The economics of carbon sequestration: adverse selection, informational structure and delegation

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Abstract. This work analyzes incentive mechanisms designed to encourage carbon sequestration in agriculture in an asymmetric information context. First, the optimal contract under adverse selection is modeled. This model underlines the trade-off between information rents and efficiency. The impacts of finer informational structures, including the costs of identifying more homogeneous agro-ecozones, are then assessed. Finally, the consequences of delegating authority within the principal-agent relationship are investigated.

Keywords: carbon sequestration, contracts, adverse selection, information structure, delegation

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1. Introduction

In the design of climate change mitigation policies, greenhouse gas emissions are not the only available command variable. Carbon sequestration is also advocated as a potentially interesting means of providing efficient alternatives to abatements. The Kyoto protocol defines carbon sequestration as “the process or activities that allow to reduce the concentration of greenhouse gases into the atmosphere”. Articles 3.3 and 3.4 of the protocol cover activities like afforestation, deforestation and reforestation, but also agricultural land use changes. Carbon sequestration in agriculture could thus contribute to meeting the targets set by international agreements.

However, several aspects of carbon sequestration make the regulation and the monitoring more difficult than in the case of emissions. The processes underlying carbon sequestration either in soils or in above-ground biomass are well-documented and “carbon-friendly” agricultural practices are well identified. Yet, two major difficulties remain: (i) the dynamic nature of carbon sequestration, and (ii) the high sensitivity of carbon sequestration potentials to variables such as soil quality, climate and management practices (Arrouays et al., 2002). This paper focuses on the second aspect.

Besides, another important source of heterogeneity lies in the diversity of costs faced by farmers to adopt “carbon-friendly” practices. Stavins (1999) develops an econometric approach to reveal the farmers true costs to adopt such practices. However, it remains difficult for a regulator to know exactly these opportunity costs, leaving room for an adverse selection issue, where agents know their true characteristic, but the principal does not.

This text examines optimal contracts to encourage farmers to sequester more carbon. This choice fits the trend in agri-environmental policies, whereby voluntary, “carrot”-based instruments are often preferred over “stick”-based regulations, in particular when dealing with positive externalities[1]. When designing such contracts, one has to account for monitoring and control costs. Antle et al. (2003) compare the relative efficiency of per-hectare and per-tonne contracts. Per hectare, practice-based contracts are acknowledgedly easier to control, but less efficient. Antle et al. show that per-tonne contracts are almost always preferable. This is mainly due to the fact that farmers can opt for the most cost-effective practices, the induced cost-savings offsetting the total control costs[2],[3].

In this text, we emphasize the loss of efficiency induced by asymmetric information. We thus restrict the analysis to contracts that are based on the best available practices (afforestation, conservation tillage, grassland conversion, improved crop rotations, etc.) and focus on the information asymmetry in opportunity costs to adopt these practices. For the

[1] See for instance the “Sustainable Agriculture Contracts” offered to French farmers.
[2] The same kind of argument can also be found in Newell and Stavins (2003) for a more general case.
[3] Control costs are considered exogenous. However, control costs should be introduced in the core of the analysis. It would be possible to do so applying the main results of Bontems and Bourgeon (2003). This model deals with control costs as a new constraint in the incentive scheme, which modifies the shape of the contracts offered to farmers.

regulator, this asymmetry of information results in a trade-off between informational rents and efficiency. In a sense, our starting point is very similar with the one of **?** (**?**). However, as most of literature, they consider that the *ex ante* information the regulator has on the distribution of agents' private parameters is exogenous. Indeed, improving the quality of *ex ante* information can reduce the efficiency loss. In this paper, we will consider *ex ante* information as a command variable. There is a small and quite recent literature about the endogeneization of the informational structure.

Among the first articles, Lewis and Sappington (1991) analyze whether the regulator should encourage agents to improve their information. This action is welfare-improving when private information has a high collective value but has little effect on agents' own rent. Cremer and Khalil (1992) describe the agent's strategy when a contract is offered and when the relation between efforts and results is not perfectly known. Gathering information can lead agents to refuse a contract when they realize that production costs are too high. Nevertheless, gathering this information is costly, and the authors show that from a social viewpoint, it is better not to give the agents the opportunity to increase their information level. In the same line, the same authors have studied the consequences of the opportunity for agents to gather information before the contract is offered. As they show that gathering information is a mix strategy for agents, the principal will have to include both possibilities in her contracts. In a more recent work, Cremer et al. (1998) show that the possibility for agents to improve their information enables them to increase their bargaining power. Consequently, even the less efficient farmers will benefit from a rent. We also consider this article as relevant for its last sentence: "Should the regulator induce the agent to reveal his information or should she use her own resources to obtain it?"

