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Sophie Thoyer, Sandra Saïd, . Unité d'Économie Et Sociologie Rurales de Rennes, . European Association of Agricultural Economists

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Agri-environmental auctions with synergies

Sandra Said *

Sophie Thoyer **

* PhD student – Inra-Lameta 2 place Viala 34060 Montpellier cedex 1 (France) –e-mail: said@ensam.inra.fr

** Professor, Département Sciences sociales, économie, gestion, SupAgro-Lameta, 2 place Viala 34060 Montpellier cedex 1 (France) e-mail: thoyer@supagro.inra.fr

Introduction

Over the last few decades in Europe, agricultural intensification accelerated the decline in soil and water quality as well as biodiversity loss. The social demand for a better environment and for better management of natural and landscape resources has led European policy-makers to increase Common Agricultural Policy (CAP) budgets dedicated to incentive payments for farmers willing to adopt more environmentally-friendly practices on their private land. The EU Rural Development Regulation grants member states a large measure of subsidiarity for designing their own agri-environmental schemes, matching them to local conditions and regional environmental priorities. This discretion has resulted in a wide variety of measures within a large range of objectives and management prescriptions.

The French agri-environmental scheme is based on a menu of more than one hundred eligible environmental measures (such as mowing pastures later in the season, using less pesticide, planting and maintaining hedgerows, or leaving uncultivated margins around fields to provide animal habitats), restricted to a shorter list for each region. From this list, farmers can design their own combination of environmental actions, best suited to their cost structure and preferences. A 5-year contract is signed between the farmer and the state, where the farmer commits himself to comply with the selected actions, in return for a yearly compensatory premium. This premium is the sum of pre-defined unit payments for each action. Payments for each action –or measure- are calculated by a regional commission (under the supervision national and European authorities) on the basis of estimated costs of compliance (in terms of revenue foregone or increased input costs) averaged at the regional level.

It is well-known that such an allocation procedure does not overcome information asymmetries between farmers and public authorities. Farmers tailor their agri-environmental contract so as to maximize the difference between the contract premium and their true compliance costs, often at the expense of environmental gains. The resulting disappointing efficiency of agri-environmental schemes has been well documented in the mid-term review of agri-environmental schemes of the European Commission (CE, 2005): it is a costly policy which has relatively little environmental impact. Since agri-environmental policies were often used by member States to supplement farm income, they were only moderately preoccupied with the efficiency issue. However, the mid-term review of the CAP in July 2003 has put greater emphasis on environmental sustainability. The European Commission required that agri-environmental schemes include quantifiable objectives, be more cost-effective, and encourage member States to adopt competitive bidding in the allocation process. There is therefore mounting pressure to evaluate the feasibility of an allocation scheme avoiding the pitfalls of posted-price contracting systems.

In the US and in Australia, decision-makers have sought to overcome information asymmetries by privileging competitive bidding procedures: by inducing competition between farmers, auctions reach outcomes which are generally Pareto-superior to a posted-price offer system. Auctions are frequently used in agri-environmental contracting (Latacz-Lohmann and Schilizzi, 2005). The US Departement of Agriculture has been awarding land retirement contracts in the Conservation Reserve Program (CRP) on the basis of competitive bidding mechanism since 1986 (Babcock et al, 1996; Johansson and Cattaneo, 2006). The State of Victoria in Australia has trialed several auction-based approaches to allocate conservation contracts to private landholders, ie the BushTender program (Stoneham et al, 2003) and the EcoTender program (Eigenraam et al, 2006). The Australian Federal State has even launched an ambitious program to extend the auction system for agri-environmental programs. It is important to note that Europe takes increasing interest in these approaches: for example the Countryside Stewardship Scheme (CSS) which is the main agri-environmental scheme in United Kingdom is based on a competitive bidding system: for a given premium per hectare, farmers bid on the package of environmental actions they are willing to undertake, in conformity with environmental priorities defined at the regional level (Dobbs et Pretty, 2001). Germany has also set up an experimental bidding process for biodiversity conservation on grassland (Groth, 2005).

Agri-environmental auctions have thus given rise to a vast theoretical and empirical literature (see Latacz Lohmann and Schilizzi, 2005, for a review). Most of this literature focuses on the case when the farmer wants to sell only one indivisible contract to a government wanting to buy a series of identical agri-environmental contracts. However, in reality, public authorities auction off several types of agri-environmental measures and farmers are willing to sign for a combination of these measures. These auctions are therefore procurement auctions for heterogeneous units (each unit corresponding to one specific agri-environmental measure AEM) in which bidders are potentially willing to sell more than one unit. What is particularly interesting to analyse – and often overlooked – is the synergy effect between AEM. When contracting, farmers tend to choose a combination of measures, which implemented together cost less than if they were implemented separately (positive synergy or sub-additivity of costs). This can be due to input jointness (set-up costs or variable costs associated with specific inputs or dedicated equipment), to economies of scope (including on intangible assets such as savoir-faire), or to complementary effects on production. On the other hand, they will tend to avoid measures which combined together cost more than separately (negative synergy or superadditivity of costs), although it could have led to more desirable environmental outcomes from the view point of society. Moreover, it is sometimes the case that farmers are presented with various contracts (Natura 2000 contracts, agri-environmental measures, local incentives) at different periods in time, preventing them from benefiting fully of the potential cost-saving impact of synergies between contracts.

