# WHEN SHOULD WE USE MULTLIPLE PURCHASER PAYMENT FOR ECOSYSTEM SERVICES SCHEMES?

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***Abstract***

In this paper we assess the potential efficiency gains from forming multiple purchaser payment for ecosystem services (PES) mechanisms. We combine the objectives of one profit maximising private company with a budget constrained public organisation and solve for optimal land-use patterns—to do this we draw on integer linear programming (ILP) optimisation techniques. We contrast the multiple purchaser PES scheme with single purchaser PES schemes and with non-cooperative sequential PES schemes and compare for various ecological and economic parameters. Key results include that cooperative multiple purchaser mechanism can provide efficiency gains over non-cooperative solutions in a number of situations, in particular we find efficiency gains when the purchasers prioritise different sites, when the public organisation is the larger purchaser (would pay for a larger PES scheme independently) and when costs across the landscape are more uniform.

## 1. *Introduction*

The preservation of ecosystem services is an objective of governments around the world; furthermore, the service flows that result from preserving ecosystems are now drawing the attention of an increasing number of companies in the private sector. There is increasing recognition that the decline in ecosystem services creates risks to business; either directly—through the reliance on ecosystem services as inputs to production—or indirectly—through markets or supply chains (TEEB, 2012). As we move to a situation in which both the public and private sector share the common objective of preserving ecosystem services it seems advisable to investigate if any potential synergies could arise from designing payment for ecosystem services (PES) schemes that incorporate funding from multiple purchasers. Potential purchasers of ecosystem services, whether from the public sector or private sector, are unlikely to assign the same value to a specific ecosystem service flow. Some potential purchasers may assign high values to biodiversity, or clean water, or regulating services such as carbon sequestration. When implementing a PES scheme it is probable that trying to preserve one particular ecosystem service will simultaneously lead to improvements in a number of other ecosystem services. For example, imagine a PES scheme in which a water company pays farmers to leave a buffer strip alongside rivers and streams on their farmland. The sole aim of the water company is to improve river water quality by preventing surface runoff from the farms into the water supply; however, the increased cover along the rivers may also lead to increases in local terrestrial biodiversity or increased carbon sequestration, or the cleaner water may lead to increased aquatic biodiversity. This type of situation, in which payment is made to private land-owners for the undertaking of a particular action that results in the improvement of numerous ecosystem services, can been described as multiple benefit, place-based PES schemes (Quick et al., 2013). The central feature of these schemes is the potential to deliver improvements in multiple ecosystem services at the same locality and with the production of multiple ecosystem services in a single locality comes the increased potential for funding from multiple purchasers.

Achieving functioning multiple purchaser PES schemes has the potential to provide vast amounts of additional funding for the provision of ecosystem services. (Defra, 2013) highlight their desire for pursuing multiple purchaser mechanisms *"There is a need to explore new means to aggregate demand from beneficiaries and mobilise funding solutions"* *"These approaches … draw in multiple sources of funding and strengthen the overall economic case for action"* p23. Furthermore, (Quick et al., 2013) cite a number of reasons for private sector potential purchasers being interested in contributing to the scheme such as, creating value in a brand, preventing regulation, reducing operational costs, and purchasing offsets. Overall, it is anticipated that multiple purchaser PES schemes could lead to an overall increase in the provision of ecosystem services that would not have otherwise occurred.

This paper examines the potential for efficiency gains from combining the objectives of multiple purchasers when designing PES schemes; to do this we draw on integer linear programming (ILP) optimisation techniques. We contrast the multiple purchaser PES scheme (combined objectives) with single purchaser PES schemes and with non-cooperative sequential PES schemes[1]. In section two we set up a specific multiple purchaser PES scenario in which one purchaser is a profit maximising water company and another purchaser is a biodiversity maximising, budget constrained government. In section three we investigate, on a catchment scale, optimisation techniques for combining the objectives of two potential ecosystem service purchasers. In section four we outline the specific scenarios, explicitly stating the parameters used in the simulation models. In section 5 we present our results and in section 6 draw some concluding remarks.

[1] In our non-cooperative sequential PES schemes one purchaser moves first and selects the sites they would pay for followed by a second purchaser who selects the sites they would pay for (knowing what the first purchaser has chosen).

## 2. *The applied setting*

In this paper we imagine a hypothetical multiple purchaser PES scheme in which there are two potential ecosystem service purchasers. One is a private water company interested only in protecting the quality and availability of their key natural resource, *water*, such that it may be profitable for them to pay farmers upstream to change their land management practices. The other purchaser we envisage as the government, with their primary interest in paying for land management changes that would improve biodiversity.