Only a few articles analyze whether it is positive for the regulator to gather information before offering a contract. In Nosal (2003), the gathered information allows the regulator to avoid some investments that would be counter-productive, but it also includes some costs. The direct ones are costs of gathering information, but the author sheds the light on indirect ones. They will result from the reactions of agents to the fact that the principal holds more information. Finally, the overall costs can make the action of gathering *ex ante* information inefficient.

The present paper analyzes a one-stage screening situation, where contracts are offered to the agents, each agent choosing the one that fits best its characteristics. We need to define what an improved information is in that case. Following Laffont and Tirole (1993), the informational structure is considered finer when it allows a finer partition of the initial distribution in K sub-divisions. Consequently, in the document, gathering information is only a way to split the initial farmer distribution into K sub-divisions. We show that it induces an increase in the shape of the incentive schemes and in some cases higher efficiency.

Once the sub-divisions are created, it seems natural to introduce the possibility for the regulator to delegate her authority. The issue of delegation cannot be forgotten in a process as complex as carbon sequestration. It is also interesting to mix delegation and theory of incentives. However, our aim is not to prove whether delegation will be positive for carbon sequestration policies, but to emphasize the links between delegation and improved information. This underlines the conditions under which the impacts of delegation will be decisive on the efficiency of the project and when it will be a less important matter. We use the main results of the literature on the intrinsic interest of delegation. More precisely, we summarize the positive and negative impacts of delegation in a parameter. Then, the mixed effects of delegation and improved information are discussed, according to the value of this parameter.

The main assumption about the intrinsic efficiency of delegated authority is the revelation principle. When the menu of contracts induces auto-selection from agents, the process reveals, without any costs, the agent's private information to the regulator. It is not surprising that in those cases, delegation will not be more efficient than a centralized mechanism. However, this principle only holds if the following assumptions are made: no cost of communication between agents and principal; no cost for the principal to process information; no cost resulting from contracts complexity; no collusive behavior between agents; the principal's decisive commitment. It is when one or some of these assumptions are relaxed that delegation can be more efficient than a centralized mechanism.

Within the revelation principle, risk aversion from the delegated authority will induce inefficiency (Faure-Grimaud and Martimort (2001)). The uncertainty surrounding the amount of carbon sequestered can induce a cautious behavior from sub-principals. They may want to protect themselves against risks, which means that a rent has to be transfered to them, inducing inefficiency compared with a centralised mechanism. To avoid that kind of situation, Mookherjee and Reichelstein (1995) insist that the regulator has to know the outcomes exchanged between agents and the sub-principal. Indeed, the main regulator should avoid establishing liability constraints on the sub-principal.

Conversely, relaxing the assumptions of the revelation principle enables to reveal the benefits of delegation. For instance, Melumad et al. (1992) manage to modelize the advantages of holding local information. When the size of messages sent to the hierarchy is limited, there is a positive impact of local hierarchies. Furthermore, Poitevin (2000) deals with the renegotiation issue. It is an important question when the complexity of contracts does not allow to deal with all the aspects of a question. In that case, local organizations will be more incline to minimize the renegotiation burden.

Whatever the assumptions chosen, it is shown in this document that delegation impacts the policy through an indirect mechanism. As gathering information introduces more benefits for less efficient farmers, the constraints on the cost of delegation are less restrictive for those farmers than for the most efficient ones. In terms of environmental policy, it means that even when the regulator improves her information and manage to split the initial distribution in more homogeneous sub-distributions, she should avoid delegating authority for the most efficient farmers. Nevertheless, the direct benefits of isolating the less efficient ones are enough to bear a relatively costly delegation mechanism for those farmers.

