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Analysis

# Conservation when landowners have bargaining power: Continuous conservation investments and cost uncertainty

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ABSTRACT

Spatially heterogeneous costs of securing conservation agreements should be accounted for when prioritizing properties for conservation investment. Most researchers incorporating conservation costs into analyses have relied on estimates of landowners' opportunity costs of accepting a conservation agreement. Implicitly assumed in such studies is therefore that those who "produce" biodiversity (landowners) receive none of the surplus available from trade. Instead, landowners could use their bargaining power to gain profits from conservation investments. We employ game theory to determine the surplus landowners could obtain in negotiations over conservation agreements, and the consequent effects on conservation outcomes, when enrolment decisions are governed by continuous variables (e.g. the proportion of a property to enrol). In addition, we consider how landowner uncertainty regarding the opportunity costs of other landowners affects these outcomes. Landowners' ability to gain surplus is highly variable and reflects variation in the substitutability of different properties for achieving a specified conservation objective. The ability of landowners to obtain profits from conservation agreements results in conservation outcomes that are substantially diminished relative to when landowners accept investment at opportunity costs. Uncertainty increases landowner profits, leading to a greater diminution in conservation benefits.

## 1. Introduction

To make conservation measures more effective and efficient, researchers in conservation planning have attempted to incorporate spatially explicit conservation costs into their analyses (Naidoo et al., 2006). For example, Ando et al. (1998) estimated conservation costs throughout the USA using average county-level agricultural land values, while Stoms et al. (2011) equated the development potential of agricultural land in California with its cost for conservation. These studies and others (e.g. Carwardine et al., 2008; Polasky et al., 2001) use the agricultural value of land as a coarse proxy for the cost of conservation for two reasons. First, there is a lack of published data on acquisition costs of land for conservation (but see Davies et al. (2010)), meaning that there is little alternative but to use proxy data. Second, agricultural land values provide a measure of the opportunity costs of using land for conservation rather than production (Adams et al., 2010).

Most conservation agreements on private land are secured through a voluntary negotiation process (Ferraro, 2008). In such a process, the range of cost outcomes is bounded below by the landowner's willingness-to-accept (WTA) and above by the conservation group's willingness-to-pay (WTP). If a landowner is indifferent between conservation and production, the WTA is bounded below by opportunity costs because such a landowner will not accept a conservation payment of a value less than can be achieved through continued production. By using the proxy of agricultural land values, researchers implicitly assume that conservation costs equal landowners' WTA. This is the best-case outcome for conservation in which all of the surplus available from trade is obtained by those who "consume" biodiversity (conservation groups), with none of the surplus going to those who "produce" it (landowners).

For this best-case scenario for conservation to be realised, conservation groups would need to hold all of the bargaining power in negotiations. In general, the distribution of bargaining power among negotiating parties depends on the level of competition in a market. A conservation group with a broad focus, and thus many potential landowners with whom to seek agreements, may indeed have a very strong bargaining position. However, where a conservation group has a more

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narrowly focused objective, increasing the abundance of a single rare species, for example, or where there are many conservation groups in competition for a valuable conservation asset, it is the landowner who would hold most of the bargaining power. This variation in the potential distribution of bargaining power means that many, if not all, conservation agreements will be reached with a division of surplus between the landowner and conservation group, rather than the conservation group obtaining the total surplus as has previously been supposed. To ensure that conservation planning exercises accurately estimate the benefits that will follow from investments, it is therefore necessary to know the amount of profit landowners could obtain from conservation contracts.

We began to investigate these ideas in Lennox et al. (2012), where we modelled the situation in which a conservation group identifies one site to enrol in its conservation programme. We determined the maximum producer surplus that this single landowner could garner, thus calculating the conservation group's WTP. Both the theoretical and numerical analyses in our paper highlighted a large gap between the WTA and the WTP, indicating that previous conservation planning studies may have significantly underestimated the cost of providing conservation.

In this present paper, we extend these ideas beyond the simple case investigated in our initial study. First, rather than identifying a single site for protection, we model the situation in which the conservation group seeks to simultaneously secure negotiated agreements on multiple sites. We employ a negotiation structure in which the conservation group solicits payment requirements from landowners for conservation measures on their sites and then makes investment decisions in light of these demands (similar to the negotiation method used in the Conservation Reserve Programme (Hanley et al., 2012) and the Victoria BushTender trial (Stoneham et al., 2003)). To contrast with previous studies that have provided the best-case scenario for conservation in which all landowners accept conservation investment at opportunity costs, we analyse the scenario in which all landowners use their bargaining power in an attempt to secure payments that maximize their profits—for a discussion of whether or not landowners are motivated solely by profits see, for example, Chouinard et al. (2008). This negotiation framework therefore involves competitive interactions between landowners: if a landowner makes excessively high payment demands, she/he will gain limited or no profits because the conservation group can choose to invest with other willing landowners. Landowners must therefore make payment demands in light of these competitive forces.

The second important difference between this and our earlier study relates to the investment decision of the conservation group. In Lennox et al. (2012), the conservation group was constrained to the simple binary choice of enrolling the site or not in the conservation programme. However, it is often the case that conservation decisions can be varied over a range of possible values. For example, decisions over how much investment to devote to a region, how much time to spend on a conservation activity or how much land on a site to procure for conservation span a continuum from zero to the available maximum. A central difference between the binary- and continuous-type investments relates to the substitutability of sites. When the decision variable is enrol/do not enrol the site, only differences between sites are important. When the decision is represented by a continuous variable, in response to landowner demands the conservation group can additionally give consideration to the substitutability of differing levels of conservation on individual sites. Negotiations with multiple rather than a single landowner and the altered nature of site substitutability between the binary and continuous decision variables could affect the ability of landowners to make profits from conservation investments and are therefore the focus of this paper.

When making payment demands to maximize profits, landowners' strategies will be guided by the information they possess about factors such as the conservation value and opportunity costs of their and other landowners' sites. The quality of this information, and its utility when making payment demands, is likely to be highly variable, depending on the nature of the conservation programme and the farming system in which the landowner is embedded. For instance, in many rural communities landowners depend on each other for services, such as the sharing of equipment and labour, land renting, joint irrigation and drainage projects, and assistance in times of need (Rashford et al., 2003). Landowners are also part of a local social network through which they are cognisant of the land use decisions of others (McGuire et al., 2013). As a consequence of these interactions, where conservation groups or particular conservation programmes operate in limited geographical areas, landowners are liable to have substantial information about one another. This information, which may not be available to conservation groups, can be used by landowners when setting payment levels to maximize profits. For conservation programmes that are more diffuse, the information available to landowners will be much less certain and this uncertainty could impact their strategies. To consider how this impact will be manifest, in this paper we also investigate how landowner uncertainty regarding the opportunity costs of other landowners influences payment demands, landowner profits and conservation outcomes.

Game theory is the mathematical study of competitive and strategic interactions. Many game theoretic models have been developed to analyse how those seeking to maximize profits should set prices in competitive contexts. The first such analysis was undertaken by Bertrand (1883) in which a duopoly with homogeneous goods and equal production costs was modelled as a game of complete information—both firms knew all salient facts about their competitor. Here, we model Bertrand competition in the context of conservation planning. Our models have more realistic assumptions than the classic Bertrand model: rather than being homogeneous, we assume that conservation benefits are differentiated substitutes; we account for asymmetric costs with variation in landowner opportunity costs; and we model games of both complete and incomplete information – landowners do not know the exact opportunity costs of other landowners – to investigate how landowner uncertainty affects outcomes. In the next section, we lay out the mathematical models. Following on from this, we analyse the case of a hypothetical duopoly (two landowner system) to exemplify the mathematical formulation and show how solutions are found. Finally, we apply our results to a case study of a farming system in the Peak District of the UK to investigate the profits landowners can make from conservation investments.

