Agri-environmental policies when the spatial pattern of biodiversity reserves matters

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Abstract

The aim of this paper is to compare different policy instruments for cost-effective habitat conservation on agricultural lands, when the desired spatial pattern of reserves is a random mosaic. We use a spatially explicit mathematical programming model which studies the farmers' behavior as profit maximizers under technical and administrative constraints. Facing different policy measures, each farmer chooses its land-use at the field level, which determines the landscape at the regional level. A spatial pattern index (Ripley L function) is then associated to the obtained landscape, indicating on the degree of dispersion of the reserve. We compare a subsidy per hectare of reserve with an auction scheme and an agglomeration malus. We find that the auction is superior to the uniform subsidy both for cost-efficiency and for the spatial pattern of the reserve. The agglomeration malus does better than the auction for the spatial pattern but is more costly.

Keywords: agri-environmental policies, biodiversity, mathematical programming, spatial optimization, reserve design, cost-efficiency.

JEL Classification: H23, Q57, Q12, Q28

1 Introduction

Over the last fifty years, farmed landscapes have experienced dramatic changes, mainly due to mechanization and intensification of farming techniques, in-

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creases in the use of chemicals and increases in the size of agricultural fields. As a result, natural habitats have been transformed, leading to many species' decline (Söderström and Part 2000). Common farmland birds in Europe, for instance, have been declining by 25% over the last two decades (Gregory et al. 2005).

In farmlands, dominated by private ownership, providing sufficient incentives to landowners to influence their land-use decisions towards biodiversity preservation is thus essential. Agri-environmental policies have progressively been introduced for example in Europe (eg. *Natura 2000*) and in the United States (eg. the *Conservation Reserve Program*) to preserve habitats. In designing these policies, the economic issue lies in the trade-off between environmental efficiency (measured in units like acres/hectares of protected area) and economic costs (opportunity costs[1], compensation payments to farmers, transaction costs). Moreover, the spatial configuration of the reserve sites matters for the persistence of species. A given number of acres of protected area does not have the same ecologic impact when it is fragmented, agglomerated or distributed as a random mosaic. The best spatial pattern depends on the considered specie: the grizzly bear would prefer an agglomerated reserve for instance whereas a black-footed ferret survives better on dispersed reserves (see Parkhurst and Shogren 2007; see also Soule and Simberloff 1986 for insights on the famous SLOSS debate: Single Large or Several Small reserves).

The aim of this paper is to compare different policy instruments for cost-effective habitat conservation on agricultural lands, when the desired spatial pattern of reserves is a random mosaic. This spatial pattern is adapted to certain threatened bird species that breed on agricultural lands, such as the Little Bustard (*Tetrax Tetrax*), an Annex 1 specie of the European Union Birds Directive (79/409/EEC).

Many studies have been devoted to optimal reserve design, mainly in the field of conservation biology (see Williams et al. 2005, for a general review; see Wossink et al. 1999, and van Wenum et al. 2004, for a more specific analysis of agricultural lands). These contributions have focused on the question of where the reserve should be located to adequately (and cost-efficiently[2])

[1]The opportunity costs of habitat conservation can be defined as the forgone profits due to implementing a reserve (eg. grassland) instead of another more profitable land-use (eg. cropland). We define here the "reserve" in a general way, i.e. as all sites characterized by environment-friendly land-uses and management options.

[2]An extension of the basic literature to the field of economics has consisted in incorpo-

protect the biodiversity. However, they do not address the question of "how to get there". They implicitly assume that the social planner has perfect knowledge on all costs and selects reserve sites minimizing opportunity costs. Unfortunately, governmental agencies have imperfect information on private costs and cannot implement the first-best reserve location in a direct way (Lewis et al. 2009).