The objective of this paper is to compare the performance of different procurement auction designs in the case of multiple heterogeneous units where bidders may potentially want to sell more than one unit and where their supply cost structure displays positive synergies. Multi-unit auctions which involve synergies between units generate different bidding strategies than the same auctions without synergies (Jeitschko and Wolfstetter, 2002; Grimm 2004; Cantillon and Pesendorfer 2004). However, there is no general result allowing to rank auction mechanisms according to their performance in terms of efficiency and cost-saving. The difficulty to identify equilibria in bidding strategies in presence of synergies has called attention to the results obtained from laboratory experiments. Our experiment is partially based on the work of Lunander and Nilsson (2004) who have compared the bidding behaviour for multiple contracts in three different sealed-bid auctions mechanisms. Whereas the design of their experiment was based on public procurement auctions of road marking in Sweden, we have tailored our experiment to take account of the specificities of agri-environmental contracting issues.

We thus compare three auction designs: (i) an auction where farmers bid simultaneously on various agri-environmental measures without bundling. This is a simultaneous auction. (ii) an auction where farmers bid sequentially on measures. Under the sequential bidding mechanism, bidders are thus allowed to observe the outcome of bidding on the measure before submitting bids to the second. It provides information about the outcome of one contest before competing for the next. This is called the sequential auction. (ii) an auction where farmers can bid on AEM separately as well as on packages of measures in order to indicate synergies. This is a combinatorial auction. The payment rule for the three designs is a sealed-bid pay-as-bid (also called first price auction in the literature) format, since all auctions conducted for agri-environmental purposes have used this format. Our experiment also allows us to analyse the impact of repetition and information on auction performance. It is likely that auctions to allocate environmental contracts will have to be organized at least on a yearly basis (like in the Conservation Reserve Program) in order to allow previously non participating farmers to enter the scheme at a later date. Repeated auctions will provide feedback information to bidders on accepted bids and may reduce the competitive pressure. One question concerns therefore the information that should be fed back to bidders after each round of auction (Cason and Gangadharan, 2004).

The paper is organized as follows: in the first section, we describe synergies in agri-evironmental measures and the resulting allocation issue. Section 2 is a literature review of theoretical and empirical findings on the performance of multi-unit auction of hetergogeneous units with synergies. Section 3 presents our experimental set-up and results. Section 4 concludes.

1. Agri-environmental contracting and synergies

By providing financial incentives to farmers for adopting environmentally friendly agricultural practices, agri-environmental schemes are currently considered as the most important policy to counteract the negative effects of modern agriculture on the environment, biodiversity loss, and landscape degradation. Their role is to promote the so-called "*multifunctionality*" of agriculture: agriculture produces jointly commodity and non commodity outputs. Whereas the former – meat, grains, dairy products etc. – are marketable, the latter – biodiversity preservation, maintenance of traditional landscapes, etc. – exhibit the characteristics of externalities or public goods and are typically underproduced. For example, an extensive ranching system will produce jointly milk and beef together with pasture and meadow biodiversity in an open landscape. By providing farmers with incentive payments, public authorities try to encourage agricultural activities and technologies which produce as a joint-product more of these desirable environmental outputs. Agri-environmental measures extend beyond this first objective because the majority of them also promote technologies reducing the joint production of agricultural commodities and undesirable outputs such as pollution or resource degradation.

The underlying rationale of agri-environmental programs is that it is cheaper to produce environmental goods jointly with agricultural activities than separately. It therefore assumes that jointness of two outputs A and B is a source of cost reduction or economies of scope[1].

$$\text{Cost (A)} + \text{Cost (B)} > \text{Cost} (A \cup B).$$

Such cost sub-additivity (also called positive synergy) can be associated to different sources of interactions referred to in the literature on multi-output production as **(i) non allocable fixed input** (whose cost is then divided by the total quantity QA+QB produced) and as(ii) technical complementarity in the case of allocable inputs, which induces a reduction of the marginal cost of producing A when the production of B increases.

Although the literature focuses mostly on the jointness between agricultural and environmental outputs (Bonnieux et al, 2000; OECD 2001, Peelings and Polman, 2004), the case of jointness between non-commodity outputs (i.e. reduction of soil pollution AND promotion of insect biodiversity) is also very important to consider when designing agri-environmental programs (Havlik and al, 2006).

When an agri-environmental contract is signed between a French farmer and the French state, several environmental objectives are sought. However, the average cost of each contracted measure is evaluated independently of the whole package, regardless of existing cost synergies across measures. The farmer may therefore receive a payment –the sum of individual premia associated with each measure - which can exceed by far the true opportunity cost of the whole package in the case of positive synergy.

There are various sources of complementarities between two non agricultural outputs. (i) They can be due to physical or biological interdependencies. For example, by contracting on mechanical weeding to reduce herbicide use, soil texture and therefore soil moisture are improved and the opportunity cost of reducing irrigation is lower. A contract on rotational cropping and cover crop to limit soil erosion will also enrich the soil with nutrients and organic matter therefore reducing the yield loss associated with a contract on lower use of chemical fertilizers. (ii) Complementarities can also be due to non allocable fixed inputs: contracting an agri-environmental measure on the management of hay meadows imposes the purchase of specific machinery which can also be used when contracting on the maintenance of hedgerows. (iii) Last but not least, positive cost synergies are often observed due to the specificities of agri-environmental measures which are often action-based rather than outcome-based. In other words compliance is measured on the basis of the "action" (ie: change of technology, of practice, of varieties grown) rather than on the basis of the environmental outcome obtained. Actions stated in some agri-environmental measures are often very similar to actions required by other measures. In the French context, farmers in mountainous areas are allowed to contract simultaneously for biodiversity protection measures and for the agri-environmental grass premium *(PHAE)*, although actions undertaken in both cases are almost identical. Contracting separately the two contracts on different pieces of land may lead to less environmental gain and to a larger total cost than the sum of the two contracts on the same land.