## 2. Mathematical Models and Solution Methods

### 2.1. Problem Formulation

We assume that the conservation group identifies a set of landowners/sites, $I = \{i | i = 1, \ldots, n\}$, of conservation interest. Function $V_i$ describes the conservation benefit of investing in site $i$. We assume that $V_i$ is concave, twice differentiable and monotonically increasing. For simplicity, we also assume that conservation benefits accrue additively over sites. The level of conservation effort that the conservation group devotes to site $i$ is represented by $x_i$, and the vector $\mathbf{x} = (x_1, \ldots, x_n)$ represents the effort level on all sites. (Conservation effort is a generic measure that encompasses all examples of continuous investments. Where applicable, we will specify what conservation effort represents.) The opportunity costs to landowner $i$ of accepting a unit increase in conservation effort is $c_i$. Landowners can make payment demands in excess of opportunity costs to gain surplus from the conservation investment. Let $\Delta c_i$ represent the payment above opportunity costs that landowner $i$ demands. Given the unobservable nature of landowners' true opportunity costs, the conservation group is unable to partition the payment demand of landowner $i$, represented by $p_i$, into the opportunity costs ($c_i$) and surplus ($\Delta c_i$) components. Finally, the total conservation investment over all sites is limited by the conservation group's budget, $B$. These assumptions lead to the following optimization problem for the conservation group:

$$\max_{\mathbf{x}\in\mathbb{R}^n_+} \sum_{i\in I} V_i(x_i)$$

subject to $x_i \geq 0, \forall i \in I$

$$\sum_{i\in I} p_i x_i \leq B$$

where $p_i = c_i + \Delta c_i$. The Lagrangian, $\mathcal{L}$, for this problem is

$$\mathcal{L}(x) = \sum_{i\in I} V_i(x_i) - \lambda_1\left(\sum_{i\in I} p_i x_i - B\right) + \sum_{i\in I} \lambda_{i+1} x_i$$

where $\lambda$ is the Lagrangian multiplier. We illustrate for the case of an interior optimal solution—boundary solutions are discussed in the Supplementary material (Section S4). Necessary and sufficient conditions for an optimal solution are then

$$\frac{\partial \mathcal{L}}{\partial x_i} = 0, \quad \forall \ i \in I \tag{1}$$

$$\sum_{i\in I} p_i x_i \leq B. \tag{2}$$

Eqs. (1) & (2) determine the optimal level of conservation effort that the conservation group should select on each of the sites given the payments required by the landowners; that is, they determine the conservation demand functions. Let these conservation demand functions be represented by

$$x_i = f_i(\mathbf{p}), \quad \forall \ i \in I$$

where the vector $\mathbf{p} \in \mathbb{R}^n_+$ represents the payment demands of all landowners.

Landowners must determine the payment demand to make that will return them the highest (expected) profit. Where landowners have complete information, the profit functions are

$$\begin{aligned} \pi_i &= \Delta c_i x_i \\ &= \Delta c_i f_i(\mathbf{p}) \\ &= \Pi_i^a(\mathbf{p}), \quad \forall \ i \in I. \end{aligned} \tag{3a}$$

Eq. (3a) states that a landowner's profit is her/his payment demand above opportunity costs multiplied by the demand for conservation on her/his site, which is dependent on the payment demands of all landowners.

Alongside the complete information analyses, we also consider how outcomes are impacted by landowner uncertainty regarding the opportunity costs of other landowners. In these incomplete information analyses, we assume that each landowner is risk neutral and has some well founded belief on the distribution of opportunity costs of other landowners, represented by the continuous uniform distribution, $U$. For presentational efficiency, here we give the expected profit functions in a duopoly, leaving the general case for the Supplementary material (Section S1). In this scenario, landowner $i$ believes that the opportunity cost of the other landowner, landowner $-i$, are distributed on $U\left(\underline{c_{-\mathrm{i}}}, \overline{c_{-\mathrm{i}}}\right)$. Therefore, the expected profit functions are

$$\begin{aligned} E(\pi_i) &= \frac{\Delta c_i}{\overline{c_{-\mathrm{i}}} - \underline{c_{-\mathrm{i}}}} \int_{\underline{c_{-\mathrm{i}}}}^{\overline{c_{-\mathrm{i}}}} f_i(\mathbf{p}) \, dc_{-\mathrm{i}} \\ &= \frac{1}{\overline{c_{-\mathrm{i}}} - \underline{c_{-\mathrm{i}}}} \int_{\underline{c_{-\mathrm{i}}}}^{\overline{c_{-\mathrm{i}}}} \Pi_i^a(\mathbf{p}) \, dc_{-\mathrm{i}} \\ &= \Pi_i^b(\mathbf{p}), \quad \forall \ i = \{1, 2\}. \end{aligned} \tag{3b}$$

Eq. (3b) states that a landowner's expected profit is her/his payment demand above opportunity costs multiplied by the likely demand for conservation on her/his site over all hypothesised values of the opportunity costs of the other landowner (or, more generally, all other landowners).

Using these profit functions, we can determine functions that specify the landowner's best reaction given the payment demands of the other landowners. Such reaction functions are derived by solving the profit-maximizing conditions for all values in the domain of $\mathbf{p}$,

$$\frac{\partial \Pi_i^*(\mathbf{p})}{\partial p_i} = 0, \quad \forall \ i \in I \tag{4}$$

where $\Pi_i^*$ equals $\Pi_i^a$ or $\Pi_i^b$ for, respectively, the complete and incomplete information analyses.

The intersection of these reaction functions gives the Nash–Bertrand (NB) equilibrium, the solution in which no landowner can increase her/his profits by unilaterally demanding a different payment,

$$p_i^{NB} = \arg\max_{p_i} \Pi_i^*\left(p_i, \mathbf{p}_{-i}^{NB}\right), \quad \forall \ i \in I \tag{5}$$

where $\mathbf{p}_{-i}^{NB}$ represents the NB equilibrium payment demands of all landowners except landowner $i$.

This modelling framework therefore defines an extensive form game in which all conservation benefit information is common knowledge; opportunity cost information can either be common or private knowledge; landowners simultaneously make payment demands for the per unit conservation effort investment on their sites; and from these demands the conservation group selects optimal levels of effort on each of the sites. Eq. (5) defines the solution to the game and states that the objective of each landowner is to chose a payment demand that maximizes her/his (expected) profit under the assumption that all other landowners will do the same.

### 2.2. Solution Method—Relaxation Algorithm

We employ an iterative method for determining equilibrium solutions based on the Nikaidô–Isoda function (Nikaidô and Isoda, 1955). This algorithm, known as the relaxation algorithm (Contreras et al., 2004; Krawczyk and Uryasev, 2000), starts with an initial guess for the NB equilibrium. Then in each iteration a landowner is selected and the payment demand that returns her/his maximum surplus is calculated (Eq. (4)) with the payment demands of the other landowners fixed at the level in the previous iteration. This process is continued until the solution converges to the NB equilibrium. The algorithm is exemplified in Section 3 and full details are given in the Supplementary material (Section S2).

### 2.3. Relationship Between Conservation Effort and Conservation Improvements

To illustrate model predictions, we assume a particular form for function $V$ describing the relationship between the conservation effort devoted to a site and the resulting conservation improvements. We use a Holling Type-II function (Holling, 1959) that in the context of our problem is characterized by showing diminishing conservation improvements for increasing conservation effort on a particular property. The general form of the Holling Type-II function is,

$$V(x) = \frac{rx}{1 + rhx}, \quad r, h > 0. \tag{6}$$

In this formulation, the parameter $r$ gives the marginal improvement in conservation gained from the first unit of conservation effort invested (i.e. $V'(0) = r$). The parameter $h$ gives the reciprocal of the asymptote, the maximum conservation gain that can be yielded from the property (i.e. $1 / \lim_{x\to\infty} V(x) = h$). Two examples of Holling functions, which will be utilized in Section 3, are shown in Fig. 1.