Designing incentive-based conservation policies, aiming at a cost-efficient reserve under information asymmetries, is thus a further step in reserve design. Many articles have examined this issue using mechanism design theory but without taking into account the spatial characteristics of the conserved area (Smith 1995; Bourgeon et al. 1995; Wu and Babcock 1996; Moxey et al. 1999; Ozanne et al. 2001). Recent contributions have introduced the spatial aspects. Lewis and Plantinga (2007), Lewis et al. (2008) and Lewis et al. (2009) examine incentive-based policies to reduce habitat fragmentation. Among other things, our analysis differs from these authors' as they use an econometric model to estimate the farmers' decisions (conversion probabilities based on passed observations) while we explicitly detail the farmers' behavior as a profit-maximizer. Wätzold and Drechsler (2005) and Drechsler et al. (2007) measure the losses due to implementing uniform payments whereas the costs and environmental benefits of conservation are spatially heterogenous. However, these analysis do not model the farmer's behavior facing different policy measures and the resulting configuration of the reserve. Smith and Shogren (2002), Parkhurst et al. (2002) and Parkhurst and Shogren (2007, 2008) have investigated the efficiency of *agglomeration bonuses* paid to farmers when they locate a reserve on a parcel adjacent to another reserve[3]. These articles, mainly based on experimental economics, examine whether rational individuals can achieve coordination but do not look into the mechanism that drives the farmers' decisions.

We use a spatially explicit mathematical programming model (called OUTOPIE) in which the farmer maximizes its profit under several technical and administrative constraints. This behavior leads to land-use choices at the field level and eventually generates a landscape at the regional level. A spatial pattern index (Ripley L function) is then associated to the obtained landscape, indicating on the degree of dispersion of the reserve. See Bamière

rating land costs (Ando et al. 1998; Polasky et al. 2008).

[3]This helps reduce reserve fragmentation which is often seen as harmful for species conservation.

et al. (2009) for a detailed description of the OUTOPIE model.

Mathematical programming farm-level models have largely been used to assess the efficiency of agri-environmental policies (Wossink et al. 1999; Falconer and Hodge 2001; van Wenum et al. 2004; Ekman 2005; Havlik et al. 2005). Our model differs in that it takes into account, in addition to the farm-level, both the field and landscape levels, linked to a spatial pattern indicator. As we have explained above, taking into account these three levels is essential when analyzing biodiversity conservation: the field is the elementary unit of the spatial pattern, the farm is the landowner's decision level, and the resulting landscape level determines the environmental result.

Our model is applied to a Natura 2000 site in France (*Plaine de Niort*), which aims at protecting the Little Bustard. This bird relies exclusively on insects found in temporary grasslands, and preferentially breeds in an arable landscape constituted of a mosaic of alfalfa, grasslands and annual crop fields (Wolff et al. 2001). It's conservation therefore implies a random mosaic of extensively managed grasslands and annual crops. While contiguity and connectivity have often been studied (Wossink et al 1999, Nalle et al 2004), to the best of our knowledge this work is one of the first attempts to account for a random mosaic distribution of the reserves (see also Bamière et al. 2009).

We assume the environmental objective is to reach a given percentage of land enrolled in the reserve (i.e. covered by extensively managed grassland), with reserve patches forming a random mosaic. We then compare various policy instruments - a subsidy per hectare of reserve, an auction scheme and an agglomeration malus - to reach this objective.

The subsidy, which has previously been studied in Bamière et al. (2009), is a payment to the farmer per hectare of reserve implemented on his/her land. The auction scheme works as a procurement auction where farmers indicate the minimum payment they wish to receive to convert one parcel of their land to reserve. The public regulator selects the lowest amount and pays it to the winning farmer against one parcel in reserve. By favoring competition among farmers, this instrument may improve cost-efficiency even when the regulator does not detain detailed information on the individual opportunity costs. It's use in conservation policies has increasingly attracted the attention of economists (Latacz-Lohmann and Van der Hamsvoort 1997, 1998; Latacz-Lohman and Schilizzi 2005; Thoyer and Said 2007; Glebe 2008; Ferraro 2008). The agglomeration malus is an instrument which accounts for the spatial issue. It consists in a subsidy per hectare of reserve completed with a malus (i.e. a reduction of the payment) when the additional reserve

site is adjacent to another reserve site. This malus is relevant in cases, such as ours, where the desired pattern of the reserve is dispersed. As mentioned before, some authors have examined a similar instrument, an agglomeration bonus (which is relevant when the desired pattern is agglomerated), using experimental economics (Parkhurst et al. 2002; Parkhurst and Shogren 2007, 2008).

