On Spatial Coordination, Site Clustering and Agglomeration Payment: The Case of Wetland Management

Nick Hanley
Stirling Management School, Division of Economics, University of Stirling

Adam Kleczkowski
Department of Computing Science and Mathematics, University of Stirling

Frans P. de Vries
Stirling Management School, Division of Economics, University of Stirling

28 May 2010

FIRST DRAFT — DO NOT CITE OR QUOTE

Abstract

This paper employs percolation theory to study how an agglomeration bonus affects the choice of land management practice and subsequently the spatial connectivity of patches of (wet)land. An agglomeration payment without accounting for spatial connectivity results in a smooth transition of farmland into wetland. In case the agglomeration payment accounts for spatial connectivity (payment made to farmers and neighbouring farmers), a small increase in the agglomeration payment can already result in a highly connected cluster of wetland. If the objective is to maximize a *single* connected area of wetland, then there exists a sharp transition from a non-connected to a connected wetland cluster. Finally, creating a connected cluster of wetland requires a higher financial budget.

1. Introduction

Wetlands provide multiple important functions for biodiversity conservation. They function as reservoirs of flood control, act as a filter for nutrients and toxins, and provide a habitat for wildlife and plants (e.g., Hallwood, 2007). In contrast to setting policies in terms of population of species, which generally imply higher transaction costs, the establishment of wetlands through land use management is interesting from a policy perspective as it is easier to monitor where conservation actually takes place. However, from an ecological point of view, connected habitats are more valuable than habitats in isolation. Since habitats are likely being heterogeneous in conservation quality, it is of crucial importance where habitat swops occur, especially in relation to the connectivity of habitats. It is this problem of spatial coordination that is explored in this paper.

Agri-environmental schemes have generally placed little attention to the spatial coordination of participation (Tanaka, 2007 and Wünscher et al, 2008). But in ecological terms, all patches of habitat in a certain area are not equivalent. High value habitat patches should be made priority for protection. Moreover, the ecological value of protecting any particular patch of habitat depends on what other areas are also being protected, because of metapopulation dynamics and community complementarity (Armsworth, 2004). Ecological principles therefore suggest a need to plan conservation at the landscape level (Chomitz et al, 2006; Siikamaki and Layton, 2007). At a finer scale, incentive designs need to recognise that target habitats and species' home ranges frequently overlap private land boundaries and payment schemes must be designed in such a way as to avoid deleterious effects associated with habitat fragmentation and excess edge habitat. In these circumstances, incentive designs need to encourage neighbouring landowners to cooperate to provide conservation benefits (e.g., Goldman et al, 2007; Warziniack et al, 2007).

One important incentive design mechanism which has been investigated to address the issue of spatial coordination is the Agglomeration Bonus (AB) (Parkhurst et al, 2002; Drechsler et al, 2010). The agglomeration bonus addresses the issue of spatial heterogeneity of ecological potential across farmers, and of how landscape-level environmental benefits will depend on spatial coordination. The AB offers additional payment to landowners who enrol parcels of land which lie next to neighbours' land which is also offered for enrolment. The AB can lead to multiple Nash equilibria, resulting in a coordination problem. The problem then is one of how to select the "best" spatial coordination of landowners (Parkhurst et al, 2002; Parkhurst and Shogren, 2007, 2008).

We employ percolation theory to examine the interdependence between the landscape level (the wetland) and the private landowner level. In particular, we investigate the incentives for cooperation and assess how an AB-type of mechanism induces farmland to be converted into wetland, in particular how the degree of clustering or connectivity of (potential) wetland sites interact with the AB. The objective of this paper is to study the aggregation payment leading to a specified environmental benefit. The benefits can be defined in different ways, but the ultimate goal is to use realistic (population) dynamics to infer the benefits of a particular scheme. Until this is done, we can use various proxies in the optimisation procedure. For example, Drechsler et al. (2010) have used a proximity measure —the number of "green" farmland within a certain distance from a given "green" farm— with a distance-dependent exponential kernel. Here we use an alternative concept of "connectiveness" defined by having at least one "green" patch of land in the immediate neighbourhood, the so-called Von Neumann neighbourhood.