We consider a potential water catchment partitioned into $N$ square parcels $i = 1, \dots, N$ of equal size arranged on a square grid with a river system running through the catchment flowing from north-west to south-east (see figure 1). The same methodology can be applied to other geometric designs and designs covering multiple catchments, but for simplicity we stick to a square grid single catchment design in this paper.

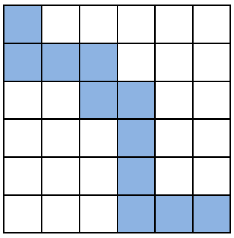

**Figure 1**. An example water catchment with river partitioned into square land parcels.

In each land parcel $i$ some form of agricultural production is taking place. The agricultural production leads to an initial level of pollution entering the water system, in addition the farmland supports an initial level of biodiversity. Both the water company and the government are interested in improving on these initial levels of ecosystem services (reducing water pollution for the water company and increasing biodiversity for the government). In each land parcel $i$ the land owner may choose to take that land parcel out of production ($x_i = 1$) or carry on with normal agricultural production ($x_i = 0$). The cost of taking a land parcel out of agricultural production is $c_i$ and is known in advance. The costs $c_i$ are normally distributed random numbers with mean 1 and standard deviation σ.

In this paper we investigate the potential for using a multiple purchaser PES scheme to achieve the water company and governments distinct aims through payment for a single action—taking land parcels out of agricultural production. Next, we set up separate models for the private water company and the biodiversity maximising government.

***The private water company:***

The private water company's objective is to maximise profit:

$$Max\ F(\boldsymbol{X}), \quad \boldsymbol{X} = \{x_i\}, \qquad x_i \in \{0,1\} \tag{1}$$

Where $i$ and $I$ are the index and set of parcels of land eligible for selection and $x_i = 0\ or\ 1$; it is 1 if land parcel $i$ is selected for the PES scheme, and is 0 otherwise. F represents a function describing the benefits $p$, and costs $c$, of taking land parcels out of agricultural production. In its most basic form it can be written:

$$F = p - c$$

We assume that the costs (payment to the land owner for taking the land parcel out of production) are independent, but it seems unlikely that the benefits are linear as modelled above. The benefits are the cost savings the water company receives from a reduced level of pollution in the water system. The relationship between cost savings and reduced pollution could be modelled in a number of ways from step functions through to a linear function, but we take an approach of assuming a diminishing benefits function. We assume diminishing benefits because even very low levels of pollution can cause significant costs to the water company as they have to meet strict drinking water regulations. In our diminishing benefits function, at high concentrations of water pollution, reducing the pollution has only a small effect on cost savings; however, at low concentrations of water pollution reducing the pollution has a large effect on cost savings. Our benefits function takes the following form:

$$f(\boldsymbol{X}) = \frac{\sum_i p_i x_i}{\sum_i p_i x_i + A} \tag{2}$$

The water company's profit maximisation function is now composed of a non-linear benefits function and linear costs:

$$Max\ \ f(\boldsymbol{X}) - C'\boldsymbol{X}, \qquad \boldsymbol{X} = \{x_i\}, \qquad x_i \in \{0,1\} \tag{3}$$

We approximate our benefits function using the TLA method. Let $L$ be the number of linear segments in the piecewise approximation with the endpoints of each segment given by $Q_L$ and $Q_{L+1}$. Let $r_l$ be the slope of segment $l$, and $q_l = Q_L - Q_{L+1}$ be the length of the segment (projected on to the x-axis). We use $f^{\alpha}(\boldsymbol{X})$ to represent the $\alpha$-error linear approximation of our benefits function such that $f^{\alpha}(\boldsymbol{X})$ consists of the sum of $L$ linear functions:

$$f^{\alpha}(\boldsymbol{X}) \approx \sum_{l=1}^{L} q_l r_l z_l \tag{3}$$

We can now model the water company's profit maximisation as a integer linear program:

$$Max \sum_{i\in I} \sum_{l=1}^{L} q_l\ r_l\ \ z_l \tag{4}$$

$$s.t. \sum_{i\in I} p_i\, x_i = \sum_{l=1}^{L} q_l\ \ z_l \tag{4a}$$

The constraint (4a) relates the $z_l$ decision variables back to the original $x_i$ decision variables and the concave shape of the function ensures the segments enter solution to the integer linear programme in the correct order.

