19) that beneficiary B_i will receive a subsidy from the social planner based only on the size of funded wetland. In other terms, a negotiation failure with one provider implies no subsidy for the beneficiary. This is a consequence of the Nash-in-Nash procedure. In case of a negotiation failure between a beneficiary and a provider, the disagreement payoff of the beneficiaries is based on the agreements reached between all the other beneficiaries and providers. Therefore, beneficiary B_i benefits only from the wetland ESs funded by other beneficiaries, while the disagreement payoff of provider P_j is nil. We implicitly assume that a provider can negotiate an agreement with only one beneficiary. This assumption rules out the possibility of stacking, whereby a provider receives multiple separate payments for the same unit of created wetland (Woodward 2011). We exclude the possibility of stacking to be consistent with the practice of PES implementation.[18] After using the payoffs of the players in case of agreement and disagreement to compute net payoffs, the Nash bargaining solution is solution of

$$\max_{\tilde{p},q_{ij}} (B(Q) - B(Q - q_{ij}) - (\tilde{p} + \mu)q_{ij} + \tilde{s}q_{ij})^{\beta} (\tilde{p}q_{ij} - C(q_{ij}))^{1-\beta}. \tag{21}$$

The first-order condition for the maximization problem (21) with respect to $\tilde{p}$ gives

$$\tilde{p} = (1-\beta)\left(\frac{B(Q) - B(Q - q_{ij})}{q_{ij}} - \mu + \tilde{s}\right) + \beta\frac{C(q_{ij})}{q_{ij}}. \tag{22}$$

Substituting equation (22) into the objective function of the maximization problem (21) yields

$$\beta^{\beta}(1-\beta)^{1-\beta}\left(B(Q) - B(Q - q_{ij}) + \tilde{s}q_{ij} - \mu q_{ij} - C(q_{ij})\right). \tag{23}$$

The first-order condition for the maximization of equation (23) with respect to q_{ij} then gives

$$\frac{\partial B(Q)}{\partial q_{ij}} + \tilde{s} = \frac{\partial C(q_{ij})}{\partial q_{ij}} + \mu. \tag{24}$$

On the basis of specified functions, we have

$$a - bQ + \tilde{s} = cq_{ij} + \mu. \tag{25}$$

Because providers are identical and under the technical assumption on the number of players, we obtain

$$Q = \frac{m(a + \tilde{s} - \mu)}{c + bm} \tag{26}$$

and

$$\tilde{p} = (1-\beta)(a + \tilde{s} - \mu - bQ) + \frac{1}{2}(b(1-\beta) + c\beta)q_{ij}. \tag{27}$$

Solving the negotiation game while assuming that beneficiaries receive the subsidy gives the following proposition.

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[18] More often than not, PES programs deter stacking by requiring a proof of additionality from each payment (Salzman 2009, Smith et al. 2019).

Proposition 3. *In the presence of transaction costs, the implementation of a negotiated PES combined with a subsidy scheme,*

$$\tilde{p}^{NBS_{i,j}} = \frac{1}{2}\frac{(an-(\mu+\delta))(b(1-\beta)+c(2-\beta))}{c+m(bn-e)}$$

$$\tilde{s}^{NBS_{i,j}} = \frac{(an-(\mu+\delta))(c+bm)}{c+m(bn-e)} - a + \mu,$$

achieves the optimal wetland size $Q^{NBS_{i,j}} = Q^{CFB}$ *and yields the following beneficiary and provider surpluses and total welfare:*

$$\begin{aligned} U_{B_i}^{NBS_{i,j}} &= \frac{1}{2}\frac{m}{n}\frac{an-(\mu+\delta)}{(c+m(bn-e))^2} \\ &\quad \times \begin{pmatrix} (b(1-\beta)-c\beta+bm(n-2))(\mu+\delta) \\ +a\left(2(c-me)(n-1)+n(c\beta-b(1-\beta))+bmn^2\right) \end{pmatrix} \\ U_{P_j}^{NBS_{i,j}} &= \frac{1}{2}(1-\beta)(b+c)\left(\frac{an-(\mu+\delta)}{c+m(bn-e)}\right)^2 \\ W^{NBS_{i,j}} &= \frac{1}{2}m\frac{(an-(\mu+\delta))^2}{c+m(bn-e)} \end{aligned}$$