The article is organized as follows. First, we present in section 2 the analytical model, from which optimal contracts are derived in a context of adverse selection and exogenous information. Contracts are proposed by a principal to many (a continuum of) agents. In this section, we put the emphasis on the trade-off between informational rents and efficiency (with a budget constraint). It then becomes natural for the regulator to ask herself whether or not it is efficient to improve her information on farmers' economical and technological characteristics, given that gathering this information is costly. This issue is addressed in section 3. Once the information is gathered, the regulator could be tempted to delegate the implementation of contracts. Section 4 is devoted to the way delegation modifies the relative efficiency of gathering information. Section 5 concludes.

2. The model

Consider a risk-neutral regulator. She seeks to encourage farmers to sequester carbon in the most efficient way. The objective of the regulator, like the one of the U.S. Department of Agriculture with the Environmental Quality Incentive Program (EQIP)[4], is to maximize the environmental benefits per euro invested. The farmers are represented by their disutility function that varies with the parameter θ ($\theta \in [\underline{\theta};\overline{\theta}]$). This parameter reflects the opportunity cost faced by each farmer to change its practices. In a sense, θ can be seen as a summary of technical and economical heterogeneities. The lower θ is, the lower the opportunity cost and then the higher the potential of carbon sequestration. The principal knows the overall distribution of farmers without knowing the specific value of θ for each farmer. The menu of contracts is built in such a way that farmers will reveal the true value of their opportunity cost. It will be in their interest to do so, and that will ensure the highest efficiency, for a given level of information. A contract $\{t(\theta), a(\theta)\}$ is thus offered. The contract consists in the obligation of adopting certain practices –summarized by the effort $a(\theta)$ and the transfer of a subsidy $t(\theta)$. Therefore, the principal maximizes her expected profits, summarized in the following expression :

$$\max_{a,\,t} \int_{\underline{\theta}}^{\overline{\theta}} [B(a(\theta)) - t(\theta)] g(\theta) d\theta \tag{1}$$

where $B(a)$ denotes the benefits for the regulator of an effort a[5], and g denotes the distribution of θ among farmers, with the usual properties[6].

In the design of the contract, the regulator faces two constraints. The first constraint is the individual rationality one. As the contract is optional, only farmers that have an

[4] See Cattanaeo (2003).

[5] We assume that $\frac{\partial B}{\partial \underline{a}} > 0$ and $\frac{\partial^2 B}{\partial a^2} \leq 0$

[6] $g(\theta) \in [0, 1]$ and $\int_{\underline{\theta}}^{\overline{\theta}} g(\theta) d\theta = 1$

interest in it will accept the principal's proposal. For the contract proposal to be accepted, the following condition has to be met:

$$t(\theta) - V(a(\theta), \theta) \geq U_0 \tag{2}$$

which means that the difference between the subsidy given to the farmer and her disutility $V(a(\theta), \theta)$[7] must be more important than U_0, where U_0 is the reservation utility, i.e. the utility that farmers get if they do not accept the proposal. Like in most papers, we choose to normalize this value to 0. An explanation could be found in the fact that the opportunity cost is summarized by the θ parameter[8].

The other constraint deals with what could make the policy inefficient. In fact, the regulator wants to avoid an imitative behavior from farmers, each farmer having to work at his best ability. To reach that objective, the contracts need to respect the following constraint:

$$t(\theta) - V(a(\theta), \theta) \geq t(\tilde{\theta}) - V(a(\tilde{\theta}), \theta),\ \forall \tilde{\theta} \in \Theta = [\underline{\theta}, \overline{\theta}] \tag{3}$$

We could have tried to solve the program based on that framework, but like other studies, we find easier and clearer to introduce the concept of informational rents: they are the difference between what farmers receive in a context of asymmetric information and what they would have received under the assumption of perfect information. Because in the perfect information case the principal would only offer to cover the costs of sequestration activities, we can infer that informational rents $R(\theta)$ are defined as:

$$R(\theta) = t(\theta) - V(a(\theta), \theta) \tag{4}$$

The problem can therefore be rewritten as follows:

$$\max_{a,\, R} \int_{\underline{\theta}}^{\overline{\theta}} \{B(a) - V(a(\theta), \theta) - R(\theta)\} g(\theta) d\theta \tag{5}$$

s.t.