***The biodiversity maximising government***

Methods for selecting land parcels to maximise biodiversity have been studied for 30 years originating in the field of conservation biology (Kirkpatrick, 1983). Many early papers used iterative heuristic solution methods for selecting the land parcels; however, a number of papers have called for more widespread use of techniques which find the optimal solution such as linear and integer programming (Rodrigues and Gaston, 2002, Rodrigues et al., 2000, Camm et al., 1996, Underhill, 1994). The biodiversity objectives have typically been defined in terms of species richness (the representation of all species from a list of target species). Consequently, two key problem designs have taken prominence in the reserve selection literature: the species set covering problem (SCP), and the maximal covering species problem (MCP). In the SCP the objective is to select the minimum number of sites (or area) whilst selecting at least one site containing each species. In the MCP the objective is to maximise the number of species represented whilst setting a limit on the number of sites selected.

The provision of biodiversity is not just based on the number of sites or size of the area, it is often dependent on the spatial configuration of land use. For example, in comparing landscapes with the same overall amount of habitat, the breeding success of species tends to be higher on landscapes where habitat is clustered rather than fragmented, for example (Drechsler et al., 2010, Polasky et al., 2008). In addition, the UK governments' Lawton Report (Lawton et al., 2010) highlights the need for ecological networks, which are a suite of sites containing the habitat requirements to maintain healthy and diverse species populations. Due to the significance given to spatial configuration in recent UK government biodiversity papers, particularly with regard to ecological networks, we desire an optimal reserve selection technique that takes into account these spatial aspects. In particular we imagine our government are interested in creating large / well connected areas of land out of agricultural production (reserves). A suitable method taken straight from the reserve selection literature maximises the number of adjacent pairs of land parcels selected for inclusion in the PES scheme (Nalle et al., 2002, Williams et al., 2005):

$$Max \sum_{j \in J} \sum_{k \in D_j, k>j} x_j x_k \quad (5)$$

$$s.t. \sum_j \delta_{sj} x_j \geq 1 \quad (5a)$$

$$\sum_j c_j x_j \leq B \quad (5b)$$

where $D_j$ is the set of sites k that are adjacent to $j$. The first constraint (5a) ensures that every species $s$ must be present in at least one land parcel in the solution; $\delta_{sj}$ is a parameter where $\delta_{sj}$= 1 if parcel $j$ contains species $s$, and $\delta_{sj}$= 0 otherwise. Traditionally, when implementing conservation schemes the government has a budget in which their aim is to maximise the biodiversity outcomes from their budget, this budget limit is enforced in the second constraint (5b) where $c_j$ represents the cost of taking land parcel $j$ out of agricultural production and $B$ is the government budget available for the scheme.

## 3. *The combined model*

Although it is interesting to look at how the profit maximising water company and the biodiversity maximising government would solve the problem separately what we are really interested in is combining the objectives of both organisations into one multiple purchaser PES scheme. The combined problem can be represented in the following simple model:

$$\text{Max } water\ profit\ \ subject\ to\ Conservation \geq \bar{S} \quad (6)$$

where the water company profits are maximised by choosing a land-use pattern with the requirement that the conservation score is at least as large as $\bar{S}$. By varying the conservation score threshold we can obtain the set of efficient outcomes. It should be noted that the set of efficient outcomes can also be obtained by maximising the conservation score subject to the water company achieving a threshold level of profit.

Although the general set up of the problem appears simple, there is an inherent difficulty in producing optimal solutions. Firstly, it is an integer problem with potentially many parcels of land, secondly, it has non-linearity in both the water company's profit function and in the spatial aspects of the government biodiversity score. There exist a number of ways these can be solved (including heuristic methods such as the greedy algorithm) but it becomes a very difficult combinatorial problem when you try to combine the joint objectives. To solve for the globally optimal solution we linearise the non-linear aspects of the model presented so far which enables us to solve with integer linear programming techniques.

From section 2 we have non-linear integer programming problem for the water company's profit maximisation and a quadratic species SCP for the government's biodiversity maximisation. The water company benefits function can be simplified by taking a piecewise linear approximation of the non-linear benefits function. We don't go into vast detail here in the paper, but using the tangent line approximation method outlined in (Aboolian et al., 2007, Aboolian et al., 2009) it is possible to approximate a twice differentiable, non-increasing, concave function (the type commonly used to describe diminishing benefits) to a specifiable error $\alpha$. The resulting piecewise linear approximation can be included in integer linear programming software and optimally solved.