Our intuitive interpretation of the results in the above proposition is quite straightforward. The total welfare corresponds to the total joint surplus of the negotiation sessions between our n beneficiaries and m providers, while both the beneficiary and provider payoffs correspond to their respective shares of the total joint surplus. For this reason, the beneficiary and provider payoffs in equilibrium depend on the beneficiary bargaining power coefficient β, while the total welfare level does not. It can also be noted that β does not affect the size of wetland created and the subsidy level in equilibrium. This is due to the fact that the latter are the results of the maximization of the total social welfare. Also, an increase in the bargaining power of beneficiaries affects the equilibrium PES, beneficiaries' payoff and providers' payoff in an intuitive way. Comparative statics with respect to a change in β suggests that an increase in the beneficiary bargaining power will lead to an increase in the beneficiary payoff and a decrease in both the PES level and the provider payoff.

2.3.2. Providers receive a subsidy and a PES

In contrast to the previous subsection, let us assume now that the social planner grants a subsidy $\widehat{s}$ per unit of wetland created to each provider P_j, who also receives a negotiated price $\widehat{p}$ for each unit of wetland created. In this case, B_i, P_j and SP respectively face the following objective functions:

$$U_{B_i} = B(Q) - (\widehat{p}+\mu)q_{ij} \tag{28}$$

$$U_{P_j} = \widehat{p}q_{ij} + \widehat{s}q_{ij} - C(q_{ij}) \tag{29}$$

$$W = A(Q) + \sum_{i=1}^{n} U_{B_i} + \sum_{j=1}^{m} U_{P_j} - (\widehat{s} + \delta)Q \tag{30}$$

It can be shown that the optimal amount of subsidy the social planner would pay to the providers per each unit of wetland created is the same as in proposition 3, i.e., $\widehat{s}^{NBS_{i,j}} = \tilde{s}^{NBS_{i,j}}$. We also obtain the following proposition.

PROPOSITION 4. *When providers receive a subsidy from the social planner, the PES negotiated between these providers and the beneficiaries becomes* $\widehat{p}^{NBS_{i,j}} = \tilde{p}^{NBS_{i,j}} - \tilde{s}^{NBS_{i,j}}$. *The PES-subsidy scheme* $\left(\widehat{p}^{NBS_{i,j}}; \widehat{s}^{NBS_{i,j}}\right)$ *also achieves the same wetland size and yields the same total welfare and the same surpluses for the beneficiaries and providers as in proposition 3.*

Proposition 4 suggests that the recipient of the subsidy (beneficiaries or providers) does not matter for the size of the created wetland and the welfare gains associated with it. As we obtain the same wetland size and welfare results as in the previous proposition, we focus on the Nash bargaining solution PES-subsidy solution $\left(\tilde{p}^{NBS_{i,j}}; \tilde{s}^{NBS_{i,j}}\right)$, with the subsidy going to beneficiaries in the rest of this paper. The next section aims to compare the results from this negotiated PES-subsidy scheme, in which the social planner has a decentralized role, with those from the the constrained first-best scheme, which implies a more centralized role for the social planner.

3. Results

It is useful to establish and compare results for the PES-subsidy schemes when the social planner plays a centralized role and a decentralized role. It is also useful to establish the impact of the number of players in this comparison. In this section, we first conduct a comparative analysis of our two main PES-subsidy schemes in the general case with n beneficiaries and m providers to distill the impact of the role played by the social planner. Then, we extend our comparative analysis to discuss three additional interesting special cases observed empirically: (i) one beneficiary and one provider, (ii) m providers and one beneficiary and (iii) n beneficiaries and one provider.

3.1. Negotiated or constrained first-best PES-subsidy scheme?

We compare the Nash bargaining solution PES-subsidy solution with the subsidy going to beneficiaries (denoted by the superscript $NBS_{i,j}$) with the constrained first-best PES-subsidy scheme (denoted by the superscript CFB), in the presence of transaction and administrative costs.[19] The results of our comparison yield the following proposition.

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[19] For the reasons mentioned above, our comparison takes both types of costs into account.