We find that, in the framework of our model, the auction does better than the subsidy to minimize payments to farmers and regarding the spatial pattern of lands. The agglomeration malus reaches a better spatial pattern than the auction but is more costly.

The rest of the article is structured as follows. First, we present our modeling approach and our method in comparing policy instruments. Then, we introduce an auction scheme and compare it to the subsidy per hectare. Next, we study the agglomeration malus and compare it with the two other instruments. Conclusions and scope for further research are given in the last section.

2 The mathematical programming model

OUTOPIE (*OUTil pour l'Optimisation des PrairIes dans l'Espace*) is a mixed integer linear programming model which accounts for three spatial levels: the field, the farm and the region. Fields are characterized by their soil type, irrigation equipment and the farm to which they belong. This determines the agricultural activities and cropping techniques that can be chosen on each field, as well as the resulting yield and gross margin. The farm is the level at which decisions concerning land allocation are made, taking into account policy constraints (e.g. milk quotas and obligatory set-asides) and technical constraints (e.g. feed requirements). Spatial relationships between fields, constituting the landscape, are accounted for at the regional level.

The model includes the major crops (wheat, winter barley, sunflower, rapeseed, maize, and sorghum), permanent and temporary grasslands, including alfalfa, and set-aside lands. The reserve is defined here as all lands covered with alfalfa and temporary or permanent grassland, managed in an environment-friendly way[4].

[4]We define here an environment-friendly management as a Little Bustard-friendly management, characterized by restrictions on livestock density, fertilization, pesticides, and mowing dates.

The model maximizes the sum of all farms' gross margins including incomes and costs due to the participation in an agri-environmental program, subject to field, farm and landscape level constraints. This is represented in program (1), where $X_{f,i,r}$ is the level of farm activities for farm f, on field i, enrolled (or not) in reserve type r (i.e. in one of the environment-friendly managed grassland); Π_f is the farm's gross margin from agricultural activities; cp_r is the compensation payment for an enrolment in reserve type r; vtc_r is a variable transaction cost per hectare of reserve; ftc is a fixed private transaction cost for program participation and RP_f is a binary variable equal to 1 if the farm participates in the agri-environmental program.

$$\max \sum_f [\Pi_f(X_{f,i,r}) + (\sum_{r,i}(cp_r - vtc_r)X_{f,i,r} - ftc)RP_f] \qquad (1)$$
$$s.t. Field(X_{f,i,r}), Farm(X_{f,i,r}), Landscape(X_{f,i,r})$$

This model is applied to a Natura 2000 site located in *Plaine de Niort*, in *Poitou-Charente*, France. This area was traditionally dedicated to mixed farming but has recently undergone a rapid specialization in crop production, threatening some populations of birds such as the Little Bustard (*Tetrax Tetrax*). The whole Natura 2000 site is about 20 000 hectares (ha) but we have chosen to concentrate on a restricted stylized area of 2 700 ha divided in 900 fields of 3 ha each (see Figure 1). There are three main groups of soils in *Plaine de Niort* - calcareous valley, deep and shallow plain soils - with different agricultural potentials. They are represented on the map (Figure 1) according to the ratio and layout observed. We considered 12 crop growing farms and 6 mixed dairy farms, both types being located on all types of soils and some of them having the possibility to irrigate a fixed set of contiguous fields. More details can be found on the description and the validation of the OUTOPIE model, as well as on the case study, in Bamière et al (2009).