We approximate our benefits function using the TLA method. Let $L$ be the number of linear segments in the piecewise approximation with the endpoints of each segment given by $Q_L$ and $Q_{L+1}$. Let $r_l$ be the slope of segment $l$, and $q_l = Q_L - Q_{L+1}$ be the length of the segment (projected on to the x-axis). We use $f^{\alpha}(\boldsymbol{X})$ to represent the $\alpha$-error linear approximation of our benefits function such that $f^{\alpha}(\boldsymbol{X})$ consists of the sum of $L$ linear functions:

$$f^{\alpha}(\boldsymbol{X}) \approx \sum_{l=1}^{L} q_l r_l z_l \tag{7}$$

We can now model the water company's profit maximisation as an integer linear program:

$$Max \sum_{i \in I} \sum_{l=1}^{L} q_l \ r_l \ \ z_l \tag{8}$$

$$s.t. \sum_{i \in I} p_i \ x_i = \sum_{l=1}^{L} q_l \ \ z_l \tag{8a}$$

The constraint (8a) relates the $z_l$ decision variables back to the original $x_i$ decision variables and the concave shape of the function ensures the segments enter solution to the integer linear programme in the correct order.

From section 2 we also have the quadratic species SCP model. We can write this linearly by introducing two new constraints:

$$Max \sum_{j \in J} \quad \sum_{k \in D_j, k > j} u_{jk} \tag{9}$$

$$\begin{aligned} s.t. u_{jk} \quad &\leq x_j \qquad \forall j \in J, \forall k \in D_j, k > j \\ u_{jk} \quad &\leq x_k \end{aligned} \tag{9a}$$

where $u_{jk}$ = 0 or 1; it is 1 if land parcels $j$ and $k$ are both selected and 0 otherwise. The two constraints (9a) ensure the definition of the binary $u_{jk}$ variables, for example, if $u_{jk}$ is 1 then both $x_j$ and $x_k$ must be greater than or equal to 1, since they are also binary variables they both have to equal 1. Finally we include a parameter $d_{jk}$ which is the distance between land parcel *j* and land parcel *k* and take the inverse so we are maximising the sum of the inverse pairwise distances in our integer linear programme:

$$Max \sum_{j \in J} \quad \sum_{k > j} \left( \frac{1}{d_{jk}} \right) u_{jk} \tag{10}$$

$$\begin{aligned} s.t. u_{jk} \quad &\leq x_j \qquad \forall j \in J, \forall k \in D_j, k > j \\ u_{jk} \quad &\leq x_k \end{aligned} \tag{10a}$$

$$\sum_{j} \delta_{sj} x_j \geq 1 \tag{10b}$$

$$\sum_{j} c_j x_j \leq B$$

The two purchasers now have linear objectives—the water company maximises profit in a piecewise linear program and the government maximises inverse pairwise distances in a linear species SCP. We are now in a position to combine the water company and government objectives by iterating through an integer linear optimisation method to find the efficient land parcels to take out of agricultural production. In general, there will be many efficient land-use patterns and we solve to find the set of efficient land-use patterns which traces out an efficiency frontier. At a particular efficient solution it is not possible to increase the water company profits without decreasing the government biodiversity score; likewise, it is also not possible to increase the biodiversity score without decreasing the water company profit.

## 4. *Analysis*

We select a landscape of N=225 land parcels (15x15) and use a base setup for the parameters which describe the spatial pattern of the biodiversity (γ=6), the cut-off for the pairwise distances (φ=1), the characteristics of the water company profits function (σ = 0.4) and relative number of land parcels purchased in the independent PES schemes (controlled through the government's budget) ($B$ = 0.75). We vary the different parameters independently from the base setup. Each parameter has a high and a low value; $B$ is varied from $B$=0.5 (the government purchasers less land parcels than the water company), to $B$=1 (the government purchasers more land parcels than the water company); σ is varied from 0.3 to 0.5, and γ is varied from 3 (all species are common) to 12 (all species are rare). We also include a cut-off parameter (φ) for the inverse pairwise distances which is varied from 1 to 2, where 1 means only adjacent selected land parcels contribute towards the objective value and 2 means land parcels up to 2 parcels away contribute. Table 1 summarises the setups.

**Table 1.** Overview of setup parameters considered for policy options

| | $B$ (Budget – Government) | σ (standard deviation of cost) | γ (Rarity of species) | φ (Pairwise distance Cut-off) |
|---|---|---|---|---|
| Base | 0.75 | 0.4 | 6 | 1 |
| Low $B$ | 0.5 | 0.4 | 6 | 1 |
| High $B$ | 1.0 | 0.4 | 6 | 1 |
| Low σ | 0.75 | 0.3 | 6 | 1 |
| High σ | 0.75 | 0.5 | 6 | 1 |
| Low γ | 0.75 | 0.4 | 3 | 1 |
| High γ | 0.75 | 0.4 | 12 | 1 |
| High φ | 0.75 | 0.4 | 6 | 2 |

For each setup and each payment option we solve for the three schemes:

(i) the combined multiple purchaser optimal solution C-MP PES;

(ii) the sequential non-cooperative solutions in which either the water company selects land parcels followed by the government or the government selects land parcels followed by the water company. With the second purchaser knowing exactly which land parcels the first purchaser selected NC-SEQ PES;

(iii) the independent optimal solutions (single purchaser PES scenario) SP PES.