Proposition 5. *The Nash bargaining solution PES-subsidy scheme achieves the constrained first-best wetland size. However, while the social planner is indifferent between the Nash bargaining solution PES-subsidy solution and the constrained first-best PES-subsidy scheme, the beneficiaries and the providers have conflicting preferences over the alternative. A strong* β *(the beneficiaries' relative bargaining power), a high* c *(the rate of change in marginal cost of wetland creation) and a low* b *(the rate of change in marginal benefit) will provide more incentives for beneficiaries to negotiate directly with providers, while the latter will prefer the intermediation of the social planner in the PES scheme, and vice versa.*

Proposition 5 suggests that the constrained first-best social optimum with administrative costs can be decentralized through a negotiation process with transaction costs of comparable magnitude with those administrative costs because the provision of wetland and the total welfare achieved are the same under the two regulatory schemes. However, these regulatory schemes yield different payoffs for all the agents but the social planner. The latter is indifferent between the negotiated PES and the centralized PES implemented through a compulsory fee. But, when the beneficiaries and the providers have a choice between PES negotiation and the intermediation of the social planner in the PES scheme, their interests are conflicting. When $b(1-\beta) < c\beta$, the beneficiaries prefer to negotiate directly with the providers, but the latter prefer the centralized solution, and vice versa when $b(1-\beta) > c\beta$.[20] The underlying intuition of the impact of β and $1-\beta$ is quite general: beneficiaries and providers prefer PES negotiation whenever their relative bargaining powers are strong. The intuition of the impact of b and c is also simple: a high b most likely increases the bargaining power of the providers and a high c provides beneficiaries with a stronger relative bargaining position. Therefore, when b is high (low), providers (beneficiaries) enjoy indirectly a stronger bargaining power over beneficiaries (providers), and when c is high (low), beneficiaries (providers) enjoy indirectly a stronger bargaining power over providers (beneficiaries).

To interpret proposition 5 better, it is useful to reflect further on the causes of the conflicting interests between beneficiaries and providers. Because $Q^{CFB} = Q^{NBS_{i,j}}$, the benefit enjoyed from wetland creation by each beneficiary B_i is the same. Therefore, to understand B_i's preference of one regulatory scheme over another, we need to compare the net price he pays for ESs under the negotiated PES-subsidy scheme (difference between the amount he has to pay and the amount of the subsidy he receives), i.e., $\left(\tilde{p}^{NBS_{i,j}} + \mu\right) - \tilde{s}^{NBS_{i,j}}$, and the compulsory price he pays otherwise, i.e., p^{CFB}:

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[20] Recall that b and c correspond to the rate of change of the marginal benefit and marginal cost of wetland creation, respectively, while β and $1-\beta$ represent the relative bargaining powers of the beneficiaries and the providers, respectively.

TABLE 2

Comparison of centralized and decentralized PES arrangements

For $b(1-\beta) < c\beta$:	For $b(1-\beta) > c\beta$:
$Q^{NBS_{i,j}} = Q^{CFB}$	$Q^{NBS_{i,j}} = Q^{CFB}$
$(\tilde{p}^{NBS_{i,j}} + \mu) - \tilde{s}^{NBS_{i,j}} < p^{CFB}$	$(\tilde{p}^{NBS_{i,j}} + \mu) - \tilde{s}^{NBS_{i,j}} > p^{CFB}$
$\tilde{p}^{NBS_{i,j}} < s^{CFB}$	$\tilde{p}^{NBS_{i,j}} > s^{CFB}$
$U_{B_i}^{NBS_{i,j}} > U_{B_i}^{CFB}$	$U_{B_i}^{NBS_{i,j}} < U_{B_i}^{CFB}$
$U_{P_j}^{NBS_{i,j}} < U_{P_j}^{CFB}$	$U_{P_j}^{NBS_{i,j}} > U_{P_j}^{CFB}$
$W^{NBS_{i,j}} = W^{CFB}$	$W^{NBS_{i,j}} = W^{CFB}$

$$(\tilde{p}^{NBS_{i,j}} + \mu) - \tilde{s}^{NBS_{i,j}} - p^{CFB} = \frac{1}{2}(b(1-\beta) - c\beta)\frac{an - (\mu + \delta)}{c + m(bn - e)} \tag{31}$$

Hence, when $b(1-\beta) < c\beta$, then $(\tilde{p}^{NBS_{i,j}} + \mu) - \tilde{s}^{NBS_{i,j}} - p^{CFB} < 0$ implying $U_{B_i}^{NBS_{i,j}} > U_{B_i}^{CFB}$. The opposite holds when $b(1-\beta) > c\beta$. In the same vein, the cost for wetland creation under the two schemes is the same for every provider P_i, so we compare the revenue received in the two cases for each unit of wetland created: (i) $\tilde{p}^{NBS_{i,j}}$ under the negotiated PES-subsidy scheme and (ii) s^{CFB} under the constrained first-best PES-subsidy scheme. From