In order to account for the spatial pattern of the obtained reserve, the model has been completed with a spatial indicator. According to some ecologist experts (Bretagnolles et al. 2009), the most suitable spatial pattern for Little Bustard conservation can be described as at least 15% of land covered by extensively managed grassland patches (3 ha being the ideal field size), randomly or regularly located within any radius between 100 and 1000 meters. As a consequence, we need to measure not only the size but also the shape of the reserve generated by the model. In order to do so, we use an

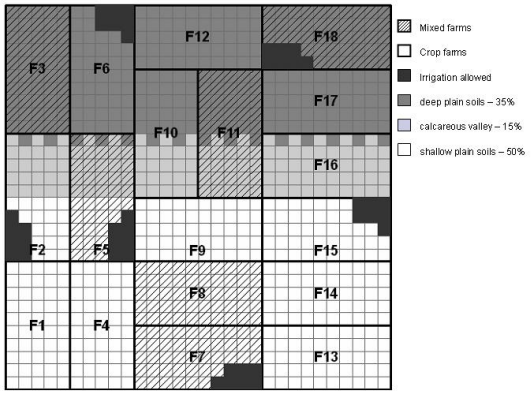

Figure 1: Model representation of the studied area (18 farms; 3 soil types)

indicator based on Ripley K and L functions (Ripley 1977, 1981). Theses functions measure both the density of the reserve and the distances between reserve sites. They are widely used in plant ecology (Haase 1995). Results can be interpreted as follows (see Figure 2 for two spatial distributions of the reserve and Figure 3 for the associated values of the Ripley function L): a) if L remains within the confidence envelope (dotted lines in Figure 3) then the spatial pattern of the reserve is significantly (Poisson) random; b) if L is above the upper limit of the confidence envelope, then the spatial pattern is clustered or aggregated. More details are given on the Ripley indicator in Bamière et al (2009).

3 A comparison of policy instruments

We now use our modeling approach to compare different policy instruments in order to reach a given environmental objective. This objective, consistent with ecologists' recommendation for the Little Bustard, is 15% of land covered with reserve and reserve patches randomly dispersed (i.e. the Ripley function must be in - or as close as possible to - the confidence envelop).

The policy instruments are compared according to two criteria. First, we compare the total costs of reaching the 15% objective (cost-efficiency). Second, we compare the spatial configuration of the obtained reserve (spatial efficiency). We have chosen to consider both these criteria independently

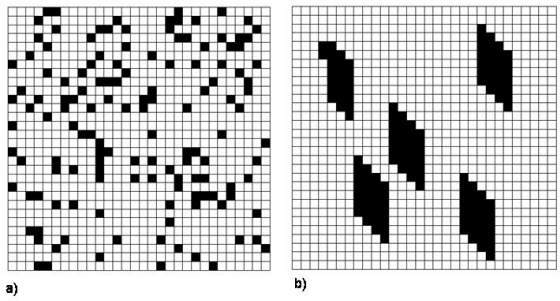

Figure 2: Spatial distribution of 135 reserve plots on a 900 plots grid: a) random, b) aggregated

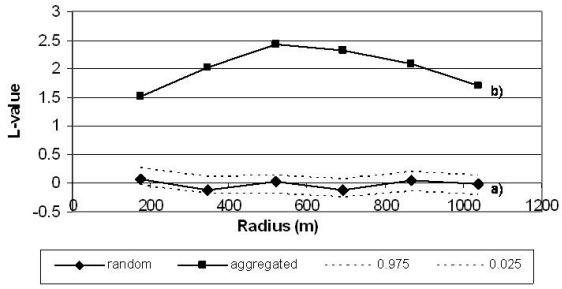

Figure 3: Ripley L function for the random (a) and aggregated (b) distributions

without giving a priority to one or the other[5].