The paper proceeds as follows. In section 2, the model, benchmark and different scenarios will be introduced. Section 3 presents the main results and Section 4 concludes.

2. Modelling framework

2.1 Benchmark and scenarios

We study the conservation benefits and associated costs associated with three scenarios. As a benchmark, Scenario 1 assumes absence of any spatial coordination, both for payment and for conservation. Scenarios 2 and 3 include a premium which is paid to the farmer if the neighbouring site is also converted. Thus, the costs for both Scenario 2 and 3 are the same, but the environmental benefits may differ. In Scenario 2, all sites that have at least one wetland site contribute the conservation benefits, but in Scenario 3 it is only the sites that belong to a single largest connected cluster. Here "neighbourhood" is defined as a von Neumann neighbourhood of order 1, including four nearest neighbours.

2.2. Model

Land is generally heterogeneous in quality, implying heterogeneous costs (and benefits). Assume the environment is distributed randomly on a square lattice, size 25 by 25 (n = 625) or 50 by 50 (n = 2500). The environmental costs, a, are drawn from a normal distribution with average 10 and standard deviation of one. Figure 1 shows a typical distribution of the environmental costs, where the darker squares correspond to sites with higher costs.

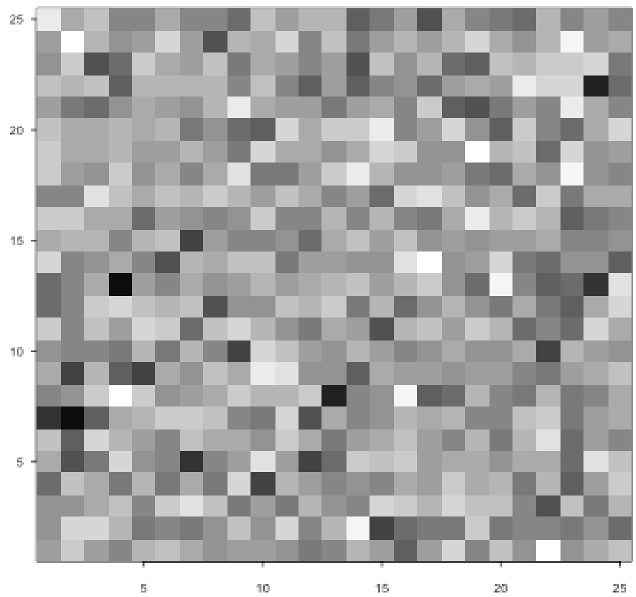

Figure 1: Typical distribution of environmental costs (n = 625)

In the simplest scheme (Scenario 1), a payment of value c_1 is made to all farmers who switch to wetland regardless of whether any of the neighbours switch to wetland as well. The final payment will then be equal to the number of all sites for which $c_1 > a$, times c_1. This can be calculated analytically as the proportion of sites for which $c_1 > a$ is given by a probability $c_1 > a$, with a being a random variable. For a normal distribution $a \sim \mathrm{N}(\mu, \sigma)$ one obtains $P(a < c_1) = \Phi(c_1)$ and the total cost $c_1 n\Phi(c_1)$.

Alternatively, the payment can only be made to those farmers who switch to wetland, provided that at least one of the neighbours switches to wetland as well (Scenarios 2 and 3). Given the von Neumann property of the neighbourhood, this reduces the costs but also reduces the number of successful conversions by eliminating isolated fields. In the following we will only study the aggregation scheme in which each farmer who wants to switch to wetland receives the aggregation payment c_1 only if one of his neighbours also switches to wetland. The simplest objective of the aggregation payment is to maximize the area converted to wetland with a fixed payment per farmer (Scenario 2). Alternatively, the objective is to maximize the *single connected* area of wetland (Scenario 3). The connectiveness serves as a proxy for environmental benefit and is defined here as having at least one converted neighbour of a converted field, i.e., there is a wetland field in the immediate neighbourhood of a wetland field. Under this assumption, the problem is similar to the site percolation on a square lattice and the optimal configuration of fields corresponds to the largest percolation cluster.