$$\tilde{p}^{NBS_{i,j}} - s^{CFB} = \frac{1}{2}(b(1-\beta) - c\beta)\frac{an - (\mu + \delta)}{c - me + bmn}, \tag{32}$$

we can see that $\tilde{p}^{NBS_{i,j}} > s^{CFB}$ and $U_{P_j}^{NBS_{i,j}} > U_{P_j}^{CFB}$ when $b(1-\beta) > c\beta$, and the opposite holds when $b(1-\beta) < c\beta$. As for the social planner, it is straightforward to understand that $W^{NBS_{i,j}} = W^{CFB}$ beause the change from a constrained first-best PES-subsidy scheme to a negotiated one has only distributional consequences. Table 2 summarizes the results of our comparison.

3.2. From one-to-one to many-to-many negotiations

A critical issue in the implementation of efficient wetland PES schemes concerns the number of beneficiaries and providers of the ESs delivered throughout the creation of wetlands. On the basis of the generic negotiation setting between many beneficiaries and many providers, analyzed above, and proposition 3, different scenarios can be obtained: one beneficiary ($n = 1$) and one provider ($m = 1$), one beneficiary ($n = 1$) and m providers, n beneficiaries and one provider ($m = 1$) and n beneficiaries and m providers. For each of these particular cases, we highlight the specific role of the social planner to achieve the social optimum with and without additional amenity services that benefit society.

The first particular case of a negotiation between one beneficiary and one provider may correspond, for instance, to a dam owner and the owner of its large upland catchment area (Everard 2018). In this case, the disagreement payoff for each negotiator is nil and the Nash bargaining solution outcome gives the following payoffs (denoted by the superscript $NBS_{1,1}$) for the beneficiary and the provider, respectively:

$$U_B^{NBS_{1,1}} = \frac{1}{2}\beta(b+c)\left(\frac{a-(\mu+\delta)}{c+b-e}\right)^2 \tag{33}$$

$$U_P^{NBS_{1,1}} = \frac{1}{2}(1-\beta)(b+c)\left(\frac{a-(\mu+\delta)}{c+b-e}\right)^2 \tag{34}$$

Clearly, equations (33) and (34) imply a split of the total welfare between the beneficiary and the provider in proportion to their respective relative bargaining powers, β and $1-\beta$. This result is in accordance with the literature on bargaining in bilateral monopoly relations (see, e.g., Mas-Collel et al. 1995, Rubinstein 1982).

An intensive water user, such as a municipal water utility or a mineral water producer, paying (directly or indirectly) for watershed conservation efforts of upstream farmers is an example for the second case involving one beneficiary and many providers. The Vittel example mentioned in section 2.3. is a perfect illustration of this case. The Vittel company negotiated bilaterally and contracted with several providers (polluting farmers) to reduce nitrate transport to groundwater in Vittel's water catchment area (Depres et al. 2008). In this case, it is arguably easy to enforce a PES program and minimize free-riding on wetland ESs. According to Engel et al. (2008), the ensuing PES from this case exhibits the characteristics of a local monopsony. The Nash-in-Nash bargaining gives the following payoffs (denoted by the superscript $NBS_{1,m}$) for the beneficiary and the providers, respectively:

$$U_B^{NBS_{1,m}} = \frac{1}{2}m(c\beta - b(1-\beta)+bm)\left(\frac{a-(\mu+\delta)}{c+m(b-e)}\right)^2 \tag{35}$$

$$U_{P_j}^{NBS_{1,m}} = \frac{1}{2}(1-\beta)(b+c)\left(\frac{a-(\mu+\delta)}{c+m(b-e)}\right)^2 \text{ and } U_P^{NBS_{1,m}} = mU_{P_j}^{NBS_{1,m}} \tag{36}$$

The gap between $U_B^{NBS_{1,m}}$, the payoff of the beneficiary, and $U_P^{NBS_{1,m}}$, the total payoff of the providers, is $U_B^{NBS_{1,m}} - U_P^{NBS_{1,m}} = (c\beta - b(1-\beta)+bm) - (1-\beta)(b+c)$. Assuming equal bargaining power, i.e., $\beta = 1/2$, we can see that $U_B^{NBS_{1,m}} - U_P^{NBS_{1,m}} = b(m-1) > 0$, which suggests that the payoff of the beneficiary exceeds the sum of the providers' payoffs for $m > 1$. This result is in line with Depres et al. (2008), who argue that, in the case of Vittel, collective bargaining would have benefited farmers at Vittel's expense.