Regarding the total costs of the policy, we first consider the private costs. These are the sum of the opportunity costs - or forgone profits - incurred by farmers when converting their lands to reserve. These costs are minimized when converting first the low quality lands, as these lands have a lower associated gross margin. The three instruments we compare are incentive-based instruments that let the farmers choose which parcel they convert to reserve. As the profit-maximizing farmer always chooses to convert first the cheapest parcels, total opportunity costs are automatically minimized. Therefore, the minimization of private costs is not a discriminatory criteria among the instruments we study. We next consider the public costs of the policy. These are defined as the sum of the compensation payments to farmers. We assume we wish to compensate farmers for the costs of reserve implementation[6]. However, we assume the policy-maker does not know the opportunity costs associated with each field. She then cannot calculate the cost of the reserve for each farmer. Moreover, farmers are not willing to reveal their real costs as, by communicating higher levels, they would increase their compensation payment (adverse selection). As a result, the public regulator cannot pay the exact amount compensating the farmers' costs. We will see how some instruments deal better than others with this issue. Contrarily to Bamière et al. (2009), we ignore public transaction costs[7] - due for instance to the implementation of the policy and to payments to farmers. These costs are present in all instruments we analyze (whenever a policy is implemented and payments are transferred) but we do not have the information on how they differ according to the instrument, so it is not a discriminatory element. This point is discussed in the concluding section.

Regarding the spatial objective, we look at which instrument reaches the closest Ripley L value to the confidence envelop.

The subsidy per hectare of reserve has been studied in Bamière et al (2009). This instrument reaches the 15% objective with a total public cost

[5]The relative weight given to each objective depends on the importance for society of this bird specie's survival (and on the exact role of the spatial pattern in its probability of survival) compared to budgetary expenditures. These considerations go beyond the scope of our analysis.

[6]This is consistent with the idea of remunerating them for an environmental service to society.

[7]We do consider private transaction costs paid by the farmers when participating to an agri-environmental program. See equation (1).

of **279 thousand euros**. Total payments to landowners exceed their real opportunity costs due to imperfect information (the subsidy rate is set so as to cover the cost of the most expensive parcel converted to reserve whereas some cheaper parcels have been converted). As a result, the cost-efficiency of the subsidy per hectare is not optimal. Moreover, this subsidy does not reach a suitable configuration of reserves: the Ripley function is largely outside the confidence envelop (in bold on Figure 5). This is linked to the fact that the parcels with the lowest opportunity costs are rather aggregated.

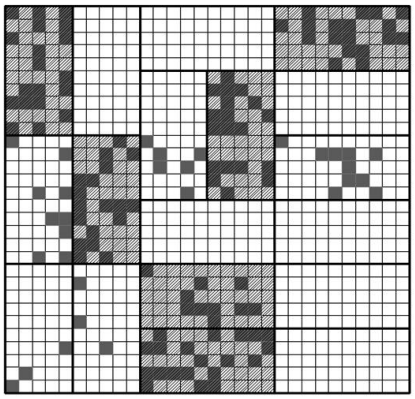

Figure 4: Reserve location with the subsidy per ha

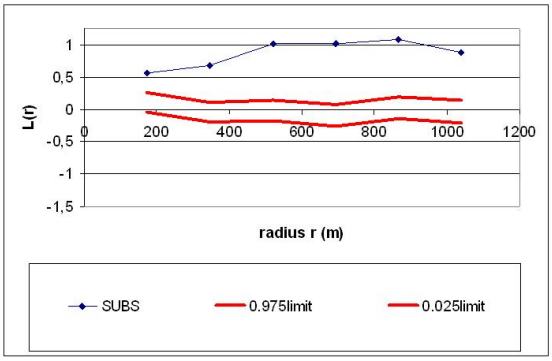

Figure 5: The Ripley L function with the subsidy per ha

We now consider other instruments that might improve the subsidy's

result either on its cost-efficiency or on the spatial objective.