We assume there is perfect information about costs and benefits. Let us further assume that initially there is only one field of wetland in the system, and let us denote this as patch i. Necessarily, it must be located on a farm where the potential benefit from the aggregation scheme exceeds the local environmental cost, i.e., $c_1 > \mathrm{a}$. Subsequently, each of the four nearest neighbours of the converted land evaluates his options and converts to wetland if $c_1 > a$. The process is repeated and given the assumption that environmental costs are time independent, the cluster of wetland grows if for at least one neighbour on the boundary $c_1 > a$. The process halts when none of the neighbours satisfies the condition, hence cluster C_i is formed (labelled by the initial location). The analysis can be repeated for all sites for which $c_1 > a$. For those sites that already belong to cluster C_i , the analysis will generate the same cluster. However, there will also be other initial sites that will lead to a different cluster. This divides the set of all sites into a (sub)set of equivalence classes (sites belonging to a given cluster) with a size equal to the number of distinct clusters and the rest of sites for which $c_1 \leq a$.

The problem as outlined above is a dynamic problem — the sites are added as the cluster grows. Alternatively, from a percolation theory perspective, the problem may be considered in a long-time limit as a static problem. In this approach, all sites for which $c_1 > a$ are labelled as *potentially* convertible to wetland. Subsequently, clusters are identified by allocating sites according to the neighbourhood. The largest percolation cluster can then be identified as an optimal solution and the total size of the final aggregation payment calculated for this cluster.

The situation is more complicated but also more interesting in the case when we are aiming at creating the single largest possible cluster of connected wetland sites (Scenario 2). Then, the size of the largest cluster is determined by the percolation theory. Although analytical approximations are available, we will use simulations to determine the size of the largest cluster for a given level of aggregation payment, S, and the achievable average size of the largest cluster for a given budget. We also assume that aggregation payment needs to be made regardless of whether the site is or is not in the largest connected cluster.

3. Results

Figure 2 shows the distribution of potential wetland sites for given levels of payment S corresponding to the distribution of costs from Figure 1.[1] Sites for which $c_1 > a$ are highlighted as points. Figure 2 includes all sites, not only the ones that are converted under the aggregation scheme, hence there is a large proportion of single sites for low values of c_1. As the level of payment increases, increasing number of sites are converted into wetland and eventually sites merge and form large clusters. As expected, for a relatively large value of S most area is converted to wetland.

[1] Again, for illustration we used the smaller system with $n = 625$.