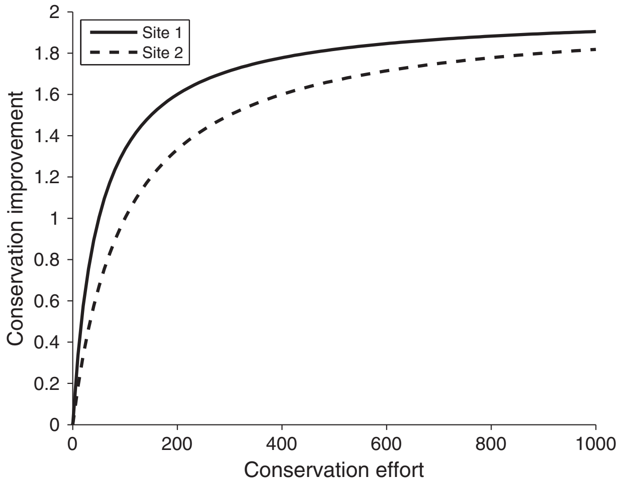

**Fig. 1.** Two examples of Holling Type-II functions. Parameters: $[r_1, h_1, r_2, h_2] = [0.04, 0.5, 0.02, 0.5]$.

## 3. Hypothetical Duopoly

To exemplify the mathematical formulation and show how solutions are found, in this section we investigate the case of a hypothetical duopoly. First, we describe the parameters of the duopoly; we then derive general landowner profit functions; next, we calculate equilibrium solutions where landowners have complete information; finally, we consider how landowner uncertainty impacts outcomes.

### 3.1. Duopoly Parameters

We parametrize the duopoly as follows: the opportunity costs per unit of conservation effort on both sites are \$1000 (throughout we give monetary figures in US dollars); the conservation group allocates a budget of \$150,000 for investment in the two sites; and the relationship between conservation effort and conservation improvements on the sites is as described in Fig. 1, namely

$$V_1(x_1) = \frac{2x_1}{50 + x_1} \quad \text{and} \quad V_2(x_2) = \frac{2x_2}{100 + x_2}.$$

### 3.2. Derivation of Landowners' Profit Functions

By Eq. (1), a condition on the optimal level of conservation effort, $(x_1, x_2)$, that the conservation group should devote to the two sites is

$$\frac{V_1^{'}(x_1)}{p_1} = \frac{V_2^{'}(x_2)}{p_2}. \tag{7}$$

Inserting general Holling Type-II functions into Eq. (7), we can derive the demand for site 1 as a function of the landowner payment demands,

$$\frac{r_1 p_2}{(1 + r_1 h_1 x_1)^2} = \frac{r_2 p_1}{(1 + r_2 h_2 x_2)^2}$$

$$\Rightarrow x_1 = \frac{\alpha_1 (1 + r_2 h_2 x_2) - 1}{r_1 h_1} \tag{8}$$

where $\alpha_1 = \sqrt{\frac{r_1 p_2}{r_2 p_1}}$.

By the budget constraint, $x_2 = (B - p_1 x_1)/p_2$. This can be used to eliminate $x_2$ in Eq. (8). Following on from this, we use Eq. (3a) to derive profit functions where landowners have complete information as

$$\pi_1 = \frac{\Delta c_1 (\alpha_1 (r_2 h_2 B + p_2) - p_2)}{r_1 h_1 p_2 + \alpha_1 r_2 h_2 p_1} \tag{9}$$

$$\pi_2 = \frac{\Delta c_2 (\Delta c_1 B - p_1 \pi_1)}{\Delta c_1 p_2}. \tag{10}$$

### 3.3. Calculation of Equilibrium Solutions

The objective of each landowner is to make a payment demand that maximizes the profit they receive from the conservation investment. Using Eq. (9), several profit functions for landowner 1 for fixed payment demands of landowner 2 are plotted in Fig. 2a. The profit available to the landowner is unimodal. When the landowner accepts at opportunity costs ($p_1 = 1000$ and thus $\Delta c_1 = 0$), no profit is obtained from the conservation investment. As the payment demand increases, profits rise steeply. However, for large payment demands, profits diminish due to the decreasing level of effort that the conservation group is willing to devote to the site. As landowner 2 makes increasing payment demands, the maximum profit available to landowner 1 increases.

The reaction function for a landowner describes the payment demand that returns maximum profits (points marked by circles in Fig. 2a) for all payment demands of the other landowner. Reaction functions for both landowners are shown in Fig. 2b. The intersection of the reaction functions marks the equilibrium solution.

The equilibrium solution can be found by inspection of the figure in a two parcel system. Nonetheless, to illustrate the relaxation algorithm that will be used for the case study in Section 4 where it will not be possible to find the solution by inspection, we use the algorithm to find the solution here and three iterations are shown in Fig. 2b. Let $\mathbf{p}^s = (p_1^s, p_2^s)$ denote the solution of the relaxation algorithm at the $s$-th iteration. We start at $s = 0$ with the guess $\mathbf{p}^0 = (2750, 1250)$. Assuming that $p_2^0$ remains fixed at 1250, we then determine landowner 1's best response, which is $p_1^1 = 3634$ and therefore $\mathbf{p}^1 = (3634, 1250)$. The same procedure is now repeated for landowner 2, giving $\mathbf{p}^2 = (3634, 2498)$. This process is then continued until we converge on the landowners' equilibrium payment demands, which in this case occurs after 5 iterations and is $\mathbf{p} = (3885, 2512)$.

In this example, the equilibrium payment demands return profits of \$62,649 and \$39,552 for landowners 1 and 2, respectively, which in total accounts for 68% of the conservation budget. Consequently, conservation outcomes are reduced by approximately 50% compared to when landowners accept conservation at opportunity costs.

### 3.4. Equilibrium Solutions When Landowners Have Incomplete Information

We now investigate how incomplete information in a duopoly can affect negotiated outcomes. Specifically, we consider how landowner payment demands and profits and conservation outcomes are impacted by increasing landowner uncertainty regarding the opportunity costs of her/his competitor.

Let us assume that landowner *i* believes that the opportunity costs of the other landowner are distributed on a continuous uniform distribution centred on the true opportunity costs. This distribution is therefore defined as $U(\underline{c_{-i}} = c_{-i} - \epsilon_i, \overline{c_{-i}} = c_{-i} + \epsilon_i)$. The parameter $\epsilon_i > 0$ determines the width of the distribution and thus represents the extent of landowner *i*'s uncertainty.

By Eqs. (3b) and (5), the NB equilibrium payment demand for landowner *i* in this situation is

$$p_i^{NB} = \arg\max_{p_i} \frac{1}{2\epsilon_i} \int_{\underline{c_{-i}}}^{\overline{c_{-i}}} \pi_i\left(p_i, p_{-i}^{NB}\right) \, dc_{-i}, \;\; \forall \; i = \{1, 2\}$$

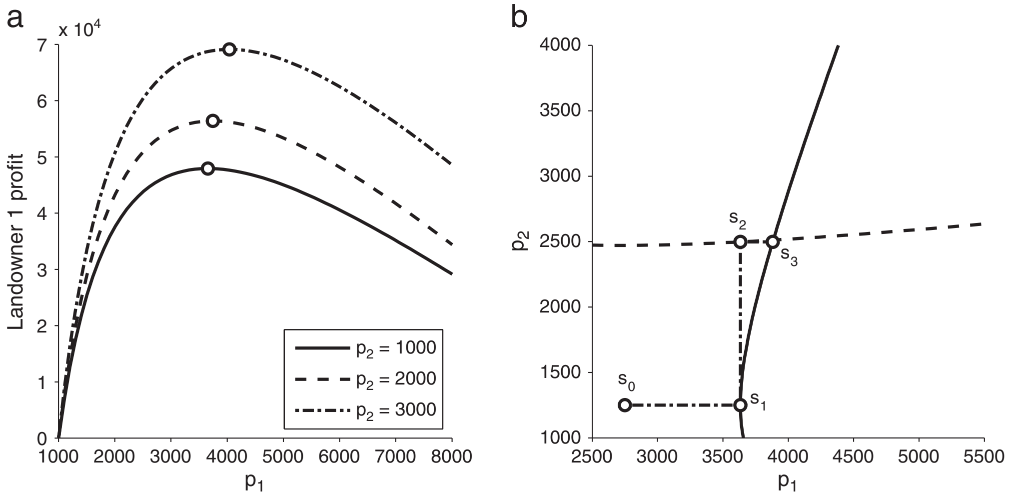

**Fig. 2.** (a) Landowner 1 profit functions—the profit landowner 1 obtains by making payment demand $p_1$ for various payment demands of landowner 2, $p_2$. The circle on the curves marks the point of maximum profit. (b) Reaction curves for landowner 1(solid line) and landowner 2 (dashed line). Also shown are three iterations of the relaxation algorithm (dot-dashed line) used to find the Nash–Bertrand equilibrium solution. Monetary figures are in US dollars.

where $\pi_i$ is given by Eq. (9) or (10) for landowner 1 or 2, respectively. Solutions are found as in the previous subsection, the only difference being now the reaction functions describe the payment demands that return the highest expected profits.