[1] In fact, the literature on the jointness in multifunctional agriculture emphasises that a production possibility frontier (with agricultural output on one axis and environmental output on the other) most often displays an increasing segment expressing the complementarity between agriculture and environment, and a decreasing one capturing the competition between them (Havlik et al, 2006.)

No studies have examined how to adapt the contract allocation mechanism in order to take account of potential positive synergies due to jointness. This is the purpose of the following section

2. Multi-unit auctions of heterogeneous units

Multiple bids in multi-unit auctions are auctions in which the auctioneer wishes to sell or buy several units of the same good and bidders are allowed to submit bids in the form of demand schedules or, for procurement auctions, supply schedules. The FCC spectrum auctions have revived theoretical and empirical research on such auctions. It is now widely acknowledged that results from single-object auctions do not generally extend to the multi-unit objects case (Binmore and Swierzbinski 2000). It is also clear that most multi-unit auctions generate multiple equilibria, rendering intractable analytical solutions for optimum bidding. In spite of the difficulties, a number of structural properties of bidding strategies have been predicted and verified through experimental work. Noussair (1995), and Engelbrecht-Wiggans and Kahn (1998a) have shown that in a uniform-price auction, bidders tend to be sincere on the first unit (their bid is close to their true valuation) and then to underbid increasingly on the subsequent units. This is called demand reduction and is explained by the fact that this strategy helps driving down the price of the last winning unit and therefore the price of all units won. On the other hand, Engelbrecht-Wiggans and Kahn (1998b) and Krishna (2002) show that there is an incentive, in a pay-as-bid format, to submit flat bidding schedules, under the true demand curve. All these results concern auctions of identical units.

One branch of the multi-unit auction literature, focuses on the case when units are heterogenous (Cramton 1997, Milgrom 2000). It may happen then that bidders have preferences over specific bundles of units. The most well-known example is the auctioning off of landing and take-off slots in airports (Rassenti, Smith and Bulfin, 1982). An air company is only interested in winning a specific landing slot provided it can be sure to win the corresponding flight-compatible take-off slot. Winning one of the two slots only is worthless. Another example is synergies in costs or complementarities in demand. In such cases, allocating units simultaneously or sequentially might lead to losses for bidders because they face the risk to win an undesired combination of units and to pay a price higher than their valuations. This is called the exposure problem (Bykowsky et al, 2000) The combinatorial auction, by allowing bidders to bid on all desired bundles of units, eliminates this risk.

A simple example can help understand the exposure risk: assume that the auctioneer wishes to buy two items A and B, in a sealed-bid pay-your-bid procurement auction with several competing bidders. All bidders can produce A and B, for different production costs. Production costs are private information and are independent of the other bidders' behaviours in the auction. Assume that cost functions display positive synergies (or sub-additivity properties): for each bidder, the cost of producing A and B simultaneously is lower than the costs of producing A and B separately.
For all i, $C_i(A) + C_i(B) > C_i(A \cup B)$ with $C_i(Z)$ production cost of item Z, Z=A, B or $A \cup B$

In a simultaneous auction, bidders can only make bids on A and B separately. They run the risk to win A without B or vice versa, therefore foregoing the benefits of cost sub-additivity. The risk of loss is even greater if they have adopted an underbidding strategy in order to increase their chance of winning the two units. For example assume that the production cost C of bidder i is 20 for unit A, 10 for unit B and 24 if both units are produced together.
$C(A) + C(B) > C(A \cup B)$

Bidder i might decide to bid a price P(A) = 16 on unit A and P(B) = 9 on unit B. If he wins A and B, he will gain P(A)+P(B)- C(A∪B);= 1 . However it is a risky strategy since he may well win only unit A (unit B being awarded to a bidder with a lower bid for B) and therefore incur a loss P(A)-C(A) = -4.

The sequential auction partially reduces the exposure risk since bidders make their bid on unit B, knowing the results of the contest for unit A. However, it does not eliminate exposure risk. The same bidder i may take the risk to underbid on unit A in order to maximise his chances of winning it , in the hope of winning also unit B and benefit of the synergy effect. Assuming again that he bids P(A)=16 on unit A and wins it. He then enters the second auction without uncertainties about the allocation of A. But he may bid P(B) = 9 on unit B and loose, therefore suffering the same loss as in the simultaneous auction. On the other hand, if he has not won A, then he is typically in a situation of a single unit auction. The optimal bidding strategy (Vickrey 1961) is one of overbidding (P(B)>C(B) and overbidding is declining when the number of bidders increases.

With combinatorial auctions, bidders are allowed to submit bids on packages of units. It reduces the uncertainty that comes with multiple bids and eliminates the exposure problem. Bidder i can now make three separate bids: one on A, one on B, and one on the package A∪B. For example, he can bid P(A)=22, P(B) = 11 and P(A∪B) = 28. Provided the auctioneer is not allowed to select separate bids for A and B from the same bidder[2], it can be expected that the combinatorial auction improves the auction performance both in terms of budget expenses for the auctioneer and in terms of social efficiency (that is buying units A and B from the lowest-cost providers). However, it is worth mentioning that another strategic incentive can crop up since a bidder's bid on one bundle can compete with his own bids on other bundles. The benefit to bidder i from lowering his bid on unit A is that it increases his chance of winning A. But it lowers his net gains on unit A and it reduces his chance of winning the package A∪B.

The consequence of this strategic behaviour is that there are examples when the combinatorial auction leads to lower efficiency and greater expenses than the corresponding simultaneous or sequential auctions (Cantillon and Pesendorfer 2004). In fact there is no general theoretical result on whether a combinatorial first price auction performs better than simultaneous or sequential auctions, although partial analytical results are available (see Bikhchandani,1999; Chakraborty, 2004).