4 The auction scheme

Auction schemes have increasingly attracted the attention of policy-makers to deal with agri-environmental regulation with incomplete information. Several real cases exist such as the *Conservation Reserve Program* in the United States (Cummings et al. 2004; Kirwan et al. 2005), the *Bush Tender* in Australia (Stoneham et al. 2003) or some regional experiences in Germany (Groth 2005). According to many economists, this policy instrument, by favoring competition among farmers, helps minimize the payments to farmers even when they detain private information on costs (see the references given in the introduction).

The auction we study here is a first-price sealed bid auction which works as follows. First, farmers indicate to the public regulator the minimum payment they wish to receive to accept converting one parcel of their land to reserve. Their bid is sealed, meaning that the other farmers cannot observe it. Second, the regulator selects the best offer, i.e. the lowest amount, and pays this amount to the winning farmer against one additional parcel of reserve on his land. If several farmers bid at the lowest amount, they all win the bidding and receive this amount against one parcel of reserve. The operation is repeated until the total desired hectares of reserve have been reached.

Our modeling of the auction is inspired from Latacz-Lohmann and Van der Hamsvoort (1997)'s seminal work. For simplicity let us denote as Π_f^0 the total gross margin of farm f without any commitment on the reserves on his land and Π_f^1 its total gross margin - not including the compensation payment - when farm f commits to one additional parcel of reserve on his land. $\Pi_f^0 - \Pi_f^1$ represents the forgone profits of farm f (or opportunity costs) due to an additional parcel of reserve. If farmer f submits a bid b in the auction scheme and if his bid is accepted, its total gross margin is $\Pi_f^1 + b$. Following Latacz-Lohmann and Van der Hamsvoort, we assume that each farmer's bidding strategy is influenced by its expectations on the threshold bid β above which no bids are accepted. Those expectations, which are assumed to be identical for all bidders, are characterized by a density function $f(b)$ and a distribution function $F(b)$. The probability that a bid b is accepted

is then:

$$P(b \leq \beta) = \int_{b}^{\bar{\beta}} f(u)du = 1 - F(b)$$

where $\bar{\beta}$ denotes the upper limit on the bidders' expectations on the bid cap, i.e. the maximum expected bid cap.

The farmer chooses b so as to maximize its expected net payoff:

$$\max_{b}(\Pi_f^1 + b - \Pi_f^0)[1 - F(b)]$$

which yields:

$$b^* = \Pi_f^0 - \Pi_f^1 + \frac{1 - F(b)}{f(b)} \tag{2}$$

As shown in (2), when choosing its bid, the farmer makes a trade-off between net payoffs and the acceptance probability. A higher bid increases the net payoff but reduces the probability of winning, and vice-versa.

Still following Latacz-Lohmann and Van der Hamsvoort, for the quantitative analysis, we assume that the bidders expectations on the bid cap are uniformly distributed in the range $[\underline{\beta}, \bar{\beta}]$ where $\underline{\beta}$ represents the minimum expected bid cap. In this case, the optimal bidding strategy becomes:

$$b^* = max\{\frac{\Pi_f^0 - \Pi_f^1 + \bar{\beta}}{2}, \underline{\beta}\} \tag{3}$$

$$s.t. \quad b^* > \Pi_f^0 - \Pi_f^1 \tag{4}$$

As shown in (3), the optimal bid is an increasing function of the opportunity cost of participation and of the expected bid cap. The constraint (4) accounts for the fact that the farmer will never offer a bid which does not at least cover the extra cost of its commitment.

Using this simple auction model, we introduce this policy instrument in the OUTOPIE model. The auction procedure is repeated until 15% of the zone has been enrolled in the reserve. To avoid learning effects and collusion among bidders, we assume there is no diffusion of information between two auction rounds (i.e. the amount of the winning bid and the identity of the winner are not revealed). As Latacz-Lohmann and Van der Hamsvoort, we assume that the range $[\underline{\beta}, \bar{\beta}]$ is given by minus 40% to plus 40% of the average opportunity cost of an additional parcel in reserve[8].