$$R(\theta) \geq 0 \tag{6}$$

$$R(\theta) \geq R(\tilde{\theta}) + V(a(\tilde{\theta}), \tilde{\theta}) - V(a(\tilde{\theta}), \theta) \tag{7}$$

Annex 1 details the steps in the simplification of the constraints. The simplified version of the program can be written as follows:

$$\max_{a,\, R} \int_{\underline{\theta}}^{\overline{\theta}} \{B(a) - V(a(\theta), \theta) - R(\theta)\} g(\theta) d\theta \tag{8}$$

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[7] By assumption, $\frac{\partial V(a(\theta),\theta)}{\partial a} > 0$, $\frac{\partial V(a(\theta),\theta)}{\partial \theta} > 0$, and $\frac{\partial^2 V(a(\theta),\theta)}{\partial a^2} \geq 0$

[8] cf. Bourgeon et al. (1995) for an endogenised treatment of the reservation utility.

$$s.t.\quad \dot{R}(\theta) = -\frac{\partial V}{\partial \theta}(a(\theta), \theta) \tag{9}$$

$$\dot{a}(\theta) \leq 0 \tag{10}$$

$$R(\overline{\theta}) = 0 \tag{11}$$

Details of the solving steps of this problem are given in Annex 2. We go here straight to the main results of this solving, the equation that will help us to find the optimal level of efforts asked to each type of farmer. Then, informational rents, subsidies and the overall surplus can be deducted from the efforts asked. We can now present the expression of the implicit solution for the level of efforts asked to each type of farmers[9]:

$$B'(a) - \frac{\partial V}{\partial a} = \frac{G(\theta)}{g(\theta)} \frac{\partial^2 V}{\partial \theta \partial a} \tag{12}$$

Equation 12 shows the trade-off between rent extraction and efficiency. The optimal level of efforts is reached when the net marginal benefit of an incremental increase in the efforts equals the marginal cost of the informational rent. The cost of the informational rent is revealed by the fact that you need to increase the rents of $G(\theta)\%$ of farmers if you want to increase in one unit the efforts asked to type θ farmers.

PROPOSITION 1. *In a context of asymmetric information, the efforts asked to the farmers to sequester more carbon will always be lower than in a context of perfect information, except for type $\underline{\theta}$ farmers.*

Once the efforts are explicitly given, it is possible to infer each farmer's disutility for taking over these activities. That is all you need to deduce the value of informational rents, and then to calculate the transfers. However, as said in introduction, we have decided not to take as given the loss of efficiency coming from the potential imitative behavior of farmers. This will be the case when we endogenise the choice made by the regulator on her level of information.

3. A finer informational structure

3.1. General Case

Antle et al. (2003) raise the issue of the optimal spatial scale for the implementation of soil carbon contracts. In fact, the carbon sequestration issue is a situation where the policy-maker knows few things about farmers on their potential. She also knows that by doing

[9] We can add a double condition to be sure that all farmers will be associated to this policy. We want:

- $B'(0) = +\infty$
- $\lim_{a \to 0} B'(a)a = 0$

studies and more field work, it is possible to improve the information on farmers and then to reduce asymmetric information. In this section, we study the consequences of getting a finer informational structure on efforts and on the overall surplus of the policy[10]. In a sense, we follow the same intuitions than the real option theory can give (see **?** (**?**) about land use changes), but in a different context. It is shown that better information allows to ask more (or as much as before) to each farmer. It is also shown that the impact on the surplus created by each farmer can be counter-intuitive, because asking more to a farmer often requires to give her more rents. The overall impact remains unambiguously positive.

First, we assume that the information gathered allows the regulator to split the initial distribution of farmers into independent subdivisions. In other words, we are in the case of finer information as defined in introduction. Each farmer will be classified in one of these subdivisions, and contracts are specific[11]. To interpret this assumption, we would say that more information allows the regulator to reveal agro-ecozones, which are geographical areas with homogeneous soil characteristics. If the principal manage to know that a farmer belongs to a certain ecozone, then the farmer's disutility can be enclosed in a specific subdivision.