The lack of theoretical guidance as to general predictions concerning revenue and efficiency of multi-unit auction mechanisms in presence of synergies has called attention to the results obtained from laboratory experiments. In an experiment involving a human subject demanding two units bidding against computer rivals, Kagel and Levin (2005) have investigated the tension between demand reduction and positive synergies, comparing sealed-bid and ascending-bid uniform-price auctions. They show that for low valuations, demand reduction behaviour dominates, therefore inducing underbidding strategies. For higher valuation, the synergy force dominates, inducing bidders to increase their bids in order to increase the chance of winning the package. It is more indeterminate at middle valuations.

[2] Alternatively, the bidder is compelled to place on a bundle a bid which is superior to the sum of the bids on individual units making the bundle (Cantillon and Pesendorfer 2003).

Leydyard, Porter and Rangel (1997) conduct test-bed experiments to respond to the following two questions in the case of heterogeneous items with synergies: Should items be auctioned off sequentially or simultaneously? Should package bidding be allowed? Their main conclusion is that, over a wide range of environments, package bidding mechanisms dominate simultaneous mechanisms which in turn dominate sequential mechanisms. They show that in environments with heterogeneous goods exhibiting complementarities, sequential auctions perform poorly. The simultaneous auction tends to produce outcomes that are either high in efficiency, revenue and losses or low in efficiency, revenue and losses. Package bidding seems to help in systematically attaining high efficiency, high revenue and no losses.

Our experiment is partially based on the work of Lunander and Nilsson (2004) who have compared the bidding behaviour for multiple contracts in the simultaneous, sequential and combinatorial formats. Their experiments show that efficiency is enhanced and procurement costs reduced by allowing combination bids.

Our analysis therefore attempts to complement his study on a simpler setting with a more careful analysis of data results. We do not address the issue of the equilibrium strategy for the sequential, simultaneous and combinatorial auction. Our research questions is to investigate the relative performance of the three different multi-unit auction format in the presence of positive cost synergies:
(i) To compare the budgetary efficiency and the allocative efficiency of sequential, simultaneous and combinatorial fist price sealed-bid auctions, for different degrees of positive synergy
(ii) To analyse the structural properties of bidding strategies under these three formats, in order to explain the differences in performance
(iii) To measure the impact on performance of information feedback (on winning bids) provided to bidders, in a context of repeated auctions.

Based on the literature review, we make the following hypothesis:
We first check that results provided by Leydyard, Porter and Rangel (1997) and Lunander and Nilsson (2004) are also valid in our experimental setting:
(i) Allocative efficiency is on average greater when combinatorial bidding is allowed than under the sequential and the simultaneous mechanisms.
(ii) Simultaneous and sequential auctions may lead to losses for auction winners to due the exposure issue. As a consequence, budgetary efficiency (from the auctioneer viewpoint) can be greater for simultaneous and for sequential auctions than for combinatorial auctions. This result should not hold if we only had risk averse bidders.
(iii) The preceding two results are more clear-cut when cost-synergy is greater
(iv) We also check the findings of Cox, Smith and Walker (1984) on information: as a side result of their pioneering experiments on bidding behaviour in multi-unit auctions, they mention that the feedback on winning bids in previous rounds has no significant impact on bidding strategies. Their justification is that it does not provide enough information to improve strategies.

The paper also provides a first analysis and comparison of bidding behaviour under the three bidding mechanisms.

3. Experiments and results

Experimental design

Each experimental session[3] (table 1) consisted of a series of auction periods where four subjects competed to sell two non identical projects A and B to the experimenter. Six non computerized sessions were conducted in 2006 with 14 periods each. In addition, two computerized sessions were conducted in 2007 with 34 periods each. The computerized experiment was programmed and conducted with the software ©z-Tree (Fischbacher 1999). Instructions and protocols were kept strictly identical to the non computerized sessions. The advantage of computerized experiments is mainly time gain, allowing to conduct a greater number of periods in the same time span (2 hours for a session).

The experiments were run under two different levels of synergies (i) low synergy and (ii) high synergy. Production costs for subject i and period t of project A $C_{i,t}(A)$ and of project B $C_{i,t}(B)$ varied across subjects and across periods but displayed the same level of synergy:

$C_{i,t}(A \cup B) = 0.7*(C_{i,t}(A) + C_{i,t}(B))$ for high synergy

$C_{i,t}(A \cup B) = 0.9*(C_{i,t}(A) + C_{i,t}(B))$ for low synergy

Private costs of A and B were randomly drawn for each subject in each auction period from a uniform distribution on the interval]0, 100]. At the beginning of a session, subjects were told that their costs for A and B were drawn from such a distribution. They also knew that they competed with three other subjects, also willing to sell two projects but they could not identify them. Each subject was given privately his costs for A, B and A∪B at the beginning of each period, and was then invited to bid.

All purchases were conducted with sealed bid pay-your-bid auctions. We have conducted three sessions using the simultaneous format, three sessions using the sequential format, and two sessions using a combinatorial auction.