To run the combined multiple purchaser (C-MP) scenario we need a method for deciding how the costs in the C-MP scenario would be split between the government and the water company—we refer to these cost splitting methods as payment options. For each setup we compare two payment options for the C-MP scenario. The first payment option we call the 'fair option' in this option the water company and the government pay the ratio of the costs from the independent SP PES scheme. For example, if, in the SP scenario, the government would purchase 20 land parcels at a cost of 100 and the water company would purchase 15 land parcels at a cost of 89 the ratio of their costs are therefore $\frac{89}{189} \sim 47\%$ (water company) and $\frac{100}{189} \sim 53\%$ (government). The second payment option we call the 'equal option'; in that option the costs in the C-MP scenario are split 50-50 between the government and the water company. We run each payment option for every setup in Table 1.

For the water company the optimal solution chooses sites that provide a positive contribution to profit; however, for the government, the optimal solution depends on the size of the budget. The budget for the government in the base setup was therefore chosen so the optimal solution has approximately the same number of land parcels as the profit maximising water company under the base setup. To account for the fact that the costs $c_i$ are random numbers we ran 100 simulations for each different setup and for each payment option.

## 5. *Results*

We used CPLEX 12.5.1, incorporated with MATLAB R2013a to solve the C-MP, NC-SEQ and SP scenarios. The key results are summarised in Table 2.

**Table 2.** Summary of key findings from the simulations (cooperative multiple purchaser C-MP, non-cooperative sequential NC-SEQ, and single purchaser (SP) PES schemes)

| Area of interest | Summary of key results |
|---|---|
| Effects of having similar priority sites | There are gains in the C-MP scenario when the purchasers prioritise different sites. These gains diminish when both purchasers prioritise the same land parcel. Above a certain threshold it becomes optimal to be the second mover in the NC-SEQ scenario. |
| Effects of the relative number of land parcel purchased | If under the SP scenario the water company would purchase more sites it is better for both purchasers if the water company goes first in the NC-SEQ. If they would purchase roughly the same number of sites the optimal strategy is the C-MP. If the government would purchase more sites there exists a second mover advantage in the NC-SEQ scenario but the optimal strategy remains the C-MP for the majority of simulations. |
| Comparison of 'equal option' versus 'fair option' payment | When the government SP costs are higher ($B$=1.0) the water company's optimal strategy is the NC-SEQ scenario in which the government moves first, especially in the 'equal option' payment. The C-MP scenario is more attractive under the 'fair option' payments when SP costs are higher for the government ($B$=1.0). When the government SP costs are lower ($B$=0.5) the reverse is true. |
| Effects of the parameters that determine the water company's | As the cost variation is increased the water company and government tend towards choosing similar sites. Thus the gains from cooperation |

| | |
|---|---|
| profit | diminish at high cost variations and it becomes an optimal strategy for the water company to move second in the NC-SEQ scenario. |
| Effects of parameters that determine species | No significant effect for both φ and γ. |

### ***5.1*** *Effects of having the same priority sites*

Substantial efficiency gains are available from cooperation (C-MP) if the two purchasers prioritise purchasing different land parcels. If there exists overlap, by which we mean that the two purchasers both prioritise changing the same parcel of land to reserve, then the efficiency gains from cooperation decline; above a certain threshold we see a switch from C-MP to NC-SEQ being the dominant strategy as both purchasers experience a second mover advantage. When both purchasers prioritise the same land parcels the incentives would be to hold out in the hope that the other company will move first and implement a SP PES scheme and as such free-ride on the other purchasers investment.