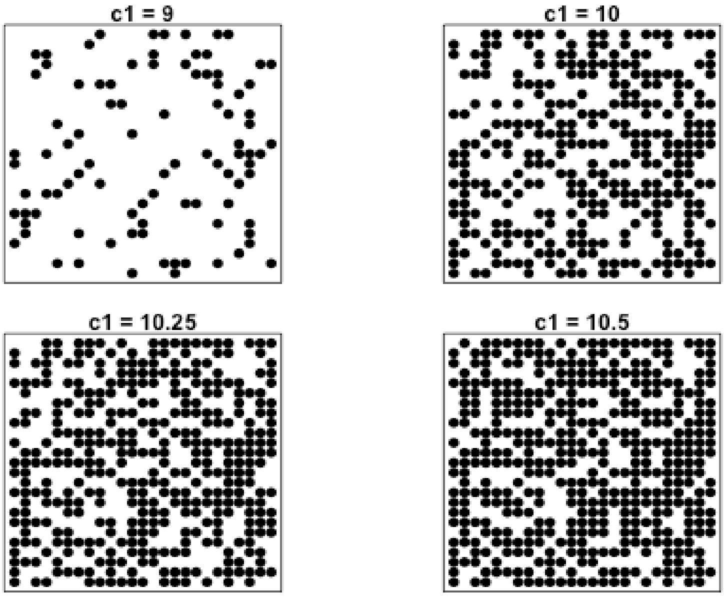

Figure 2: Distribution of potential wetland *sites* for given levels of payment

For the aggregation scheme, only sites that are connected to at least one other site receive a payment and contribute to the conservation effort. Figure 3 shows the same distribution as in Figure 2, but without isolated sites and with clusters of size larger than 1 labelled in different colours, with the largest cluster in black. For a small value of c_1 only very few sites are converted to wetland and they tend to be in very small clusters. An environmental benefit associated with such small clusters is also very small. When the aggregation payment increases, more area is converted to wetland and larger clusters appear. However, the wetland area is still highly fragmented as most clusters have a similar size (see Figure 3, c_1 = 10). As the aggregation payment increases, the density of potential wetland sites approach the percolation threshold and a single large cluster emerges, connecting a large proportion of sites (see Figure 3, c_1 = 10.25). Thus, even a small increase in c_1 very rapidly changes the conservation benefit associated with the conversion to wetland. For large values of c_1 most of the sites are interconnected. The percolation threshold is associated with large variation in the size of critical clusters and we therefore use a larger (100 by 100) system to study the transition in detail.

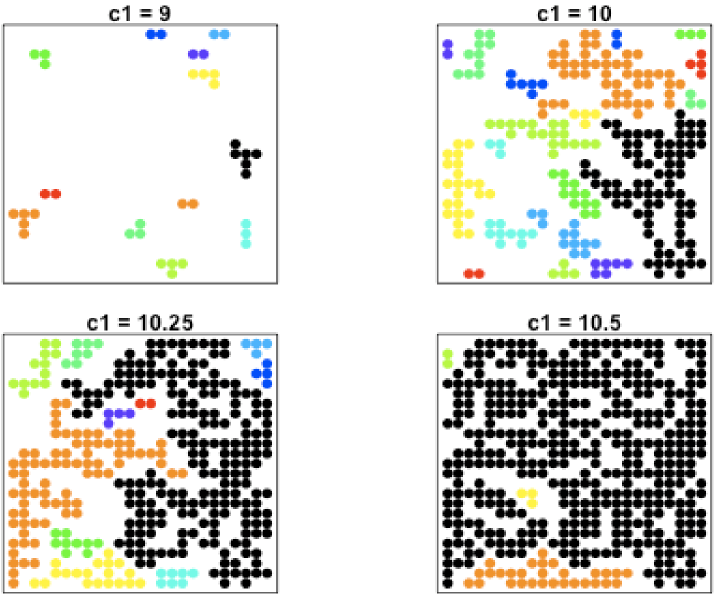

Figure 3: Distribution of potential wetland *clusters* for given levels of payment

The conservation benefit is associated with the conversion of sites into wetland. If one is simply interested in the total area of wetland (Scenario 1), the conservation benefit is related to the proportion of sites (see Figure 4, broken line). For a low value of the single site payment S, there are only few sites for which c_1 > a and their proportion is given by $P(a < c_1) = \Phi(c_1)$. As the aggregation payment increases, it sweeps the environmental cost values and an increased number of sites are transformed into wetland. The graph of the proportion of wetland sites as a function of the aggregation payment is essentially a cumulative distribution function of P(a) — see Figure 4 solid line — for a system of i = 2500 sites. The change of the way in which the conservation benefit is calculated, from Scenario 1 (*all* sites) to Scenario 2 (*connected* sites) does not change the picture much (see Figure 4, solid line) as only very few sites are isolated for any given value of the aggregation payment. However, there is a big difference between Scenario 2 and Scenario 3 (largest connected cluster). That is, for small aggregation payments, the distribution of sites is very fragmented and is therefore characterised by large number of relatively small clusters. It is only when the density of wetland sites reaches the critical percolation threshold that a single large cluster appears. This largest cluster grows very rapidly and quickly dominates the cluster distribution, with all remaining clusters being very small. This results in the steep graph of the proportion of wetland sites as a function of the aggregation payment (see Figure 4, thick line). Jaggedness of the line is related to large fluctuations at the critical percolation threshold for relatively small systems.