In the first two negotiation scenarios with only one beneficiary discussed above, it can be shown that the intervention of a social planner (or any other third party) to achieve efficiency is not required in the absence of amenity services that benefit society. When $e = 0$, the subsidy and corresponding administrative costs are zero: $\tilde{s}^{NBS_{1,m}} = \delta = 0$. But when wetland creation is associated with additional amenity services as well, a social planner is required to balance the beneficiary utility, the amenity benefits and the providers' profits. The size of created wetland and total welfare increase with the number of providers: $Q^{NBS_{1,m}} > Q^{NBS_{1,1}}$ and $W^{NBS_{1,m}} > W^{NBS_{1,1}}$, for $m > 1$. The subsidy also increases with the number of providers, while the payment to each provider decreases for $b > e$ because $\tilde{p}^{NBS_{1,m}} - \tilde{p}^{NBS_{1,1}} = -\frac{1}{2}(b-e)\frac{(m-1)(a-\mu-\delta)(b(1-\beta)+c(2-\beta))}{(c+b-e)(c+m(b-e))}$.

We now consider a symmetric scenario of a monopolist provider dealing with many beneficiaries. This third special case, the outcomes of which we denote by $NBS_{n,1}$, corresponds, for example, to a local community of farmers that has joint property rights to the land, which therefore acts as a collective ES provider (Rojahn and Engel 2005). Here, the provider creates (or conserves) a wetland area that benefits all the beneficiaries because ESs are public goods. A PES arrangement is put in place with the objective of making all beneficiaries pay for the ESs they benefit from. In this case, the intervention of a social planner is required to achieve the constrained first-best optimal wetland size even in the absence of additional amenity services that benefit society. Indeed, the implementation of a positive subsidy is required for $n > 1$: $\tilde{s}^{NBS_{n,1}} = \frac{c+b}{c+bn}(an - \mu - \delta) - a + \mu > 0$.

In this scenario of a single provider $(m = 1)$ with n beneficiaries, the role of the social planner to achieve the constrained first-best social optimum is important to solve the free-riding issue of the beneficiaries. As pointed out by Matsushima and Shinohara (2019), when the provider does not commit to the production of a public good before negotiations, the amount of the public good is not produced efficiently and the beneficiaries have strong incentives to free ride.

Proposition 6. *In the presence of several beneficiaries, even when there are no amenities, the social planner achieves the constrained first-best social optimum by preventing free-riding.*

Proposition 6 suggests that the effectiveness of wetland PES schemes improves following the involvement of the social planner, even when wetland creation does not provide amenity services. Also, it is analogous to the result obtained by Matsushima and Shinohara (2019), who found that the public good, corresponding to wetland creation in our model, will be under provided in equilibrium and the beneficiaries will enjoy the public good at no cost.[21]

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[21] Contrary to Matsushima and Shinohara (2019), we do not consider an approval or disapproval stage for the provider.

Finally, in the case with many beneficiaries and many providers, we assume an identical number of providers and beneficiaries and that one beneficiary and one provider can sign only one agreement. As mentioned in section 2.3.1, this latter assumption is in line with the practice of PES, which discourages the possibility of stacking (Salzman 2009, Woodward 2011, Smith et al. 2019). With many providers and many beneficiaries, the free-riding issue remains and the intervention of the social planner is necessary to achieve the constrained first-best social optimum.

4. Conclusion

This paper has analyzed the economic efficiency of different decentralized arrangements of PES for the provision of wetland ESs. These PES arrangements consist of a combination of a negotiated price for wetland ESs between the beneficiaries and the providers of such ESs with a subsidy granted by a third party—such as a social planner or government agency—acting in the interest of society. We considered different negotiation scenarios ranging from one-to-one to many-to-many negotiations. In all negotiation scenarios, a Nash-in-Nash procedure consisting in a Nash equilibrium computed from the Nash bargaining solutions between the different parties has been used. We addressed the role played by the third party in these negotiations to ensure the optimal provision of ESs through subsidies. We found that there is an active role for the third party in ensuring that PES are efficient, in addition to the potential reduction of transaction costs already documented in the literature (Wunder et al. 2008, Vatn 2010). This result departs from the theory that sees PES as a Coasian market solution, but it is consistent with the practice of PES (Vatn 2010).