- In the simultaneous auction, subjects were allowed to make two separate bids, one for project A and one for project B. The experimenter (or the computer) ranked the bids for A and for B and selected the lowest bid for project A and the lowest bid for project B. Subjects were privately informed whether they had won project A or project B or both . They were invited to calculate their gains. Then another period started with new costs being announced.
- In the sequential auction, subjects were first invited to bid on project A. The experimenter ranked the bids, selected the lowest bid and informed the winner. Then bidders were invited to bid on project B. The experimenter ranked the bids on project B, selected the lowest bid and informed the winner.
- In the combinatorial auction, subjects were invited to submit three bids, on A, on B and on A∪B. The experimenter (or computer) calculated the 12 sums of bids on A and bids on B (excluding thus the sum of bids on A and B submitted by the same bidder) and selected the lowest. This bid combination is compared to the lowest bid on A∪B. The lowest of the two indicates the winner(s), who is (are) then informed.

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[3] Experimental sessions were conducted with students from the University of Montpellier and from Montpellier-SupAgro. More sessions are planned in September to investigate negative synergy and to complete results.

In the first 7 (for non computerized sessions) or 17 periods (for computerized sessions), the winning bid was only communicated to the winner. In the last 7 or 17 periods, the value of the winning bid was made public but the identity of the winner was not revealed (except for the winner himself of course).

Table 1: Experimental design

Number of sessions	8	Two combinatorial sessions Three sequential sessions Three simultaneous sessions
Number of auction periods per session	14 or 34	In the first 7 or 17 periods, winning bids are not public information In the last 7 or 17 periods, winning bids are public information
Number of groups per session	2 or 4	Groups with low cost synergy (0.9) Groups with high cost synergy (0.7)
The combinatorial auction	First price sealed-bid	Subjects bid simultaneously on project A, project B and project (A∪B).
The sequential auction	First price sealed-bid	Subjects bid first on project A, then auction results are provided. Subjects then bid on project B, and auction results for project B are provided. There is no bid on the project (A∪B)
The simultaneous auction	First price sealed-bid	Subjects bid simultaneously on project A and project B. There is no bid on the project (A∪B)

Winners calculated their gains as follows: if a bidder won either of the two projects, then his profit was equal to the difference between his winning bid and his cost for the winning project:

$\pi(A) = M(A) - C(A)$ for project A

$\pi(B) = M(B) - C(B)$ for project B

However, if he won the two projects, then his profit was equal to the difference between the sum of his winning bids on the two projects (for a simultaneous or a sequential auction) or his winning bid on the project A∪B (in the combinatorial auction) and the cost of project A∪B:

$\pi(A \cup B) = M(A) + M(B) - C(A \cup B)$ for the simultaneous or the sequential auction

$\pi(A \cup B) = M(A \cup B) - C(A \cup B)$ for the combinatorial auction

Gains were cumulated from one period to another. Total gains were paid at the end of each session, using an exchange rate of 10% (10 yens =1€). The average total gains is equal to 15 € per subjects to which was added a 10 euro show-up fee, for a two hour session.

Experimental results on auction performance

Analysing auction performance is a multi-dimensional task. In our paper we choose to analyse the allocation efficiency (AE) and the budgetary efficiency (BE).

Allocative efficiency is attained when projects are allocated to the lowest-cost producer(s), indicating thus that projects are produced at the lowest social cost. We calculate indicator AE as the ratio of the lowest attainable production cost to obtain projects A and B, to the

production costs of selected producers of projects A and B. If AE =1, allocative efficiency is maximized. The lower AE, the lower the allocative efficiency of the auction.
Budgetary efficiency is attained when the price paid by the auctioneer for a project(s) does not exceed the true production cost of the project(s). We calculate indicator BE as the ratio of the winning projects' costs to the winning projects' bids. If BE = 1, the price paid exactly compensates the costs: there is no information rent for the bidder. If BE <1, it indicates that the auctioneer is overpaying the project. The lower BE, the lower budget efficiency. It may happen that BE >1 : the auctioneer pays less for the project than their true cost of production, and winners suffer a loss. This is the exposure problem already mentioned in the previous section.

$$AE = \frac{\min\left(\left(LPAC + LPBC\right), LPABC\right)}{WPC} \quad \text{and} \quad BE = \frac{WPC}{WBP}$$

where,
$LPAC$ is the project A's lowest cost
$LPBC$ is the project B' lowest cost
$LPABC$ is the project A∪B's lowest cost
WPC is the cost of winning project(s)
WBP is the tbid (or sum of bids) of winning project(s)

We are also concerned about whether or not there is a trade off between the two criteria, because it will have consequences for decision-makers when designing an agri-environmental auction (Miller and al, 2004). To ensure that its method for attaining environmental benefits meets other policy objectives or political constraints, policy makers may choose to sacrifice economic efficiency for reduced budget costs. In the current European context, where support for rural development for the 2007-2013 programmation period has planned a reduction of the European Agricultural Fund for Rural Development, governments may be tempted to adopt budgetary efficiency as a dominant criterion when auction design is determined. The loss in allocation efficiency may be small compared to the gain in budgetary efficiency.

Table 2 calculates average AE and BE scores -and their standard deviations- obtained in the three auctions mechanisms, for the two levels of synergy. It also indicates the number of periods when full allocative efficiency or full budgetary efficiency (including when BE>1) is observed. We test if this performance indicators differ significantly across auction mechanisms and across synergy levels using a 5% Wilcoxon rank-sum unmatched data test[4].

[4] We don't use Student test because sample size are unequals, some of observations don't verify the normal distribution and finally after using some equality variance tests, in most of the cases we reject the hypothesis that variances are equal.