Ex ante, the principal wants to maximize the expected surplus that gathered information can allow. Therefore, in the case of two subdivisions, she wants to optimize the following program, subject to incentive and participation constraints, on each subdivision:

$$\max_{a,\,t} E(S) = g(1)\int_{\underline{\theta}}^{\theta_1}[B(a(\theta)) - t(\theta)]g(\theta/1)d\theta + g(2)\int_{\theta_1}^{\overline{\theta}}[B(a(\theta)) - t(\theta)]g(\theta/2)d\theta \quad (13)$$

s.t.

$$t(\theta) - V(a(\theta), \theta) \geq U_0,\ \forall\theta \in [\underline{\theta}; \overline{\theta}] \quad (14)$$

$$t(\theta) - V(a(\theta), \theta) \geq t(\tilde{\theta}) - V(a(\tilde{\theta}), \theta),\ \forall\,\tilde{\theta} \in \Theta = [\underline{\theta}, \theta_1] \quad (15)$$

$$t(\theta) - V(a(\theta), \theta) \geq t(\tilde{\theta}) - V(a(\tilde{\theta}), \theta),\ \forall\,\tilde{\theta} \in \Theta = [\theta_1, \overline{\theta}] \quad (16)$$

We then start by solving the model on each subdivision. First, Equation 13 shows that contracts are now fixed from conditional probabilities. So, density functions become:

$$g_i(\theta) = g(\theta/i) = \frac{g(\theta \cap i)}{g(i)} \quad (17)$$

where $g(i)$ is the probability to be in distribution i. Following the same methodology, the conditional distribution functions become:

$$G_i(\theta) = \int_{\underline{\theta}_i}^{\theta} g(\theta/i)d\theta \quad (18)$$

[10] cf. equation 1 to recall what the regulator's surplus is.

[11] This is the same mechanism than pricing in trains depending on the age of passengers.

The hazard rate, i.e. the $\frac{G(\theta)}{g(\theta)}$ ratio, will then be modified as follows:

$$\frac{G_i(\theta)}{g_i(\theta)} = \frac{G(\theta) - G(\underline{\theta}_i)}{g(\theta)} \tag{19}$$

As the segmentation of the initial distribution means that in each agro-ecozone, the most efficient farmer ($\underline{\theta}_i$) is closer to the other farmers, the hazard rate will always be lower than with the initial distribution, except for the most efficient farmers, who belong to the first subdivision and where $\underline{\theta}_i$ remains $\underline{\theta}$. Consider now the function ϕ_i defined as:

$$\phi_i(a_i, \theta) = \frac{\partial B}{\partial a_i} - \frac{\partial V}{\partial a_i} - \frac{G_i(\theta)}{g_i(\theta)} \frac{\partial^2 V}{\partial a_i \partial \theta} \tag{20}$$

At the equilibrium, that function is equal to zero. When the hazard rate $\frac{G_i(\theta)}{g_i(\theta)}$ decreases, as we have already made the assumptions that $\frac{\partial^2 B}{\partial a^2} \leq 0$, $\frac{\partial^2 V}{\partial a^2} > 0$ and $\frac{\partial^3 V}{\partial a^2 \partial \theta} > 0$, the optimal effort asked to each type of farmer must increase to respect the equilibrium condition.

This necessarily induces an increase in the disutility of farmers, because they have to produce more efforts. But the difference with benefits remains positive because farmers get closer to the efficient level. Then, the variation of surplus for each θ depends on the relative variation of information rent. In fact, two opposite effects appear. By definition:

$$R(\theta) = \int_{\theta}^{\bar{\theta}_i} \frac{\partial V(a(\theta), \theta)}{\partial \theta} d\theta \tag{21}$$

First, farmers can only imitate a type closer to their own one, which tends to reduce rents; but as efforts asked to each farmer increase, marginal disutility increases, pushing towards more information rents.

The impact of finer information on the surplus provided by each type of farmers could then be ambiguous, at least for some types[12]. Let us denote what this surplus is for an effort a and a type θ, in an agro-ecozone i:

$$s(a_i(\theta)) = B(a_i) - V(a_i(\theta), \theta) - \int_{\theta}^{\bar{\theta}_i} \frac{\partial V(a_i(\theta), \theta)}{\partial \theta} d\theta \tag{22}$$

It has to be compared with the surplus that that farmer produced with the initial available information. On the first subdivision, as $\underline{\theta}$ does not change, efforts asked do not change either. However, information rents are lowered due to not so many opportunities to imitate another farmer's characteristic. So, on the first subdivision, individual and collective surplus increase.