In the presence of transaction or negotiation costs, we compared the outcome of the decentralized arrangements, which combine negotiated PES and subsidy solutions, with that of a centralized approach or constrained first-best PES-subsidy scheme implemented by the third party while taking into account the associated administrative costs. With both regulatory options, we showed that the constrained first-best optimal size of wetland is achieved, suggesting that the constrained first-best social optimum can be decentralized. However, while the third party is indifferent between the two regulatory options, beneficiaries and providers have conflicting preferences between the negotiated solution and the centralized scheme. As a consequence, even if the size of the created welfare surplus is the same, the redistribution of the associated surplus creates conflicting interests. Such a result may explain why the implementation of PES can be difficult in practice, and it suggests an active role for a third party (a social planner or government agency).

The suggested role for a social planner or government agency in maximizing the efficiency of PES may need further qualifications after one considers information asymmetries between wetland ES providers and beneficiaries

(Ferraro 2008). It is well known that inefficiency is inherent in the outcomes of a large family of bargaining games with incomplete information (Osborne and Rubinstein 1990). For example, providers could potentially use their private information about the opportunity costs of supplying wetland ESs to capture significant informational rents. Should we extend our model to include hidden information, another role of the social planner could be to reduce these informational rents. As explained by Myerson and Satterthwaite (1983), a central planner could pay a lump-sum subsidy to the negotiating parties to create a Bayesian incentive-compatible mechanism that is ex post efficient and individually rational. Myerson and Satterthwaite (1983) also suggest that the central planner could be a broker who either subsidizes or exploits the negotiating parties, but in this case, direct bargaining between the beneficiaries and the providers is not possible as in our paper. A more complex analysis might also model the design of PES in a more realistic way that considers the fact that the multiple wetland ESs are sometimes interdependent in production and/or consumption (Goldman et al. 2007, Lundberg et al. 2018). Understanding the consequences of these features as well as other relevant stylized facts of PES implementation, however, will require additional research.

Appendix A: Proof of proposition 1

Substituting (4) into (7) and (10) gives the PES-subsidy scheme in proposition 1:

$$p^{SO} = a - bQ^{SO} = \frac{a(c-me)}{c+m(bn-e)} \tag{A1}$$

$$s^{SO} = \frac{c}{m}Q^{SO} = \frac{nac}{c+m(bn-e)} \tag{A2}$$

We then get the expression of the beneficiaries' surplus, providers' profits and total welfare by substituting equations (4), (A1) and (A2) into the respective functions. ■

Appendix B: Proof of proposition 2

The welfare surplus with administrative costs can be rewritten as

$$W = A(Q) + nB(Q) - (\delta+\mu)Q - mC\left(\frac{Q}{m}\right). \tag{A3}$$

Using the specified functions, we obtain

$$W = \frac{e}{2}Q^2 + anQ - \frac{bn}{2}Q^2 - (\delta+\mu)Q - \frac{mc}{2}\left(\frac{Q}{m}\right)^2. \tag{A4}$$

The first-order conditions for the maximization of equation (A4) with respect to p and s are

$$\frac{\partial W}{\partial p} = \left(eQ + an - bnQ - \delta - \mu - \frac{c}{m}Q\right)\frac{\partial Q}{\partial p} = 0,$$
$$\frac{\partial W}{\partial s} = \left(eQ + an - bnQ - \delta - \mu - \frac{c}{m}Q\right)\frac{\partial Q}{\partial s} = 0,$$

giving

$$Q^{CFB} = \frac{m(an - (\mu + \delta))}{c + m(bn - e)}, \tag{A5}$$
$$p^{CFB} = a - bQ^{CFB}, \tag{A6}$$
$$s^{CFB} = \frac{c}{m}Q^{CFB}. \tag{A7}$$

Substituting equation (A5) into equations (A6) and (A7) gives the PES-subsidy scheme in this proposition. We then get the expressions of the beneficiaries' surplus, providers' profits and total welfare by substituting the expressions of Q^{CFB}, p^{CFB} and s^{CFB} into the respective functions. Note that to derive the expressions of the utility levels of individual agents, one has to distinguish between the individual beneficiary's demand ($q_i = Q^{CFB}/n$) and the individual provider's supply ($q_j = Q^{CFB}/m$). ■