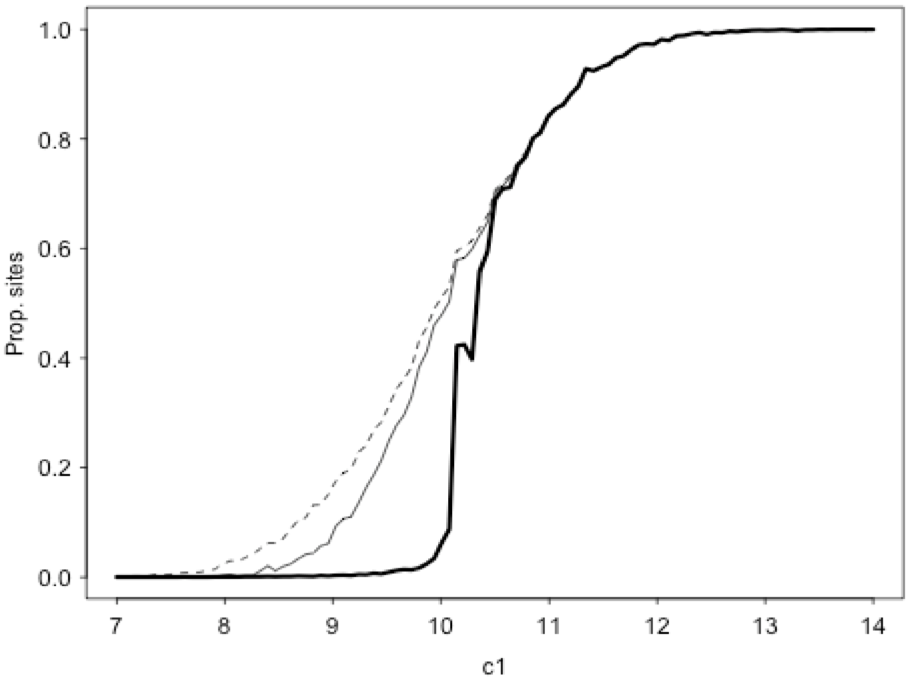

Figure 4: Propensity of wetland sites for given levels of payment under three scenarios

The increased conservation benefit comes at a price as we need to make the aggregation payment for all sites that are converted to wetland and connected. We can therefore ask a question of what is the attainable conservation benefit under the different Scenarios for a given budget. Table 1 lists the different scenarios and the corresponding costs and benefits. For Scenario 3 we assume that while we need to pay for all sites, it is only those sites that are located in the largest connected cluster that contribute to the conservation benefit. This reflects the fact that it is difficult to distinguish farmers who are in the largest cluster from other farmers. We can, however, easily limit the payment to those sites that have at least one converted site in the neighbourhood.

Table 1: Costs and benefits under the three scenarios

Scenario	**Costs**	**Benefits**
1	Payment for all converted sites (where $c_1 > a$)	Every converted site
2	Payment for all converted sites if a neighbouring site is also converted	Every converted site, requires a neighbour to convert
3	Payment for all converted sites if a neighbouring site is also converted	Only converted sites that have a converted neighbour, located in the largest connected cluster

Figure 4 shows the dependence of the conservation benefit on a single site payment. The total payment, however, depends also on the spatial distribution and in particular on the Scenario. As the single site payment increases and more sites are converting, the total payment increases more rapidly until most sites are converted to wetland (see Figure 5). In Figure 5, the broken line corresponds to Scenario 1; the solid line to Scenario 2 and Scenario 3. The total cost increases monotonically and is highest for Scenario 1 for a fixed single-site payment, because for this Scenario the conversion is higher in this case.