In first considering how uncertainty affects outcomes, we assume that only one of the landowners has incomplete information: landowner 1 is uncertain about the opportunity costs of landowner 2; landowner 2 knows the true opportunity costs of landowner 1; and these conditions are common knowledge to both.

Increasing landowner 1's uncertainty about the opportunity costs of landowner 2 leads to an increasing payment demand from landowner 1 (Fig. 3a). In general, payment demands above that which returns the maximum profit lose less surplus than those of the same magnitude below, as can be seen in the example profit functions in Fig. 2a. Therefore, in the presence of cost uncertainty, the landowner's optimal strategy is to err on the side of high payment demands. The effect of landowner 1's increasing payment demand as uncertainty increases is that landowner 2 is able to gain higher profits, while

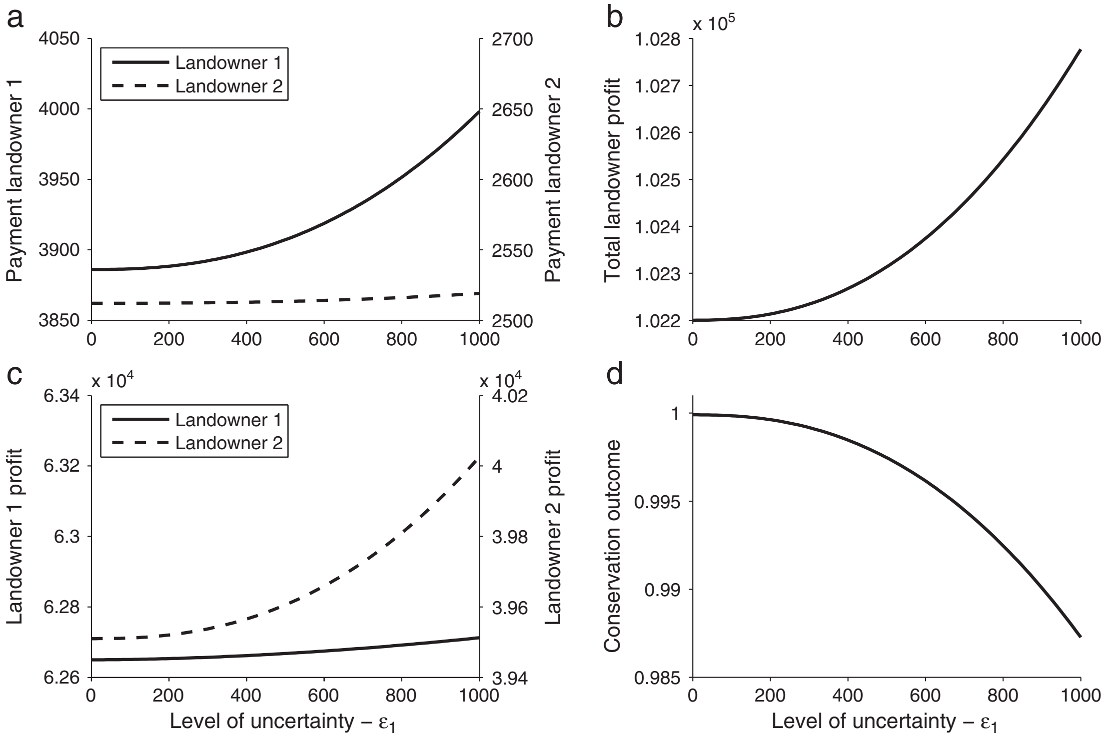

**Fig. 3.** Outcomes when landowner 1 is uncertain about the opportunity costs of landowner 2. (a) The equilibrium payment demands of landowner 1 (left axis) and landowner 2 (right axis) as landowner 1's uncertainty, $\varepsilon_1$, increases. (b) The total landowner profit that arises from the payment demands in panel a. (c) Landowner 1's (left axis) and landowner 2's (right axis) profits that arise from the payment demands in panel a. (d) Conservation outcomes compared to when landowners have complete information as landowner 1's uncertainty increases. Monetary figures are in US dollars.

landowner 1's profits increase but only marginally (Fig. 3c). To achieve this higher profit, landowner 2 does not significantly change her/his payment demand from the complete information equilibrium level (Fig. 3a). The fact that both landowners' profits increase with uncertainty is reflected in total landowner profits (Fig. 3b). Consequently, conservation outcomes decrease with uncertainty (Fig. 3d).

Let us now extend the example to the situation where both landowners are uncertain about the opportunity costs of their competitor. For presentational clarity, we assume that the landowners share the same level of uncertainty (i.e. $\varepsilon_1 = \varepsilon_2 = \varepsilon$; we relax this assumption in the Peak District case study of Section 4). As previously, the optimal strategy of the landowners is to demand increasing payments as their uncertainty increases (Fig. 4a). The same effect on landowner profits is evident as when only landowner 1 is uncertain: now when landowner 2 is uncertain about the opportunity costs of landowner 1, landowner 1 is able to gain higher profits, with the profits of landowner 2 largely unaffected (Figs. 3c and 4c). As a consequence, total landowner profit increases with uncertainty at a faster rate compared to when a single landowner is uncertain (Figs. 3b and 4b), leading to a greater decrease in conservation outcomes (Figs. 3d and 4d).

Therefore, we have what appear to be two counter-intuitive results. First, as landowner uncertainty regarding the opportunity costs of her/his competitor increases, the equilibrium profit the landowner obtains by strategically making payment demands increases and conservation outcomes deteriorate. While this result may seem counter-intuitive, it is standard in game theory: increasing a player's uncertainty does not necessarily lead to worse outcomes for that player. In terms of our model, this effect can be explained by the impact uncertainty has on site substitutability. As uncertainty increases, landowners' optimal strategy is to increase their payment demands. This increases the per unit effort cost of conservation, reducing site substitutability. As a consequence of the reduced site substitutability, landowners have greater bargaining power and can thus gain higher profits in the negotiations.

The second seemingly counter-intuitive result is that increasing uncertainty for one landowner can have little impact on their profits but can markedly affect those of the other landowner. The explanation for this result again lies with site substitutability. Greater uncertainty for one landowner results in that landowner increasing her/his payment demand, which, as noted above, reduces site substitutability. This can be exploited by the other landowner who can gain greater profits because of the reduction in investment options that decreased substitutability means for the conservation group.

Overall, the quantitative differences between the complete and incomplete information analyses were small. In the worst-case scenario for conservation – uncertainty is at the highest level for both landowners – total landowner profit is only 1% higher and conservation outcomes 1.5% lower than in the best-case for conservation—both landowners are completely informed. In all cases, the conclusion remains the same: the ability of landowners to gain profits from conservation investments can significantly reduce the potential effectiveness of those investments.

## 4. Case Study—The Peak District

We now turn to our case study from the Peak District of the UK. Here, we determine the profits landowners can gain from conservation investments and the consequent effects on conservation outcomes. We also consider how landowner uncertainty regarding other landowners' opportunity costs impacts these results.