[12] As the Spence-Mirlees condition stipulates that the difference in opportunity costs of the efforts asked should be decreasing in type and effort, the only thing we are sure is that the slope of the information rent function is more important.

LEMMA 1. *Revealing the sub-division including the most efficient farmers always implies an increase in the surplus produced by those farmers, but only via a reduction in the cost of information, efforts being unchanged.*

The impact on the second subdivision is not as straightforward as on the first one. What is certain is that the net marginal benefit increases, due to increasing efforts getting farmers closer to the first-best. What is more counter-intuitive is that information rents increase. First, farmers are tempted to imitate the same type of farmers ($\overline{\theta}$) and second, as efforts are higher, disutilities are higher too. If the principal wants to avoid an imitative behavior, she has to give enough rents to compensate this potential disutility. In some cases, for farmers with the highest potential imitative behavior, this can lead to a lower net surplus, because more efforts have required too many rents.

LEMMA 2. *A finer information does not always imply an increase in the surplus produced by all types of farmers. In fact, information rents can more than compensate the higher efficiency of farmers.*

Proof: See the counter-example in next subsection.

However, what matters here is mainly a comparison between global surpluses, taking into account the overall impact of finer information. Actually, Equation 13 can be rewritten as to make appear the former objective function. First, if conditional probabilities are modified, the overall distribution remains the same, and then the density function does not change either. Consequently,

$$g(\theta \cap i) = g(i)g(\theta/i) = g(\theta) \tag{23}$$

This is due to the fact that the initial distribution has not changed, even after segmentation. So, the overall expected effort is calculated from the same densities:

$$\begin{aligned} E(S) &= \int_{\underline{\theta}}^{\theta_1} \Big\{[B(a(\theta)) - t(\theta)]g(\theta)\Big\}d\theta + \int_{\theta_1}^{\overline{\theta}} \Big\{[B(a(\theta)) - t(\theta)]g(\theta)\Big\}d\theta && (24) \\ &= \int_{\underline{\theta}}^{\overline{\theta}} \Big\{[B(a(\theta)) - t(\theta)]g(\theta)\Big\}d\theta && (25) \end{aligned}$$

So, the objective function remains the same, but subject to less restrictive conditions, because incentive constraints only have to be respected in each sub-division. For instance, efforts only have to be decreasing on each sub-segment. The following proposition can be sustained:

PROPOSITION 2. *When gathering information allows the regulator to obtain a finer informational structure, which means to reveal more homogeneous agro-ecozones, then this process intrinsically increases the regulator's surplus, before taking into account the cost of information.*

Proof: First, we have seen that on the first subdivision, surplus always increases due to less rents distributed. Therefore, we need to prove that the surplus never decreases on the second subdivision. Incentive constraints are meant to avoid lies from farmers, tempted to imitate less efficient farmers. As on that subdivision, farmers being likely to be imitated are the same than in the global distribution, the space of constraints is not more restrictive. Therefore, the principal could always decide to choose initial contracts if new ones are less efficient. By iteration, the same line of argument can be used whatever the number of subdivisions.

3.2. A specific case

In this subsection, we assume a uniform distribution between farmers. With that distribution, the hazard rate is simply equal to:

$$\frac{G(\theta)}{g(\theta)} = \theta - \underline{\theta} \tag{26}$$

Let us now denote:

$$V(a(\theta), \theta) = a(\theta)^2\theta \tag{27}$$

$$B(a(\theta)) = a(\theta) \tag{28}$$

Both functions respect the conditions to solve the model presented in the previous section. Despite their simplicity, they allow to describe the main effects of a finer informational structure. Given these functions and using Equation 12, the explicit function for the efforts asked according to the agent's type is the solution of:

$$1 - 2a(\theta)\theta = (\theta - \underline{\theta})2a(\theta) \tag{29}$$

which is:

$$a(\theta) = \frac{1}{4\theta - 2\underline{\theta}}, \ \ \forall\, \theta \in \Theta \tag{30}$$