[8] We assume farmers are able to estimate the average opportunity cost of one additional parcel in reserve in the studied area.

We find that the auction reaches the 15% objective with a total public cost of approximately **255 thousand euros**. The auction therefore reaches a better cost-efficiency than the subsidy, which was 10% more expensive. There still is overcompensation of farmers compared to their real costs as their bid equals their opportunity cost plus a value which depends on their expectations of the bid cap. However, in our case, the overcompensation is lower with the auction than with the subsidy. Regarding the spatial configuration of the reserve, the auction dos not reach the exact desired pattern (see Figures 6 and 7 where the Ripley function is shown to be slightly outside the confidence envelop) although it does a little better than the subsidy.

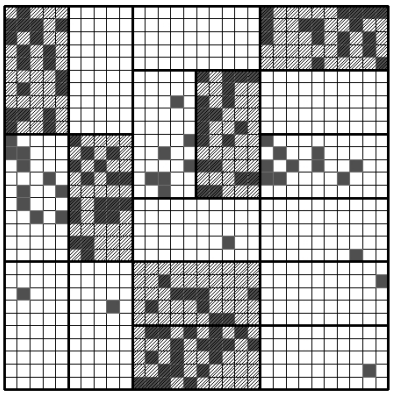

Figure 6: Reserve location with the auction scheme

Let us now look into another policy instrument that explicitly takes into account the spatial issue.

5 The agglomeration malus

For many species, the spatial configuration of the habitat reserve - and not only its total size - is crucial for survival. There is no scientific consensus on the optimal spatial pattern of the reserve - which depends on the specie - and only very few policy instruments have been developed to take into consideration these spatial issues. In the emerging literature on the topic, the most recurrent objective is to avoid reserve fragmentation. Parkhurst et

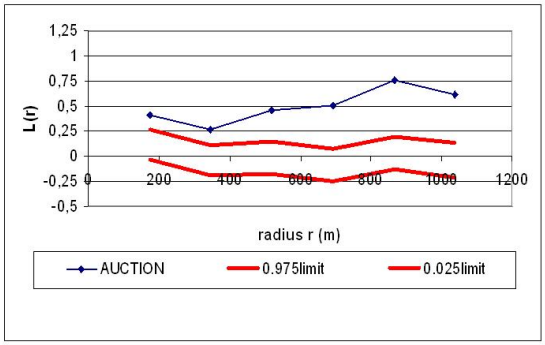

Figure 7: The Ripley L function with the auction scheme

al. (2002) and Parkhurst and Shogren (2007, 2008) for instance examine an incentive mechanism called an agglomeration bonus, which awards farmers bonus payments for the conservation of adjacent parcels[9]. These authors use experimental economics to examine whether players are able to coordinate and reach the desired spatial configuration of land when facing such an agglomeration bonus.

We focus here on a similar instrument but reversed, so as to take into account our objective of a dispersed reserve: an agglomeration malus. We assume the farmers receive a payment per hectare of reserve but pays a malus when the remunerated parcel is adjacent to an existing reserve. We distinguish the parcels that are completely adjacent to the remunerated parcel from those having only one corner in common with this parcel. For example, if we assume a farmer receives a payment for the conversion of parcel 5 to the reserve (see Figure 8). He will pay the total malus if parcel 2, 4, 6 or 8 is in the reserve. And he will pay a lower amount - say half the malus - if parcel 1, 3, 7 or 9 is in the reserve, as these parcels only have one corner in common with parcel 5. The farmer pays the malus per adjacent parcel in reserve (or half the malus per parcel with one corner in common with the remunerated parcel). In the example below, where parcels in grey are in

[9] A real-world application of an agglomeration bonus is Oregon's Conservation Reserve Enhancement Program (CREP), established in 1998 with the goal of assisting the recovery of salmon and trout species through the creation of riparian buffers along stream habitat (Grout 2010).

the reserve, the farmer has to pay 2.5 times the malus when receiving the payment for converting parcel 5 to the reserve.