### 4.1. Data for Model Parametrizations

Data needed to parametrize our models are not available in exactly the required form. In fact, the unobservable nature of landowners' true WTA means that it will always be problematic to estimate. However, a recent study by Armsworth et al. (2012) provides data with many of required characteristics. These authors used optimization modelling

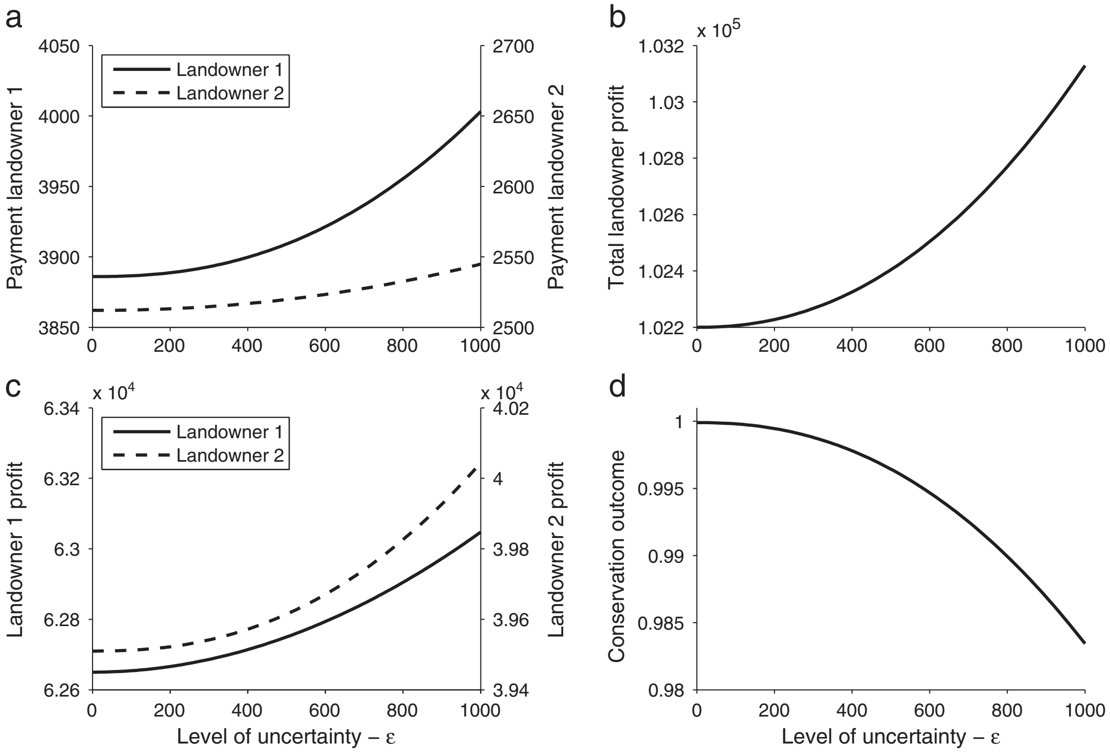

**Fig. 4.** Outcomes when both landowners are uncertain about the opportunity costs of their competitor. (a) The equilibrium payment demands of landowner 1 (left axis) and landowner 2 (right axis) as uncertainty increases. (b) The total landowner profit that arises from the payment demands in panel a. (c) Landowner 1's (left axis) and landowner 2's (right axis) profits that arise from the payment demands in panel a. (d) Conservation outcomes compared to when landowners have complete information as uncertainty increases. Monetary figures are in US dollars.

to estimate landowners' WTA given sets of restrictions on farming activities.

Specifically, biodiversity and socio-economic data were collected from 44 farms in the Peak District of the UK. The biodiversity data records the density of avian species of conservation concern over the in-bye portion of the farm holding. The socio-economic data records quantities of and prices for inputs and outputs in production, including the per hectare rental price of land (Acs et al., 2010; Armsworth et al., 2012).

Armsworth et al. (2012) used these data to parametrize models that predict the amount of foregone farm income required to achieve a given improvement in some biodiversity indicator under the assumption that landowners are profit-maximizers. The authors divided the study region into three subregions based on abiotic characteristics (e.g. elevation and wetness gradients) and characteristics of the farming systems. The optimization models were then parametrized using average biodiversity and economic values across farms in each of the subregions, giving three representative farm models in total.

Using these models, Armsworth et al. (2012) produced trade-off curves relating biodiversity benefits of conservation activities ($V_i$) to the overall cost of securing those benefits when paying at landowners' WTA ($c_i x_i$; see Fig. 2 in Armsworth et al. (2012)). Unfortunately, the data do not break that down further to measure landowners' WTA in terms of the per unit cost of different conservation activities ($c_i$), which would be particularly helpful in parametrizing our models. Indeed, it is not clear how the authors would do so given that the conservation activities are a combination of agricultural practices (changing stocking rates of sheep and cows, changing fertilizer application rates and changing frequency with which grazing areas are cut for fodder), with the particular combinations changing along the trade-off curves.

Despite these limitations, the trade-off curves show diminishing returns for increasing conservation investment and spatial variation in landowners' opportunity costs across the three representative farms, the key features of data required for our models. Therefore, to use these data, we assume that conservation effort is measured by the area of farm used for conservation and use the heterogeneous rental prices for land to provide an independent estimate of landowner's opportunity costs.

Recognising these admittedly strong assumptions, we fit Holling Type-II functions to the relationship between farm area used for conservation and the improvement in the density of a single species, Song Thrush (*Turdus philomelos*), and the density of all recorded bird species. The fitted functions are shown in Fig. 5, with the estimate of opportunity costs of conservation on each farm given in the caption.

When the objective is to maximize the increase in Song Thrush density over the three farms (Fig. 5a), the site that offers the highest conservation benefit (South West) also has the highest opportunity costs; the site that ranks second in terms of conservation benefit (East Moors) has the second highest opportunity costs; and the site that offers the lowest conservation benefit (Dark Peak) has the lowest opportunity costs. These benefit and cost distributions therefore result in three conservation investments of similar value and thus a high degree of site substitutability. Consequently, while it is difficult to predict the distribution of profits among the landowners, we expect the range to be small. In contrast, when the objective is to maximize the increase in overall species density (Fig. 5b), the landowner of the Dark Peak farm should have the greatest ability to gain profits from the conservation investment: that site offers by far the highest conservation benefit at the lowest opportunity cost, and therefore site substitutability is low in this case.

### *4.2. Results*

The distribution of profits among landowners and conservation outcomes, though not absolute profit levels, are only marginally affected by the level of the budget. Therefore, we document results when the budget is set to 500 times the mean per hectare opportunity costs of land over the three sites (≈$255,000); the results for other budget levels are contained in the Supplementary material (Section S5). We also refer readers to the Supplementary material (Section S3) for the derivation of landowners' profit functions in a three parcel system (extending Eqs. (9) & (10)).

#### *4.2.1. Complete Information*

We begin by calculating landowner profits and conservation outcomes when landowners have complete information. When the conservation objective is to maximize the increase in Song Thrush density over the three farms, the landowner of the South West farm, the site with highest conservation benefit but highest opportunity costs, has the greatest ability to profit from the conservation investment (Fig. 6). The landowner from the East Moors, the site offering the second highest conservation benefit but second highest opportunity costs, can gain the least profit. As anticipated, however, given the high degree of substitutability among the sites in this instance, variability in landowners' profit is relatively small.

In total, the ability of landowners to use their bargaining power in negotiations means that approximately 78% of the conservation budget is ceded in landowner profits in this example. Consequently, conservation outcomes are significantly diminished when compared to the situation presumed in other writing on conservation costs: Song Thrush density increase is 50.7% lower than if landowners accept conservation investment at opportunity costs.