Table 2: Performance criteria results across synergy and mechanisms

	High level			Low level		
Auction mechanism	**Simu**	**Seq**	**Combi**	**Simu**	**Seq**	**Combi**
Average AE	0.69	0.68	0.98	0.93	0.92	0.96
Average BE	0.94	0.99	0.89	0.88	1	0.92
Std dev AE	0.04	0.06	0.04	0.05	0.07	0.06
Std dev BE	0.19	0.21	0.1	0.07	0.41	0.07
Number of auctions for which AE=1	0	0	21	24	21	20
Number of auctions for which BE ≥1	26	48	1	4	27	4
Number of auctions	96	96	28	90	90	28

According to table 2, the combinatorial auction generated fully efficient allocations for both synergy levels in 70% of the experiments, compared to respectively 0% in the high synergy scenario and less than 30% in the low synergy scenario for the sequential and simultaneous auctions. Moreover, the average AE for combinatorial auction is close to one and greater than average AE obtained by simultaneous or sequential auctions. The results from Wilcoxon unmatched data test in table 3 confirm that the combinatorial auction leads to more efficient allocation than the sequential and simultaneous auctions for both synergy levels. Table 3 also show that the greater the level of synergy, the greater the allocation efficiency advantage of the combinatorial auction over the two other mechanisms.

Proposition 1: Allocation efficiency is enhanced by allowing combinatorial bidding as compared to sequential or simultaneous bidding

Average figures for budget efficiency in table 2 show a different picture. The sequential auction displays the highest average BE, followed by the simultaneous auction. This is entirely due to exposure: by taking the risk to bid below cost in order to increase their chance to win a bundle (i.e. in the sequential auction, 20% and 17% of bids on project A and project B respectively were below-cost bids), bidders often end up winning an item and making a loss. It is equivalent to the well-known winner's curse of common value auctions. This is a short-term benefit for the auctioneer but it has to be underlined that in a real agri-environmental auction, such outcome would not be welcome since it is likely to lead to unsatisfaction with the auctioning procedure, increasing distrust from farmers, and a drop-off of participation rate in subsequent auctions. The Wilcoxon unmatched data test in table 3 demonstrates that the sequential auction does lead to higher budget efficiency than the simultaneous auction and that the combinatorial auction does not display greater budgetary efficiency than the two other mechanisms.

Proposition 2: the sequential auction leads to greater budgetary efficiency than the simultaneous auction for both levels of synergy
Proposition 3: the combinatorial auction does not display greater budgetary efficiency than the simultaneous auction.

Comparing performance across synergy levels, we find that allocation efficiency of the combinatorial auction is relatively insensitive to synergy levels. On the other hand, allocative efficiency of the simultaneous and sequential auctions is greater when synergy levels are low.

Table 3: Wilcoxon unmatched data test for performance criteria

		AE z-statistics	BE z-statistics	Observations
Across mechanism	**LS**			
	Seq - Sim	-0.8	3.82**	180
	Sim - Combi	-3.44**	-1.66	118
	Seq - Combi	-3.82**	1.3	118
	HS			
	Seq - Sim	-0.78	2.92**	192
	Sim - Combi	-8.04**	2.11*	124
	Seq - Combi	-8.04**	3.53**	124
Across synergy	HS Sim - LS Sim	-11.75**	3.09**	186
	HS Combi - LS Combi	0.43	-0.85	56
	HS Seq - LS Seq	-11.24**	2.25*	186

** significantly different at 99% confidence level
* significantly different at 95% confidence level
LS: low synergy HS high synergy
Seq: sequential auction Sim: simultaneous auction Combi: combinatorial auction

From the budget efficiency viewpoint, results are less clear. The budgetary efficiency does not vary significantly with the level of synergy in the case of the combinatorial auction. For simultaneous and sequential auctions, budgetary efficiency is greater for high levels of synergy.

Proposition 4: The performance (AE and BE) of the combinatorial auction is independent of the level of synergy.
Proposition 5: Simultaneous and sequential auction display greater allocative efficiency and lower budgetary efficiency when synergy levels are low.

Tables 4 and 5 compare performance criteria in the presence or not of feedback information on winning bids. Although slight differences can be detected, the Wilcoxon matched data test demonstrates that the information feedback does not have any significant effect on the average allocation ad budgetary efficiency for the three auctions formats. The only exception is for the combinatorial auction under high synergy, which displays a slightly higher budget efficiency when winning bids are made public than when winning bids remain private information. However, the test is only valid at 95% confidence level. More data are required to confirm or not this last result.

Proposition 5: Information feedback in the form of making available to all bidders the value of winning bids in previous auctions, does not significantly affect performance of the three auction mechanisms.

Table 4: Performance criteria across information for high synergy

	High synergy					
	Without information feedback			With information feedback		
Auction format	**Simu**	**Seq**	**Combi**	**Simu**	**Seq**	**Combi**
Average AE	0.69	0.68	0.98	0.68	0.67	0.97
Average BE	0.92	1.01	0.85	0.96	0.98	0.93
Std dev AE	0.03	0.04	0.03	0.05	0.07	0.05
Std dev BE	0.16	0.2	0.11	0.22	0.22	0.07
Number of auctions for which AE=1	0	0	10	0	0	11
Number of auctions for which BE ≥1	13	25	0	13	23	1
Observations	48	48	14	48	48	14
	Low synergy					
Auction format	**Simu**	**Seq**	**Combi**	**Simu**	**Seq**	**Combi**
Average AE	0.92	0.91	0.94	0.93	0.92	0.98
Average BE	0.88	1.05	0.92	0.88	0.96	0.91
Std dev AE	0.05	0.06	0.08	0.05	0.07	0.03
Std dev BE	0.08	0.59	0.05	0.07	0.14	0.08
Number of auctions for which AE=1	9	8	8	15	13	12
Number of auctions for which BE ≥1	4	14	1	0	14	3
Observations	42	42	14	48	48	14