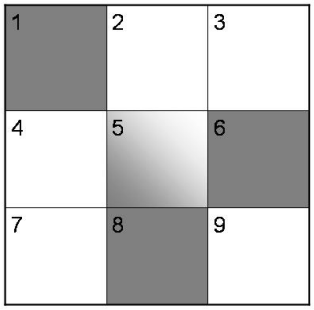

Figure 8: The agglomeration malus

We assume farmers can observe the existing parcels in reserve, as is consistent with reality. However, they do not know which parcels their neighbors farmers will choose to put into reserve simultaneously to their own decision, so they might have to pay an unexpected malus. But we assume they take their decision considering only the existing reserve sites without building expectations on the coming reserve sites.

We find that this instrument reaches 15% of reserve with a total public cost of **283 thousand euros**. It therefore turns out to be more expensive than the standard subsidy and, *a fortiori*, than the auction scheme. However, this instrument leads to a spatial pattern of lands very close to the desired pattern (see Figures 9 and 10): the Ripley L function is inside the confidence envelope, except for the first point (for a 200 meters radius) due to over-dispersion.

6 Conclusion

We have compared three incentive-based policy instruments - a subsidy per ha of reserve, an auction and an agglomeration malus - in order to reach a given size of reserve on agricultural lands, with reserve patches forming a random mosaic. In the framework of our model, the auction scheme has proven to

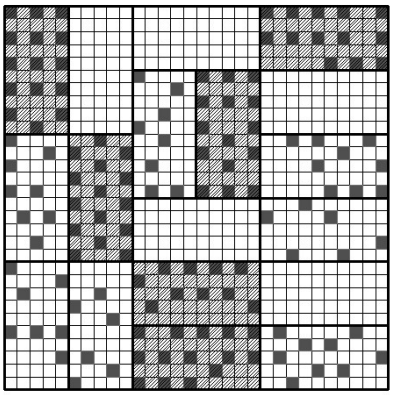

Figure 9: Reserve location with the agglomeration malus

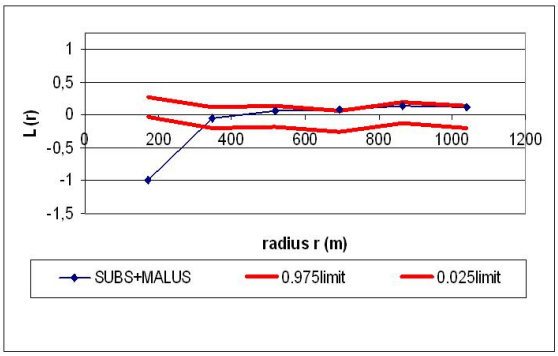

Figure 10: The Ripley L function with the agglomeration malus

be more efficient than the subsidy both for the public expenditures and for the spatial pattern of the reserve. The agglomeration malus is more costly than the subsidy and the auction but allows a better spatial pattern than both other instruments. As a result, we cannot rank the auction compared to the agglomeration malus as the former is more cost-efficient whereas the latter is more spatially efficient. We therefore observe a trade-off between minimizing the public costs of the policy and reaching the desired spatial pattern of reserves.

Our work can be improved in many directions. First, we could introduce other policy instruments such as an heterogeneous payment scheme (based on mechanism design theory) or a reserve trading scheme, both potentially improving cost-efficiency. Second, we could improve the design of the auction scheme so as to deal more specifically with the spatial issue. This includes revising the scoring of bids taking into account a selection criteria which depends on the status of the adjacent parcel. Also, the public transaction costs of the agri-environmental policy could be added. This is important as an auction scheme or an agglomeration malus may induce higher administrative costs than a standard subsidy, due to more complex procedures or duplicated payments.

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