Reference to Fig. 5b shows that when the conservation objective is focused on all species, the Dark Peak farm offers a significantly more attractive investment, both in terms of conservation benefits and opportunity costs, than those in the other regions. As a result of these benefit and cost distributions, the landowner from the Dark Peak is able to gain profits that are over 900% and 500% higher than those of the landowners from the East Moors and South West farms, respectively (Fig. 6). Indeed, the bargaining power of the landowner of the Dark Peak farm in this example means that he/she is able to gain profits that are over twice as high as the highest landowner profit when the objective was focused solely on Song Thrush.

The bargaining power of the Dark Peak landowner when the conservation objective considers all species results in 88% of the conservation budget being spent in landowner profits, an amount considerably greater than when the objective was focused on Song Thrush. This results in a greater diminution in conservation outcomes, with the increase in overall species density 52% lower compared to when landowners accept conservation investment at opportunity costs.

#### *4.2.2. Incomplete Information*

We now investigate how the case study results are affected by landowner uncertainty regarding the opportunity costs of other landowners. The objectives of these analyses are: to determine how landowner uncertainty affects the distribution of profits among landowners; to investigate the relationship between landowner uncertainty and average landowner profits; and to consider how landowner uncertainty impacts conservation outcomes. To achieve these objectives we take a simulation approach. For each conservation objective (increase Song Thrush or overall species density), we randomly assign distributions to each landowner's uncertainty regarding the opportunity costs of the other landowners. We then calculate landowner profits and conservation outcomes. We repeat this process 100 times in order to reveal the relationships described above.

We construct distributions for landowners' beliefs about the opportunity costs of other landowners in a manner similar to that in Section 3.4. There are, however, several noteworthy differences. First, we assign a unique level of uncertainty to each landowner's belief about the opportunity costs of other landowners, relaxing the assumption of Section 3.4 where both landowners had the same level of uncertainty. The range of uncertainty was randomly drawn from the continuous uniform

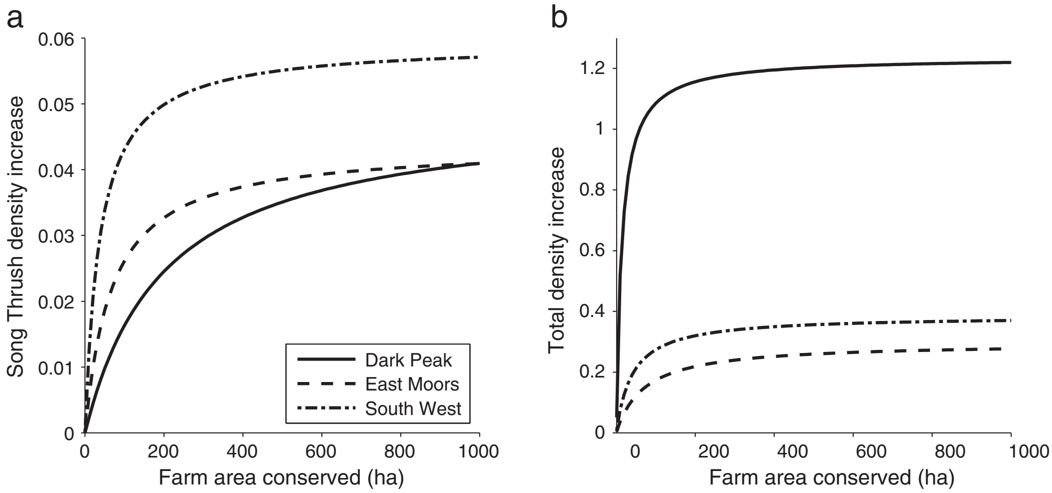

**Fig. 5.** Best-fit Holling Type-II functions for the Peak District data; farm names are given in the legend. Song Thrush (panel a) and all species (panel b) density increase for farm area conserved. Parameters (to 2 s.f.) for panel a are $[r_{DP}, h_{DP}, r_{EM}, h_{EM}, r_{SW}, h_{SW}] = [0.00024, 20, 0.00065, 23, 0.0016, 17]$ and for panel b are [0.088, 0.81, 0.0041, 3.4, 0.0094, 2.6]. Opportunity costs per hectare are: Dark Peak = \$183.6, East Moors = \$538.2 and South West = \$810.

distribution $U(0,2000)$. If the assigned level of uncertainty for a landowner's belief about the opportunity costs of another landowner resulted in a distribution with negative costs when centred on the true opportunity costs, we translated the distribution such that it was bounded below by zero. Otherwise, the distribution was centred on the true opportunity costs. This method negates the possibility of negative costs while providing a large range of possible landowner beliefs about others' opportunity costs.

As in the hypothetical duopoly of Section 3, landowner uncertainty regarding the opportunity costs of other landowners increases profits and decreases conservation outcomes compared to when landowners have complete information (Fig. 7). The nature of this relationship is most clearly seen when we equalise the level of landowner uncertainty and then determine results (black circles on the panels of Fig. 7). Deviation from this tendency is determined by the distribution of uncertainty that goes to make the particular average. For example, when considering average landowner profits with the objective focused on all species (Fig. 7c), the vast majority of average landowner profits that lie above the curve of equal uncertainty occur when the Dark Peak landowner, the landowner with the greatest bargaining power, has a relatively low level of uncertainty.

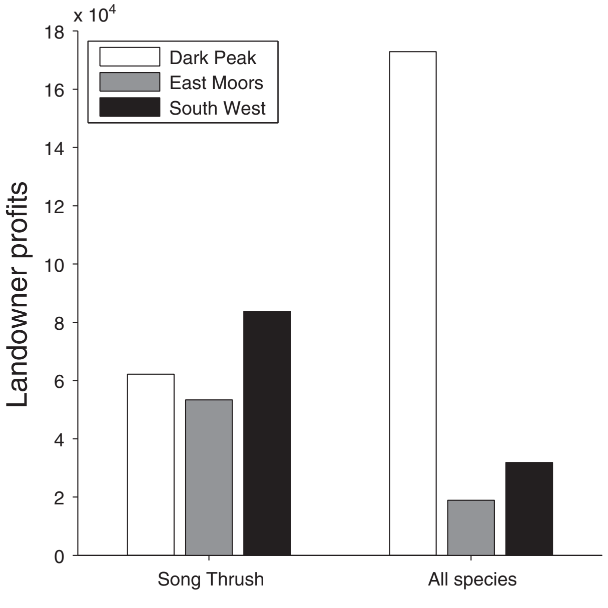

**Fig. 6.** Landowners' profits from the Peak District case study when the objective is to maximize the increase in density of Song Thrush and when the objective is to maximize the increase in density of all species. Monetary figures are in US dollars.

Also in line with the results from the hypothetical duopoly, quantitatively landowner uncertainty at the levels we investigated had only a small effect on outcomes. At most, landowner uncertainty increased average profits by 2.5% in comparison to when landowners had complete information (Fig. 7a). This effect was not large enough to impact the distribution of profits: landowners who received the most or least profits with complete information did so also when landowners were uncertain about others' opportunity costs. Similarly, the overall effect on conservation outcomes was small in absolute terms—at maximum, a 6% reduction compared to complete information (Fig. 7b).

Our simulation results revealed quantitative and qualitative differences in the effects of landowner uncertainty between the two conservation objectives. Landowner uncertainty had a larger impact on profits and conservation outcomes when the objective focused on Song Thrush as opposed to all species. In addition, the shape of the relationships was different, with average profits increasing and conservation outcomes decreasing markedly at lower levels of uncertainty when attempting to maximize Song Thrush density increase. As with the hypothetical duopoly of Section 3, these differences can be understood by considering site substitutability in light of uncertainty. When the objective considers all species, site substitutability is very low (Fig. 5b). Uncertainty does not alter landowners' payment-setting strategies sufficiently to alter this. When the conservation group is focused solely on Song Thrush, site substitutability is high (Fig. 5a). As such, changes in landowners' strategies that result from uncertainty, small as they may be, can considerably alter the balance of bargaining power. This results in greater impacts on landowner profits and conservation than when substitutability is low.