Appendix C: Proof of proposition 3

Solving the maximization problem (21), we obtain equations (26) and (27). Now, let us assume that the social planner grants a subsidy amount of $\tilde{s}$ to the beneficiary to increase the size of the wetland. From equations (26) and (27), a rise of $\tilde{s}$ increases Q as well as $\tilde{p}$. The social planner's objective is to maximize the total surplus:

$$\begin{aligned}\max_{\tilde{s}} W &= A(Q) + nB(Q) - (\mu + \delta)Q - \sum_{j=1}^{m} C(q_j) \\ &= (an - \mu - \delta)Q + \left(\frac{e}{2} - \frac{bn}{2} - \frac{c}{2m}\right)Q^2 \end{aligned} \tag{A8}$$

This gives the optimal amount of the subsidy:

$$\tilde{s}^{NBS_{i,j}} = \frac{(an - \mu - \delta)(c + bm)}{(c + m(bn - e))} - a + \mu \tag{A9}$$

Substituting equation (A9) into equations (26) and (27) respectively gives

$$Q^{NBS_{i,j}} = \frac{m(an - \mu - \delta)}{c + m(bn - e)}, \tag{A10}$$
$$\tilde{p}^{NBS_{i,j}} = \frac{1}{2}\frac{(an - \mu - \delta)(b(1 - \beta) + c(2 - \beta))}{c + m(bn - e)}. \tag{A11}$$

We then get the expressions of the beneficiaries' surplus, providers' profits and total welfare by substituting equations (A9), (A10) and (A11) into the respective functions while using the same steps as in the proof of proposition 2. ■

Appendix D: Proof of proposition 4

The proof follows the same logic as in proposition 3 with the following payoff functions: when an agreement is reached, payoffs of each beneficiary and each provider are respectively

$$U^a_{B_i} = B(Q) - (\widehat{p} + \mu)q_{ij}, \tag{A12}$$

$$U^a_{P_j} = \widehat{p}q_{ij} + \widehat{s}q_{ij} - C(q_{ij}), \tag{A13}$$

while in case of disagreement, we respectively have

$$U^d_{B_i} = B(Q - q_{ij}), \tag{A14}$$

$$U^d_{P_j} = 0. \tag{A15}$$

Note that the provider does not receive the subsidy in case of disagreement. Net payoffs $\left(U^a_{B_i} - U^d_{B_i}\right)$ and $(U^a_{P_j} - U^d_{P_j})$ can be computed from the above payoff expressions. The Nash bargaining solution is the solution of

$$\max_{\widehat{p},q_{ij}} (B(Q) - B(Q - q_{ij}) - (\widehat{p} + \mu)q_{ij})^{\beta} (\widehat{p}q_{ij} + \widehat{s}q_{ij} - C(q_{ij}))^{1-\beta}. \tag{A16}$$

The first-order condition for the maximization with respect to $\widehat{p}$ gives

$$\widehat{p} = (1 - \beta)\left(\frac{B(Q) - B(Q - q_{ij})}{q_{ij}} - \mu\right) + \beta\left(\frac{C(q_{ij})}{q_{ij}} - \widehat{s}\right). \tag{A17}$$

Substituting equation (A17) into equation (A16) gives the new program:

$$\max_{q_{ij}} \beta^{\beta}(1 - \beta)^{1-\beta} \left(B(Q) - B(Q - q_{ij}) + \widehat{s}q_{ij} - C(q_{ij}) - \mu q_{ij}\right),$$

which is equivalent to the one obtained before. The first-order condition for the maximization with respect to q_{ij} gives

$$\frac{\partial B(Q)}{\partial q_{ij}} + \widehat{s} = \frac{\partial C(q_{ij})}{\partial q_{ij}} + \mu. \tag{A18}$$

On the basis of the specified functions, we obtain

$$Q = \frac{m(a + \widehat{s} - \mu)}{c + bm}, \tag{A19}$$

$$\widehat{p} = (1 - \beta)\left(a - \mu + \frac{b}{2}q_{ij} - bQ\right) + \beta\left(\frac{c}{2}q_{ij} - \widehat{s}\right). \tag{A20}$$

The objective of the social planner is to maximize the total surplus:

$$\max_{\widehat{s}} W = A(Q) + nB(Q) - (\mu + \delta)Q - \sum_{j=1}^{m} C(q_j) \tag{A21}$$

The program is the same and implies the same solution as before:

$$\widehat{s}^{NBS_{i,j}} = \tilde{s}^{NBS_{i,j}} = \frac{(an - \mu - \delta)(c + bm)}{c + m(bn - e)} - a + \mu \tag{A22}$$