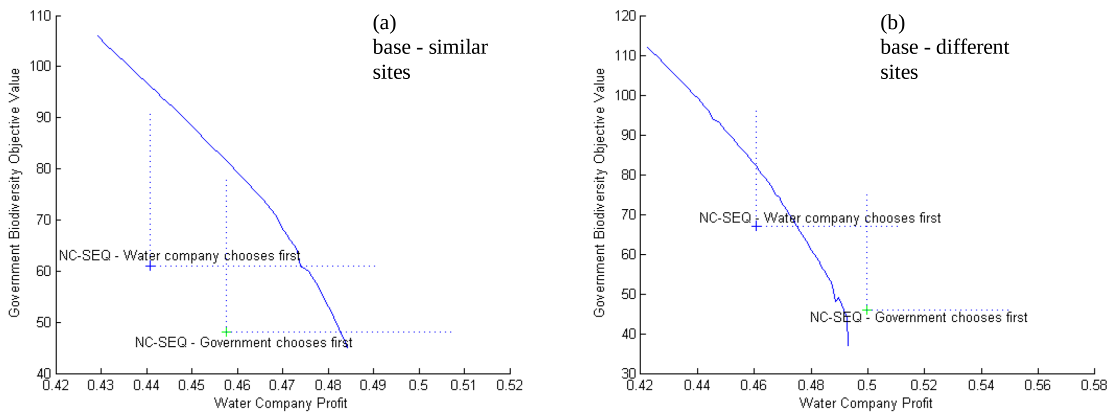


**Figure 2.** Comparison where the water company and government prioritise similar land parcels (a) and different land parcels (b)

### ***5.2*** *Effects of the relative number of land parcels purchased*

If under the SP scenario the water company would purchase more land parcels ($B$=0.5) it is better for both purchasers if the water company goes first in the NC-SEQ scenario. Or put another way, the water company moving first dominates the government moving first in the NC-SEQ when the water company would purchase more land parcels. In addition, the NC-

SEQ solution in which the water company selects first is better than the C-MP solutions for the $B$=0.5 scenario. We see this result because the government only has enough budget to select a small number of sites. If the water company selects land parcels first then the government can use those land parcels to form larger and more connected reserves by essentially filling in the gaps; leading to a higher biodiversity score, and because the reserves are close to the river it leads to a higher water company profit too. If they would purchase roughly the same number of sites ($B$=0.75) the optimal strategy is the C-MP. If the government would purchase more sites ($B$=1.0) there exists a second mover advantage in the NC-SEQ scenario but the optimal strategy remains the C-MP for the majority of simulations. Overall, the evidence suggests that as long as the government would purchase at least as many land parcels in the SP scenario then there are good opportunities for gains from cooperation by using a multiple purchaser PES scheme but if in the SP scenario the government would purchase less, then a Non-cooperative sequential move scheme in which the water company moved first would be better for both purchasers.