## 5. Discussion

In this paper, we investigated the profits landowners could obtain in negotiations over conservation agreements, and the consequent effects on conservation outcomes, when enrolment decisions were governed by continuous variables. We also considered how landowner uncertainty regarding the opportunity costs of other landowners affected outcomes. Our results indicate that landowners can use their bargaining power in negotiations to secure payments far in excess of the minimum level set by their opportunity costs. Consequently, conservation benefits that follow from investments may be substantially less than suggested

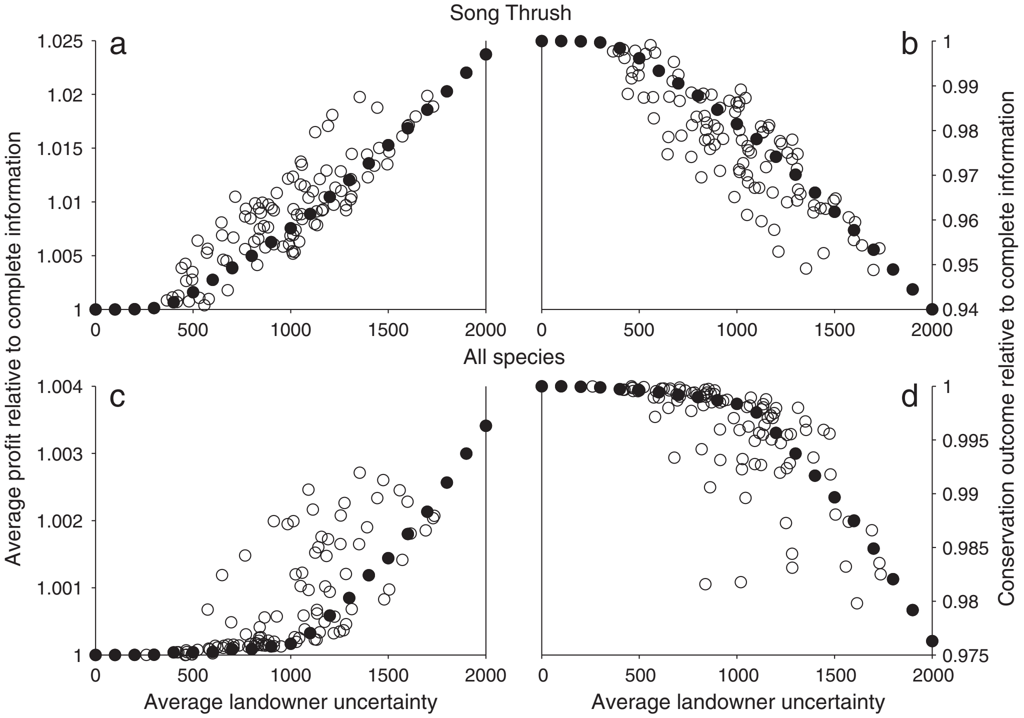

**Fig. 7.** Results from the Peak District case study when landowners are uncertain about the opportunity costs of other landowners. The conservation objective is focused on increasing the density of Song Thrush in (a) and (b); In (c) and (d), it is focused on increasing the density of all species combined. (a) and (c) show average landowner profits relative to complete information for increasing average landowner uncertainty. (b) and (d) show conservation outcomes relative to complete information for increasing average landowner uncertainty. The black circles show results when all levels of landowner uncertainty are equal.

by those analyses in which it is implicitly assumed that landowners will accept conservation measures with minimum payments.

In our previous paper investigating related issues (Lennox et al., 2012), we modelled the situation in which the conservation group had the binary choice of enrolling a site or not in its conservation programme. In those analyses, we found that potential landowner profits ranged from approximately 0.1 to 3 times opportunity costs. Although several landowner profits were in a similar range in the analyses of this paper – for example, the East Moors landowner's profits when the conservation objective considered all species were 1.4 times her/his opportunity costs – landowner profits were often higher and could be considerably higher here—for example, the Dark Peak landowner's profits were 72 times opportunity costs when the conservation objective focused on all species. A number of factors may account for the large disparity in landowner profits between the two studies. First, in this paper we limited our investigations to two or three landowner systems for analytical clarity/ tractability. In our previous analysis, there were over 40 sites in which the conservation group could invest, providing a much larger supply of sites, and thus many more potential substitutes, than was the case here. As a consequence, landowners' bargaining power is likely to be substantially diminished in comparison to the situation analysed in this paper. Second, the nature of site substitutability is altered when the investment is continuous as compared to binary. Rather than being forced to enrol the site or not, continuous investments allow the conservation group to augment the amount of conservation effort devoted to a particular site given the landowner's payment demand. Potential profits available to landowners may be larger in this case because it can be optimal for the conservation group to invest in a site whose landowner demands high payments, albeit at low levels of effort, rather than disregarding a site completely. Landowners may therefore be able to increase costs substantially more than would be the case if the possible level of conservation effort was fixed.

Throughout the analyses we found that landowner profits depended crucially on site substitutability. In the Peak District case study of Section 4 we considered two conservation objectives. This produced benefit and cost distributions that resulted in one scenario in which substitutability was low and another in which substitutability was high. As a consequence, landowner profits varied enormously over the objectives, with the potential for considerably higher profits where substitutability was low. Moreover, where uncertainty affected landowners' payment setting strategies, the results could be understood in terms of site substitutability—uncertainty increased payment demands, which decreased substitutability, leading to higher landowner profits. Therefore, in deciding with which landowners to negotiate, conservation groups must be aware of how site characteristics shape site substitutability and, consequently, landowners' bargaining power. As we show, where landowners have significant bargaining power, the potential exists for them to gain large profits from conservation investments.

In considering the impacts of landowner uncertainty regarding the opportunity costs of other landowners, results were consistent throughout the analyses: this source of uncertainty acted to increase landowners' payment demands and profits and depress conservation outcomes. In terms of conservation policy, this result may mean that where landowners set prices, conservation programmes that reveal information to landowners may result in cost efficiencies compared to situations where landowner gain little or no information. This may be particularly pertinent to the increasingly researched field of conservation auctions, the most obvious situation where landowners set prices (e.g. Latacz-Lohmann and Schilizzi, 2005; Lennox and Armsworth, 2013; Schilizzi and Latacz-Lohmann, 2007). For example, conservation auctions that are structured with training rounds to familiarise participants with each other and with the auction format (e.g. Jack et al., 2009) may result in more favourable outcomes than those where landowners are largely uninformed.

Of course, this policy prescription would hold in general only if uncertainty in the Bertrand model setting always resulted in outcomes similar to ours. This question has been considered in the game theory literature, with equivocal results. In line with our findings, Spulber (1995) determined that private cost information results in higher producer surplus as compared to when cost information is common knowledge. Hansen (1988) found the opposite result, however—private cost information results in lower producer surplus. In an attempt to clarify this matter, Lagerhōf (2012) considered the question in a market framework more general than those in previous studies. The results in Lagerhōf (2012) indicate that, where cost distributions are asymmetric, as is the case in our study, uncertainty does indeed leads to lower producer surplus. Though more general than earlier models, the model of Lagerhōf (2012) assumed market conditions that do not correspond to those in our model. For example, in Lagerhōf (2012) goods were homogeneous, resulting in a single market price and a single demand function, which was assumed to be linear. In our model, goods (conservation benefits) were differentiated substitutes, resulting in multiple prices and multiple demand functions, each of which was non-linear. Comparing these across-model differences suggests that the impact of uncertainty in Bertrand competition may depend on market structure. Our paper is the first to apply the Bertrand setting to conservation investments, and it may be that the characteristics of such investments mean that high levels of landowner uncertainty are not advantageous to conservation. The overall impact of landowner uncertainty regarding each other's opportunity costs is, however, small relative to the effects of differential substitutability among sites.