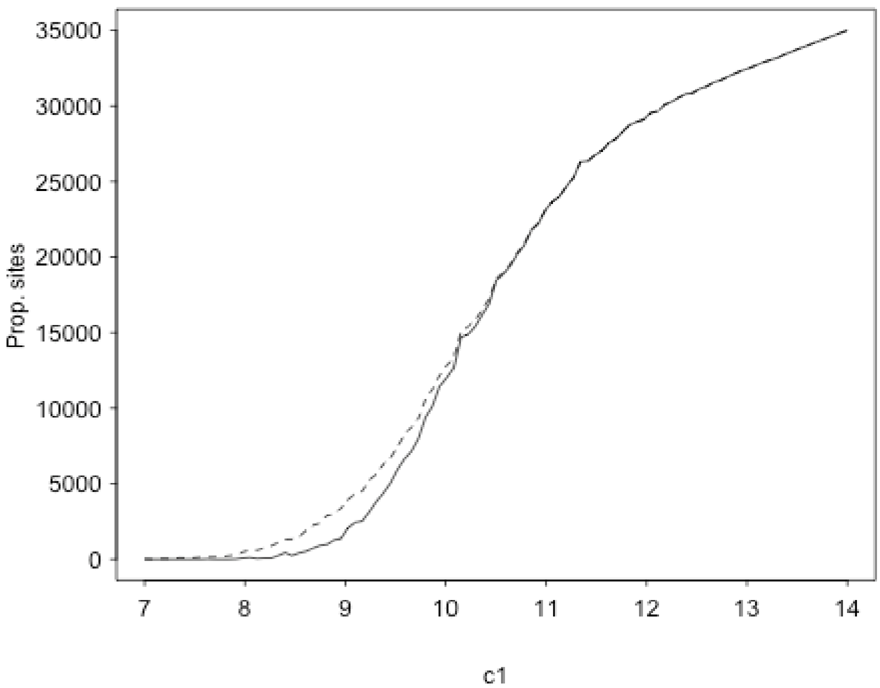

Figure 5: Total costs under scenario 1 (broken line) and Scenario 2 and 3 (solid line)

In practice, we need to answer a reverse question. There is usually a target associated with the conservation benefit. What is the total budget that needs to be allocated to the environmental policy to reach this target? Clearly, it is easiest to reach a given level of the conservation benefit for Scenario 1 when we are simply interested in conversion to wetland regardless of any spatial consideration. In Scenario 2 we want to have at least two wetland sites together and therefore we are only paying the premium for the spatial coordination. Scenario 3 corresponds to the most "wasteful" situation as we need to pay for the conversion but are only interested in a subset of sites. Thus, the difference between the total cost under Scenario 2 and Scenario 1 for a given conservation benefit corresponds to the spatial coordination premium we need to pay to achieve the stricter target in Scenario 2. Similarly, the difference in the total cost under Scenario 3 and Scenario 2 corresponds to the connectedness premium that needs to be paid to achieve a single connected cluster.

Eventually, we will need to decide whether it is worth paying the spatial coordination or the connectedness premium. Let us concentrate on the difference between Scenario 2 and Scenario 3 and assume that each wetland site that is connected to the largest cluster brings e, where $e >> c_1$. We assume that the wetland site that is not connected to the largest cluster does not bring any premium. What is the value of the aggregation payment c_1 for which the total gain becomes positive? Figure 6 shows the dependence of the benefit (e_1 times the size of the largest cluster) minus the cost (c_1 times the total number of converted sites) as a function of the environmental benefit (the size of the largest cluster) for different values of c_1. Figure 7 shows also the difference between the benefit and the cost, but this time as a function of the total budget that needs to be spent to achieve the particular goal.