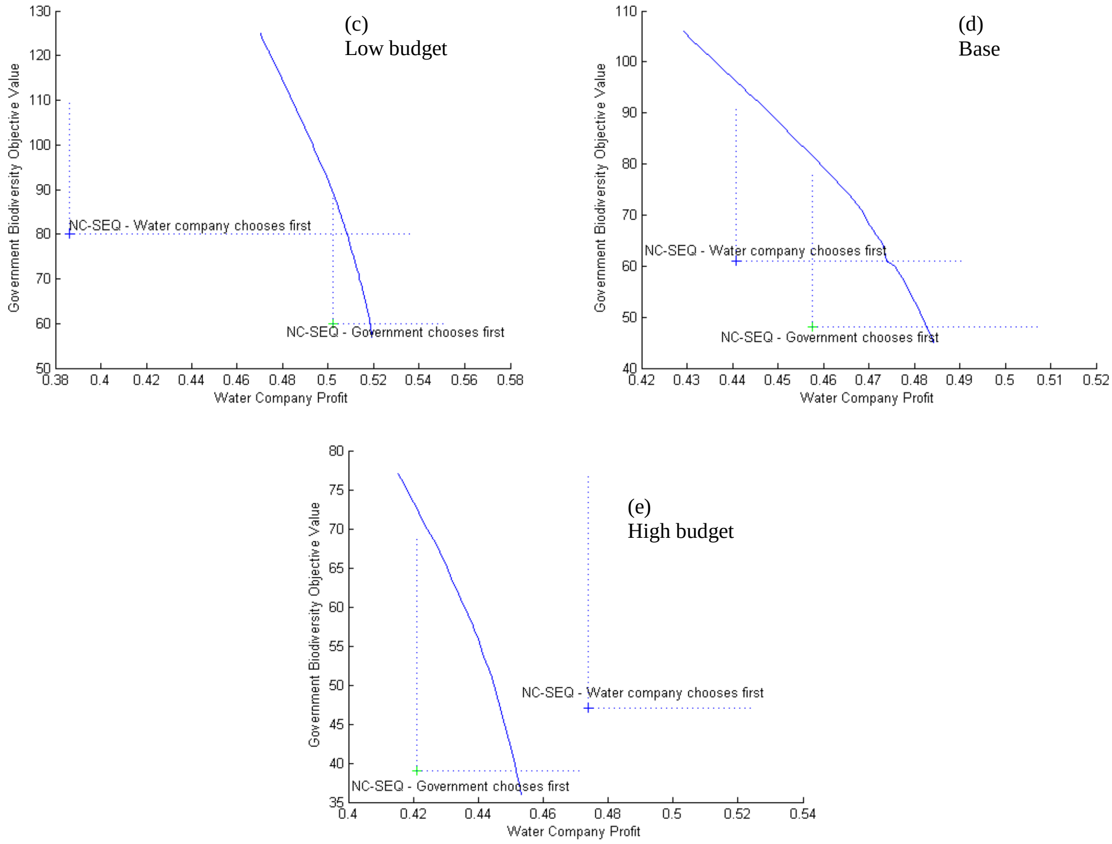


**Figure 3.** Comparison of low government budget (c) base (d) and high government budget (e)

### *5.3 Comparison of the payment options 'Fair option' and 'Equal option'*

As would be expected there is no difference between the 'fair option' and the 'equal option' when independent SP costs are approximately equal (base). When the government SP costs are higher than the water company's ($B$=1.0), the water company's optimal strategy is the NC-SEQ scenario with the government moving first, this is especially true in the 'equal option' payment. Or put another way the C-MP is more attractive under the 'fair option' payments when SP costs are higher for the government. When the government SP costs are lower ($B$=0.5) the reverse is true, under the 'fair option' payment the C-MP becomes less attractive. Thus when the water company is required to pay a larger share the C-MP becomes less attractive. We attribute this to the fact that the government has more to gain from cooperative solutions because their biodiversity score relates to the spatial connectivity of the selected land parcels.

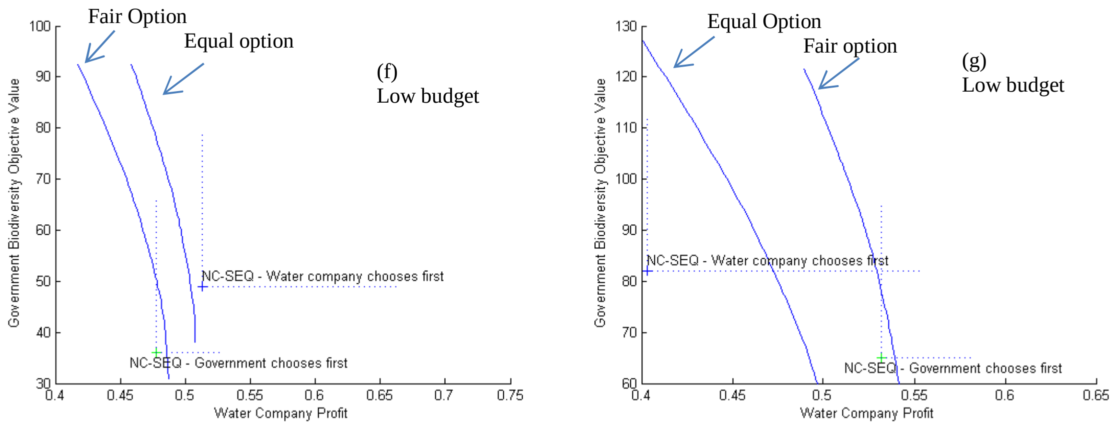


**Figure 4.** Comparison of Equal option payment versus Fair option payment at high budget (f) and low budget (g)

### *5.4 Effects of the parameters that determine the water company's profit*

As the cost variation is increased the water company and government tend towards choosing similar sites. For example if we count the number of sites that both the water company and the government would select in the SP scenario we see a clear trend. When the cost variation is low ($\sigma$ = 0.3) the mean number of same land parcels is 5.04, for medium cost variation ($\sigma$ = 0.4) the mean is 8.41 and for the high variation setup ($\sigma$ = 0.5) the mean is 13.85. We have already seen that choosing similar sites reduces the gains from cooperation and makes it a dominant strategy to move second in the NC-SEQ scenario, and this is the same pattern we see for increasing cost variation.