Substituting equation (A22) into equations (A19) and (A20) gives

$$Q^{NBS_{i,j}} = \frac{m(an - \mu - \delta)}{c + m(bn - e)}, \tag{A23}$$

$$\begin{aligned} \widehat{p}^{NBS_{i,j}} &= \tilde{p}^{NBS_{i,j}} - \tilde{s}^{NBS_{i,j}} \\ &= \frac{\begin{matrix} ((b + c + 2bm)\beta(\delta + \mu) + 2(c - me)(a - \mu) \\ +an(b(1 - \beta) - c\beta) - 2bmn\mu) \end{matrix}}{2(c + m(bn - e))}. \end{aligned} \tag{A24}$$

We immediately get the expressions of the beneficiaries' surplus, providers' profits and total welfare by substituting equations (A22), (A23) and (A24) into the respective functions. ■

Appendix E: Proof of proposition 5

It is immediate to show that $W^{NBS_{i,j}} - W^{CFB} = 0$. We compute $U_{B_i}^{NBS_{i,j}} - U_{B_i}^{CFB}$ and $U_{P_j}^{NBS_{i,j}} - U_{P_j}^{CFB}$ as follows:

$$U_{B_i}^{NBS_{i,j}} - U_{B_i}^{CFB} = \frac{1}{2}\frac{m}{n}(c\beta - b(1 - \beta))\left(\frac{an - (\mu + \delta)}{c + m(bn - e)}\right)^2, \tag{A25}$$

$$U_{P_j}^{NBS_{i,j}} - U_{P_j}^{CFB} = \frac{1}{2}(b(1 - \beta) - c\beta)\left(\frac{an - (\mu + \delta)}{c + m(bn - e)}\right)^2 \tag{A26}$$

It is easy to see that $U_{B_i}^{NBS_{i,j}} \gtreqless U_{B_i}^{CFB}$ iff $b(1 - \beta) \lesseqgtr c\beta$ and $U_{P_i}^{NBS_{i,j}} \gtreqless U_{P_i}^{CFB}$ iff $b(1 - \beta) \gtreqless c\beta$. ■

Appendix F: Proof of proposition 6

Assume no intervention of a social planner and no amenities ($e = 0$), and consider negotiations between a single provider P and n beneficiaries, B_i with $i = 1, ..., n$. The provider and each beneficiary have the following utility functions:

$$U_P = pQ - C(Q) \tag{A27}$$

$$U_{B_i} = B(Q) - pq_i \tag{A28}$$

We first define the socially optimal level of the public good Q as follows. For each $k \in \{1, .., n\}$, $Q(k)$ is defined as the socially optimal level of the public good such that

$$Q(k) = \arg\max_{Q \geq 0} kB(Q) - C(Q). \tag{A29}$$

Using our specification, we obtain $Q^{SO}(k) = \frac{ka}{bk+c}$.

The Nash bargaining solution associated with the negotiation between the provider and one beneficiary is given by

$$\max_{p, q_i} (B(Q) - B(Q - q_i) - pq_i)^{\beta} (pq_i - C(Q) + C(Q - q_i))^{1-\beta}. \tag{A30}$$

The first order condition of (A30) with respect to p gives

$$p = (1 - \beta) \left(\frac{B(Q) - B(Q - q_i)}{q_i} \right) + \beta \left(\frac{C(Q) - C(Q - q_i)}{q_i} \right). \tag{A31}$$

Substituting equation (A31) in the maximization problem (A30) gives

$$\max_{q_i} \beta^{\beta} (1 - \beta)^{1-\beta} (B(Q) - B(Q - q_i) - C(Q) + C(Q - q_i)). \tag{A32}$$

The first order condition of the maximization problem (A32) gives

$$\frac{\partial B(Q)}{\partial q_i} = \frac{\partial C(Q)}{\partial q_i}, \tag{A33}$$

for each $i \in N$ and

$$q_i^{NBS} = \arg\max_{q_i \geq 0} B(Q) - C(Q). \tag{A34}$$

This leads to $\sum_{i \in N} q_i^{NBS} = Q^{SO}(1) = \arg\max_{Q \geq 0} B(Q) - C(Q)$. Using our specification, we obtain $Q^{NBS} = \frac{a}{b+c} = Q^{SO}(1)$. As shown by Matsushima et Shinohara (2019) in their proposition 1, the amount of public good will be $Q^{SO}(1)$ and the provider will not supply the public good efficiently. Moreover, some beneficiaries will be free riders and will enjoy the public good at no cost. ■

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