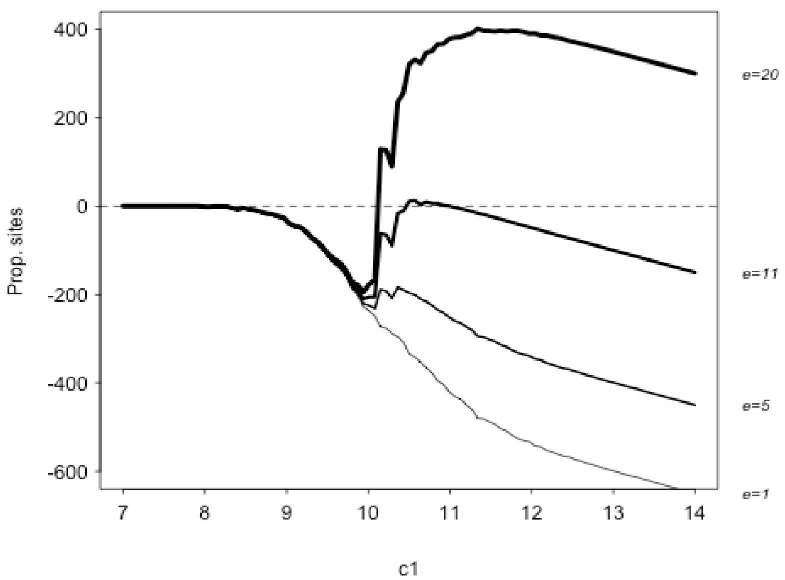

Figure 6: Net conservation benefit as function of agglomeration payment

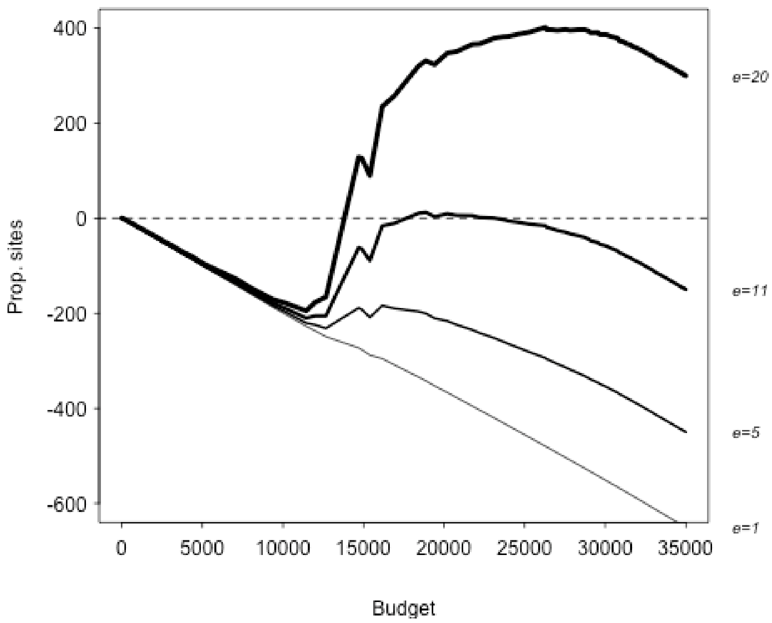

Figure7: Figure 6: Net conservation benefit as function of budget

For small individual payment c_1 —and the corresponding total budget— the sites converted to wetland are small and fragmented leading to a very small conservation benefit. Thus, even if the conservation benefit per each site is high (e = 20 in Figures 6 and 7), the cost exceeds the overall benefit. In order to 'break even' we need to create a large percolation cluster and to achieve this we need to provide a large enough aggregation payment c1 and a large enough total budget. For example, if we follow the line with e = 11 in Figure 6, we see that for small values of c_1 the costs exceed the benefit, but as we increase the payment past the value of $c_1 \cong 10$, a single large cluster of wetland sites appears and rapidly grows. As a result, the overall conservation benefit increases rapidly and reaches a positive value at around $c_1 \cong 10.4$. However, further payments do not increase the overall benefit, as at this point almost all sites are converted to wetland except a few for which the environmental costs are very high (see Figure 4 for the same value of c_1 showing that about 80% of sites are converted at

$c_1 \cong 10.5$. In this case, a further increase in c_1 leads to a very small increase in the conservation benefit but at the increase in the overall costs. Moreover, it is not possible to achieve the positive overall benefit (conservation benefit minus the total aggregation payment) for every value of e. This is related to the fact that the aggregation payment is "wasted" on sites that do not belong to the largest connected cluster in Scenario 3. For example, in Figure 6 the values of $e \leq 10$ do not correspond to a positive overall benefit for any value of aggregation payment. We can generalise this result to state that the conservation benefit per site must exceed the average environmental cost, a (which is equal to 10). There is also a maximum attainable overall benefit (see Figure 6). For example, in Figure 6 it is not worth paying more than $c_1 = 10.5$ for $e = 11$ and more than $c_1 = 11.5$ for $e = 20$. The critical aggregation payment in Scenario 3 corresponds to a critical total budget, Figure 7. To summarise, for the values in Figure 6 and for e=11, the minimum aggregation payment that achieve "break even" is around $c_1 = 10.4$ and the optimal aggregation payment is around $c_1 = 10.5$, corresponding to a budget of 16,000 and 17,000 for a system of 50 times 50 sites ($n = 2500$), respectively. For a higher conservation benefit, e.g., $e = 20$, the minimum aggregation payment is about 10.2 and the optimum payment about 11.5 (total budget 13,000 and 28,000).