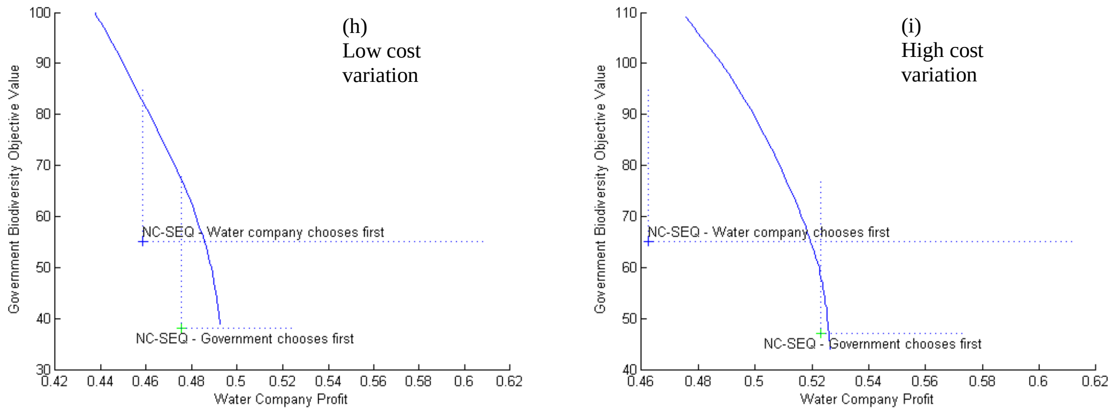


**Figure 5.** Comparison of low cost variation (h) with high cost variation (i)

*5.5 Effects of parameters that determine species*

No significant effects were observed when both the species rarity parameter (γ) and the pairwise distance cut-off parameter (φ) were varied.

## 6. Conclusion

The majority of private sector involvement in PES schemes around the world occurs because of perceived business benefits by doing so. But for many businesses, barriers to PES remain as they question why they should begin paying for something that they have not funded before, or why the government is not funding it. In this paper we take the starting point that there exist opportunities for private companies (water company in our case) to invest in PES schemes that would deliver additional profit through operational cost savings and that they are interested in investing. We also take the starting point that the government is interested in implementing a PES scheme with the primary aim of improving biodiversity. From this we develop independent PES models for both the water company and the government. Both independent models contain non-linearity making the combination of objectives in the C-MP scenario problematic to solve optimally. To solve this problem we use novel techniques to linearise both models, using a piecewise linear program to model the water company's profit function and a linear spatial SCP for the government biodiversity maximisation, by doing this we are able to combine and solve the joint model and find optimal land use patterns.

In summary, we find that substantial efficiency gains are possible from implementing a multiple purchaser PES scheme when the purchasers prioritise different sites. If both purchasers would select the same land parcels then the optimal strategy for both purchasers is to free ride on the others investment—a classic public goods problem. Additionally, when the government is the larger purchaser (independently would purchase more land parcels) or they are roughly of equal size then our results show that gains from cooperation are possible by implementing a multiple purchaser PES scheme. We also observe potential gains from cooperation when the water company pays a smaller percentage contribution to the purchaser costs (‘equal option’ when water company costs are higher and ‘fair option’ when water company costs are lower). Finally, we observe potential gains from cooperation when costs across the landscape are more uniform.

Policy makers may use these results to initially test where pursuing multiple purchaser PES mechanisms may be likely to produce benefits to all parties. Also importantly these results can be used to understand the circumstances where there are no gains from cooperation as it would be optimal to use single purchaser PES mechanisms or sequential single purchaser PES mechanisms. For example, consider a situation in which the water company is interested in a large PES scheme and the government is interested in implementing a small PES scheme (small budget). In this situation our results indicate that it would be beneficial for both purchasers if the water company implemented their SP PES scheme first and then the government can move second connecting the land parcels spatially to create larger and better connected reserves.

Overall, we have presented a number of situations in which cooperation between multiple ecosystem services purchasers could be in the best interest of all parties, however this is not a universal result and depends on the specifics of the landscape and payment mechanism. In our paper the land-owners costs are known in advance and fixed, further research might consider the bargaining procedure that would take place between the land-owners and the two purchasers. For example in our paper we set out two payment options for how the two purchasers might split the costs, but how would the negotiations proceed between the two purchasers and how would the costs of the land-owners be learned. We have also assumed that the land parcels are exactly the same size and shape and that they can be purchased as individual parcels, in reality there may be large land-owners, small land-owners and also land owners not interested in participating in a PES scheme. Experiments may provide insights into the bargaining procedures between the parties (the land-owners and two purchasers).

It is important to remember our analysis is based on there being a single action that the land-owner can undertake which leads to multiple ecosystem benefits. Although it may be common for an action taken by land owners to lead to multiple ecosystem services we acknowledge that our results do not necessarily apply to PES schemes in which a particular action leads to a specific single ecosystem benefit. It is also worth noting that although we have spoken in specifics throughout this paper about a water company and a government, but the results can and should be generalised to a profit maximising private company and a budget constrained organisation (public or private) attempting to preserve spatially dependent biodiversity.

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