In the formulation of the conservation group's optimization problem (Section 2.1), we assumed that conservation benefits accrue additively over sites. Depending on the nature of the conservation objective, this assumption may or may not be warranted. We investigated the situation where the conservation group was focused on increasing the density of a single or multiple species, both of which are additive objectives. However, if the objective of the conservation investments recognised site complementarity (e.g. Church et al., 1996; Justus and Sarkar, 2002; Margules et al., 1988), when focusing on species richness, for example, then benefits would accrue non-additively. In our previous analysis (Lennox et al., 2012), we found that objectives that incorporate site complementarity increase the ability of landowners to make profits in comparison to objectives that focus on additive benefits. The underlying reason for this was that the amount of landowner profit was positively correlated with site irreplaceability (Ferrier et al., 2000; Pressey et al., 1994), and irreplaceability increases when incorporating site complementarity. Whether these dynamics between additive and non-additive benefits would be evinced with continuous investments remains an open question.

We have shown that assuming landowners will agree to accept conservation investment with payments equal to opportunity costs is suspect because they have the potential to demand payments substantially greater than these minimum levels. The most important implication of this is that conservation research that incorporates costs through estimates of opportunity costs is likely to overestimate conservation outcomes. For conservation science to deliver that which it says it can, accurate estimates for the cost of conservation measures must be determined.

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## Appendix A. Supplementary Data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.ecolecon.2013.04.016.

## References

Acs, S., Hanley, N., Dallimer, M., Gaston, K.J., Robertson, P., Wilson, P., Armsworth, P.R., 2010. The effect of decoupling on marginal agricultural systems: implications for farm incomes, land use and upland ecology. Land Use Policy 27, 550–563.

Adams, V.M., Pressey, R.L., Naidoo, R., 2010. Opportunity costs: who really pays for conservation? Biological Conservation 143, 439–448.

Ando, A., Camm, J., Polasky, S., Solow, A., 1998. Species distributions, land values, and efficient conservation. Science 279, 2126–2128.

Armsworth, P.R., Acs, S., Dallimer, M., Gaston, K.J., Hanley, N., Wilson, P., 2012. The cost of policy simplification in conservation incentive programs. Ecology Letters 15, 406–414.

Bertrand, J., 1883. Review of Theorie mathematique de la richesse sociale and of Recherches sur les principles mathematiques de la theorie des richesses. Journal des Savants 67, 499–508.

Carwardine, J., Wilson, K.A., Ceballos, G., Ehrlich, P.R., Naidoo, R., Iwamura, T., Hajkowicz, S.A., Possingham, H.P., 2008. Cost-effective priorities for global mammal conservation. Proceedings of the National Academy of Science 105, 11446–11450.

Chouinard, H.H., Paterson, T., Wandschneider, P.R., Ohler, A.M., 2008. Will farmers trade profits for Stewardship? Heterogeneous motivations for farm practice selection. Land Economics 84, 66–82.

Church, R.L., Stoms, D.M., Davis, F.W., 1996. Reserve selection as a maximal covering location problem. Biological Conservation 76, 105–112.

Contreras, J., Klusch, M., Krawczyk, J.B., 2004. Numerical solutions to Nash–Cournot equilibria in coupled constrained electricity markets. IEEE Transactions on Power Systems 19, 195–206.

Davies, Z.G., Kareiva, P., Armsworth, P.R., 2010. Temporal patterns in the size of conservation land transactions. Conservation Letters 3, 29–37.

Ferraro, P.J., 2008. Asymmetric information and contract design for payments for environmental services. Ecological Economics 65, 810–821.

Ferrier, S., Pressey, R.L., Barrett, T.W., 2000. A new predictor of the irreplaceability of areas for achieving a conservation goal, its application to real-world planning, and a research agenda for further refinement. Biological Conservation 93, 303–325.

Hanley, N., Banerjee, S., Lennox, G.D., Armsworth, P.R., 2012. How should we incentivize private landowners to “produce” more biodiversity? Oxford Review of Economic Policy 28, 93–113.

Hansen, R.G., 1988. Auctions with endogenous quantity. The RAND Journal of Economics 19, 44–58.

Holling, C.S., 1959. Some characteristics of simple types of predation and parasitism. The Canadian Entomologist 91, 385–398.

Jack, B.K., Leimona, B., Ferraro, P.J., 2009. A revealed preference approach to estimating supply curves for ecosystem services: use of auctions to set payments for soil erosion control in Indonesia. Conservation Biology 23, 359–367.

Justus, J., Sarkar, S., 2002. The principle of complementarity in the design of reserve networks to conserve biodiversity: a preliminary history. Journal of Biosciences 27, 421–435.

Krawczyk, J.B., Uryasev, S., 2000. Relaxation algorithms to find Nash equilibria with economic applications. Environmental Modeling and Assessment 5, 63–73.

Lagerhōf, J.N.M., 2012. Does cost uncertainty in the Bertrand model soften competition? Working Paper—Economics Department, University of Copenhagen. Available at http://www.johanlagerlof.org/Hansen-Spulber-11.pdf (Accessed 3 December 2012).

Latacz-Lohmann, U., Schilizzi, S., 2005. Auctions for Conservation Contracts: A Review of the Theoretical and Empirical Literature. Scottish Executive Environment and Rural Affairs Department, Edinburgh (Available at http://www.scotland.gov.uk/Resource/Doc/93853/0022574.pdf (Accessed 7 December 2012).).

Lennox, G.D., Armsworth, P.R., 2013. The ability of landowners and their cooperatives to gain surplus from conservation contracts. Conservation Biology. http://dx.doi.org/10.1111/cobi.12039.

Lennox, G.D., Dallimer, M., Armsworth, P.R., 2012. Landowners' ability to leverage in negotiations over habitat conservation. Theoretical Ecology 5, 115–128.

Margules, C.R., Nicholls, A.O., Pressey, R.L., 1988. Selecting networks of reserves to maximise biological diversity. Biological Conservation 43, 63–76.

McGuire, J., Morton, L.W., Cast, A.D., 2013. Reconstructing the good farmer identity: shifts in farmer identities and farm management practices to improve water quality. Agriculture and Human Values 30, 57–69.

Naidoo, R., Balmford, A., Ferraro, P.J., Polasky, S., Ricketts, T.H., Rouget, M., 2006. Integrating economic costs into conservation planning. Trends in Ecology & Evolution 21, 681–687.

Nikaidô, H., Isoda, K., 1955. Note on non-cooperative convex games. Pacific Journal of Mathematics 5, 807–815.

Polasky, S., Camm, J.D., Garber-Yonts, B., 2001. Selecting biological reserves cost-effectively: an application to terrestrial vertebrate conservation in Oregon. Land Economics 77, 68–78.

Pressey, R.L., Johnson, I.R., Wilson, P.D., 1994. Shades of irreplaceability: towards a measure of the contribution of sites to a reservation goal. Biodiversity and Conservation 3, 242–262.

Rashford, B.S., Weber, B.A., Lewis, D.J., Evonuk, R.M., 2003. Farm Neighbors, Land Use Policy and Farmland Conversion: A Dynamic Simulation of Land Use Change in Polk County, Oregon. Agriculture Infrastructure Project. Available at http://ruralstudies.oregonstate.edu/sites/default/files/pub/pdf/farmneighbors.pdf (Accessed 3 December 2012).

Schilizzi, S., Latacz-Lohmann, U., 2007. Assessing the performance of conservation auctions: an experimental study. Land Economics 83, 497–515.

Spulber, D.F., 1995. Bertrand competition when rivals' costs are unknown. The Journal of Industrial Economics 43, 1–11.

Stoms, D.M., Kreitler, J., Davies, F.W., 2011. The power of information for targeting cost-effective conservation investments in multifunctional farmlands. Environmental Modelling and Software 26, 8–17.

Stoneham, G., Chaudhri, V., Ha, A., Strappazzon, L., 2003. Auctions for conservation contracts: an empirical examination of Victoria's BushTender trial. The Australian Journal of Agricultural and Resource Economics 47, 477–500.