4. Conclusions

This paper examines the interaction between an agglomeration payment and the degree of clustering of connectivity of land, or alternatively, how the agglomeration payment interacts with environmental benefits. This interaction is illustrated for the case of wetland management. We distinguish three scenarios to study the interaction. In Scenario 1, a (uniform) payment is made to all farmers who switch to wetland regardless of whether any of the neighbours switch to wetland as well. The aim under this scenario is simply to maximize the area of converted land to wetland (with a limited budget). In contrast, the aim under Scenario 2 is to maximize the *connected* area of wetland (with limited budget), also assuming a fixed payment per farmer. Finally, under Scenario 3 the objective is to maximize a *single* connected area of wetland. The difference of Scenario 3 with Scenario 2 is that under Scenario 3 wetland sites are connected but also belong to the *largest* connected cluster.

We find that an increase of the agglomeration payment induces a smooth transition of converted wetland sites under Scenario 1. Under Scenario 2, a small change in the agglomeration payment results in a highly connected cluster. Further, for Scenario 3 there exists is a sharp transition from a non-connected to a connected wetland cluster. There is a minimum aggregation payment that leads to positive overall benefit (conservation benefit minus aggregation costs). There also exists a minimum environmental benefits per site below which the optimal strategy is to do nothing as any aggregation scheme will cost more than any potential benefit. Finally, a higher budget is required to create a connected cluster of wetland.

References

Armsworth P. (2004) “An introduction to biodiversity concepts for environmental economists” *Environmental and Resource Economics* 26, 115-136.

Chomitz K., da Fonseca G., Alger K., Stoms D., Honzák M., Landau E., Thomas T., Thomas W. and Davis F. (2006), “Viable reserve networks arise from individual landholder responses to conservation incentives”, *Ecology and Society* 11: Article 40.

Drechsler M., W ätzold F., Johst K., and Shogren J.F. (2010), “An agglomeration payment for cost-effective biodiversity conservation in spatially structured landscapes”, *Resource and Energy Economics* 32, 261-275.

Goldman R.L., Thompson B.H. and G.C. Daily (2007), “Institutional incentives for managing the landscape: Inducing cooperation for the production of ecosystem services”, *Ecological Economics* 64, 333-343.

Hallwood P. (2007), “Contractual difficulties in environmental management: The case of wetland mitigation banking”, *Ecological Economics* 63, 446-451.

Parkhurst G.M., Shogren J.F., Bastian C., Kivi P., Donner J. and Smith R.B.W. (2002), “Agglomeration bonus: an incentive mechanism to reunite fragmented habitat for biodiversity conservation”, *Ecological Economics* 41: 305-328.

Parkhurst G. and Shogren J. (2007), “Spatial incentives to coordinate contiguous habitat”, *Ecological Economics* 64: 344-355.

Parkhurst G. and Shogren J. (2008), “Smart subsidies for conservation”, *American Journal of Agricultural Economics* 90, 1192–1200.

Siikamaki J. and Layton D. (2007), “Potential cost-effectiveness of incentive payment programs for the protection of non-industrial private forests”, *Land Economics* 83, 539-560.

Tanaka T. (2007), “Resource allocation with spatial externalities: Experiments on land consolidation”, *The B.E. Journal of Economic Analysis and Policy* 7 (Topics): Article 7.

Warziniack T., Shogren J.F. and Parkhurst G. (2007). “Creating contiguous forest habitat: An experimental examination on incentives and communication”, *Journal of Forest Economics* 13, 191-207.

Wünscher T., Engel, S. and Wunder S. (2008), “Spatial targeting of payments for environmental services: A tool for boosting conservation benefits”, *Ecological Economics* 65, 822-833.