Table 5: Wilcoxon matched data test for performance criteria

Across information	**EA z-statistics**	**EB z-statistics**	**Observations**
LS			
Sim Without - Sim With	-0.29	0.01	42
Seq Without - Seq With	-0.53	0.21	42
Combi Without - Combi With	-1.96*	0.53	14
HS			
Sim Without - Sim With	0.64	-0.37	48
Seq Without - Seq With	-0.08	0.44	48
Combi Without - Combi With	-0.23	-2.29*	14

** significantly different at 99% confidence level
* significantly different at 95% confidence level
LS: low synergy HS high synergy
Seq: sequential auction *Sim: simultaneous auction* *Combi: combinatorial auction*

Conclusion: from these preliminary results, we show that allocative efficiency is enhanced by allowing combinatorial bidding when compliance costs are subadditive, which is coherent with Lunander and Nilsson (2004). However, these results are obtained in a given set-up (bidders do not communicate, they know the distribution from which compliance costs are drawn, as well as the number of bidders and the number of rounds). Then generalisation from our results to the agri-environmental context should be drawn with these facts in mind.

Experimental results on bid patterns

From the analysis of bid results, we try to explain the bidding behavior and their main differences between the three auction mechanisms. We used panael data analysis. Tests show that the fixed effect model is the most robust.

We therefore estimated three fixed effect regression:

- $MA_{it} = a_1 + a_2 CA_{it} + a_3 CASYN_{it} + a_4 CAINFO_{it} + \varepsilon_{it}$

where MA_{it} and CA_{it} are respectively the bid and private cost for **project A** of subject i in auction period t, $CASYN_{it}$ and $CAINFO_{it}$ are slope dummy variables which are equal to CA_{it} when synergy level is low and when there is information feedback, zero otherwise. ε_{it} is an error term with the usual properties.

- $MB_{it} = b_1 + b_2 CB_{it} + b_3 CBSYN_{it} + a_4 CBINFO_{it} + b_5 CBGA_{it} + \varepsilon_{it}$

where MB_{it} and CB_{it} are respectively the bid and private cost for **project B** of subject i in auction period t, $CBSYN_{it}$ and $CBINFO_{it}$ are slope dummy variables which are equal to CB_{it} when synergy level is low and when there is information feedback, zero otherwise. $CBGA_{it}$ is a slope dummy variable used only for the sequential auction regression. It is equal to CB_{it} if the bidder has won the project A, zero otherwise. ε_{it} is an error term with the usual properties.

- $MAB_{it} = c_1 + c_2 CAB_{it} + c_3 CABSYN_{it} + c_4 CABINFO_{it} + c_5 CABGA_{it} + \varepsilon_{it}$

where MAB_{it} and CAB_{it} are the bid and private value for the project (A∪B) of subject i in auction period t. However, there is no bid for (A∪B) project in the sequential and simultaneous auctions. To be able to compare between auctions mechanisms, we have calculated $MAB_{it} = MA_{it} + MB_{it}$ and $CAB_{it} = CA_{it} + CB_{it}$ for the sequential and simultaneous auctions. $CABSYN_{it}$ and $CABINFO_{it}$ are slope dummy variables which are equal to CAB_{it} when synergy level is low and when there is information feedback, zero otherwise. $CABGA_{it}$ is a slope dummy variable used only for the sequential auction regression. It is equal to CAB_{it} if the bidder has won the project A, zero otherwise. ε_{it} is an error term with the usual properties.

In estimating these equations for each auction mechanism, our primary concern was with the sign and statistical significance of the slope coefficients. We also examined if bids line up with costs or not, by testing the equality to one of the estimated cost coefficients.
In the regressions, $\hat{a}_1, \hat{b}_1, \hat{c}_1$ indicate the fixed mark-up between bids and costs whereas $\hat{a}_2, \hat{b}_2, \hat{c}_2$ indicate the impact of project A's cost, project B's cost and project AB's cost on bid values. $\hat{a}_3, \hat{b}_3, \hat{c}_3$ provide a measure of the synergy's impact on each bidding behaviour and $\hat{a}_4, \hat{b}_4, \hat{c}_4$ provide a measure of the impact of feedback information on each bid function. $\hat{b}_5, \hat{c}_5$

indicate whether winning the fist unit has an impact on the bid strategy on the second project B in the sequential auction

Table 6 reports the results of fixed effect regression models for the project A. The slope coefficient $\hat{a}_2$ is significantly different from zero for the three auctions mechanisms and indicates that the greater the project A's costs, the greater the bid. Furthermore, it is significantly greater than one in the combinatorial auction and less than one in the sequential and simultaneous auctions. The intercept is also significantly greater than zero indicating a fixed mark-up between bids and costs which is greater for simultaneous auctions and lower for combinatorial auctions[5].

The statistical significance of CASYN slope dummy coefficient is only observed for the sequential and simultaneous auctions but with a different sign. In the simultaneous auction a negative $\hat{a}_3$ indicates that subjects bid less when synergy is lower. However, in the case of sequential auction, a lower synergy increases the bid.

Finally coefficient values for $\hat{a}_4$ are significant and negative for the simultaneous and combinatorial auctions, indicating that under feedback information, subjects decrease their bids.

Table 6: Auction outcomes for project A

	Simultaneous auction	**Sequential auction**	**Combinatorial auction**
Intercept	7.61**[6] (0.39)	6.26** (0.4)	5.12** 0.94
CA	0.97** (0.1)	0.87** (0.01)	1.06** (0.03)
CASYN	-0.07** (0.01)	0.05** (0.01)	-0.05 (0.04)
CAINFO	-0.03** (0.00)	-0.01 (0.00)	-0.05** (0.01)
R^2	94%	93%	92%
Observations	768	768	224

** significantly different at 99% confidence level
* significantly different at 95% confidence level

Table 7 provides regression results for bidding strategies on project B. For the three auction mechanisms, the slope coefficient $\hat{b}_2$ is significantly different from zero indicating that bids

[5] We have also tested for a different model in which we estimated the difference between bids and costs as a function of costs. However, this model did not provide statistical good results, indicating that the overbidding or underbidding strategies are not dependent on costs. This contradicts what is known for multi-unit auction optimal bidding and is currently being investigated further with more sophisticated econometric models.
[6] Significantly different from 0 at the 1% level

on B increase in project B's costs. The intercept remains high indicating an average fixed mark-up between bids and costs of more than 6.
The CBSYN dummy variable is only significatively different from zero in the simultaneous auction, indicating that subjects bid less when synergy is lower. The impact of information feedback is only significant for the simultaneous and combinatorial auctions and leads to a bid reduction. Finally, the coefficient $\hat{b}_4$ indicates that bidders who have won the project A in the first auction of the sequential mechanism tend to reduce their bid on B to increase their chance of winning the bundle.

Table 7: Auction outcomes for project B

	Simultaneous auction	Sequential auction	Combinatorial auction
Intercept	6.67** (0.93)	6.37** (0.88)	6.16** (1.64)
CB	0.99** (0.01)	0.94** (0.01)	1** (0.03)
CBSYN	-1.1** (0.02)	-0.01 (0.02)	0.01 (0.04)
CBINFO	-0.02** (0.00)	0 (0.00)	-0.03** (0.01)
CBGA	-	-0.1** (0.00)	-
R^2	87%	89%	90%
Observations	768	768	224

** significantly different at 99% confidence level
* significantly different at 95% confidence level

The fixed effect regression model results for bids on project (A∪B) is reported in Table 8. We do not claim to examine this regression for the sequential and simultaneous auctions given that bidding for the project (A∪B) is not allowed. However, we just use them to compare with the combinatorial auction. The slope coefficient $\hat{c}_2$ is strictly positive and close to 1. Moreover, the intercept $\hat{c}_1$ is significatively lower for the combinatorial auction than for the simultaneous or the sequential auction. We note also that neither synergy nor information have a significant impact on the project (A∪B) bid for the combinatorial auction. Combinatorial bidding is insensitive to the level of positive synergy and to the information feedback rules.

Table 8: Auctions outcomes for project AB[7]

	Simultaneous auction	Sequential auction	Combinatorial auction
Intercept	15.09**	14.16**	8.94**
	(1.23)	(4.29)	(3.14)
CAB	1.38**	1.29**	1**
	(0.02)	(0.07)	(0.05)
CABSYN	-0.38**	-0.27**	0
	(0.02)	(0.02)	(0.06)
CABINFO	-0.03**	0.01	-0.03
	(0.00)	(0.00)	(0.01)
CABGA	-	-0.1**	-
		(0.01)	
R^2	91%	92%	81%
Observations	768	768	224

** significantly different at 99% confidence level
* significantly different at 95% confidence level

4. Conclusion

The purpose of this work was (i) to compare the performance of different procurement auction designs in the case of multiple heterogeneous units which display positive synergy. The comparison was made by using two performance criteria: budget efficiency and allocative efficiency. We also testes if performance results are affected by information feedback to bidders after each auction period. (iii) to explain performance results by the analyses of bidding behaviour in the three mechanisms. Given insufficient theoretical guidance from the literature, this was done by means of controlled laboratory experiments.
Some clear conclusions emerge from this study. The first is that allowing combinatorial bidding enhances the allocation efficiency compared to sequential and simultaneous bidding. This result is close to the Ledyard et al's conclusion (1997). However the sequential auction leads to greater budget efficiency than the simultaneous auction for both levels of synergy. This is due to excessive risk exposure and is obtained at the expenses of bidders making losses. The second conclusion is that information feedback seems to have not effect on performance in any of the three auction mechanisms.
The third conclusion reports that in a simultaneous auction, subjects reduce their overbidding strategy when synergy is lower, while in the sequential auction they bid more on the first project and less on the second. Because of positive synergy effects, when a bidder wins the first project, he reduces in consequence his bid on the second project in order to increase his chance to win the bundle. Unlike these two auction mechanisms, the combinatorial bidding is insensitive to the level of positive synergy. The last conclusion indicates a less intuitive result. Even though information feedback does not affect performance criteria in the simultaneous and sequential auctions, the bidding behaviour models show that subjects decrease their bids,

[7] For sequential and simultaneous auctions we sum MA&MB , in order to compare with the combinatorial auction's MAB

in the presence of information feedback, on the two projects for the simultaneous auction and on the first project for the sequential auction.
The underlying rationale of using heterogeneous multi-unit auctions is the presence of potential positive synergy between agri-environmental measures. A special feature of agri-environmental multi-unit auctions are that several measures can be auctioned off simultaneously allowing submitting for combinatorial bids in addition to stand-alone bid or allowing sequential bid. However, the feasibility of combinatorial auction is more complex than the experimental auction. Actually more than two measures can be auctioned off for more than four farmers leading to a huge set of propositions. The number of propositions increase exponentially in the number of proposed measures and in the number of participating farmers. This is called the winner determination problem, whose resolution requires a complex computing and algorithmic consideration. Because of the exposure problem, the feasibility of sequential auction can induce farmers to losses and reduces their participations leading to insufficient environmental services.

This work was framed in the context of agri-environmental auctions but they are of interest in the general case of multi-unit auctions for the allocation of heterogeneous goods.

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