One can easily see that the level of efforts asked to the farmers will increase with the value of $\underline{\theta}$. In other words, you can ask more to a farmer when the gap between his own parameter and the less important one of the subdivision is reduced. It is exactly what the segmentation of the distribution introduces, except on the first subdivision. From this function, explicit functions for disutility, informational rents and surplus can be deduced:

$$V(a(\theta), \theta) = \frac{\theta}{(4\theta - 2\underline{\theta})^2}, \ \ \forall\, \theta \in \Theta \tag{31}$$

$$R(\theta) = \frac{1}{4}\left(\frac{1}{4\theta - 2\underline{\theta}} - \frac{1}{4\bar{\theta} - 2\underline{\theta}}\right), \ \ \forall\, \theta \in \Theta \tag{32}$$

$$w(\theta) = \frac{1}{4(4\bar{\theta} - 2\underline{\theta})} + \frac{4\theta - 3\underline{\theta}}{2(4\theta - 2\underline{\theta})^2}, \ \ \forall\, \theta \in \Theta \tag{33}$$

We find again the results presented above. Each farmer's surplus of the first subdivision will increase, because the only impact will be via a lower $\overline{\theta}$. Conversely, on the second subdivision, there exists a $\tilde{\theta} \in [\theta_1; \overline{\theta}]$ for which lower values of θ lead to a reduction in the surplus. However, this will only concern a marginal number of farmers, and the overall surplus will always be increasing.

In order to illustrate the results, a simulation is now performed. The distribution of θ among farmers is assumed to be uniform between $\underline{\theta} = 1$ and $\overline{\theta} = 5$. The first stage of the simulation works from the overall interval (the black continuous lines) and then, we cut the segment into two equal sub-divisions (corresponding to the black-dotted lines) and then four smaller intervals (the black-dashed lines). As a comparison, we have also introduced what perfect competition would imply (the white continuous lines). This simulation will help us to present the main impacts expected from finer information. We had to solve the model at each stage like it has been done theoretically in the second section of this document. The main results of this simulation are presented graphically in Annex 2 and can be explained as follows.

Figure 1 shows that gathering information allows to require efforts to farmers closer to what the optimal level would be with perfect information. We still have an efforts curve decreasing within each subdivision but more information makes possible to ask more to farmers on each sub-division without taking the risk of an imitative behavior. This implies an increase in the farmers' disutility (as shown in Figure 2). However, subsidies are built to compensate this higher disutility. They also include informational rents, which will be lower for the first sub-division, higher for the last one, and uncertain for the intermediate distributions (Figure 3). It is interesting to note that the most efficient farmers on the intermediate subdivisions manage to receive higher informational rents than with less information. This can result, for some types, in a surplus lower than the one with less information. Nevertheless, the overall regulator's surplus, is always increasing in n (Figure 4).

This was only a first step in the regulator's strategy. She should now try to take into consideration the costs of gathering information. If we want to summarize what the regulator wants to solve, we would say that she seeks to optimize the following program:

$$P \begin{cases} \max_n & S(n) - C(n) \\ \text{s.t.} & B'(a) = \frac{\partial V}{\partial a} + \frac{G_i(\theta)}{g_i(\theta)} \frac{\partial^2 V}{\partial \theta \partial a} \\ & \forall \theta \in \Theta, \forall i \in N \end{cases}$$

where $S(n)$ gives the surplus of the policy as a function of the number of subdivisions and $C(n)$ represents the costs induced by the gathered information[13]. In other words, the regulator would want to improve her information as soon as the costs of gathering it is not more important than the benefits it induces. Moreover, this program states that

[13] One could argue that benefits could only be expected . In fact, the regulator decides to implement some studies without knowing ex ante what the real benefits will be, due to uncertainty in the accuracy of the results of the studies.

the equilibrium conditions need to be ensured on each of the subdivisions. Finally, it should be assumed that an optimal number of subdivisions can be reached, the marginal surplus created by a new subdivision decreasing and the marginal costs necessary to reveal this new subdivision increasing. The regulator needs to sharpen her diagnosis of the agronomical characteristics of farmers, notably to be able to discover geographical areas with homogeneous soil characteristics. All these costs will be highly increasing as the regulator wants to know farmers better and better. There should be a point where a new piece of information is useless, according to a cost-benefit analysis.

The last stage of the document is dedicated to the impact of delegation on efficiency. Once the regulator has revealed the number of subdivisions she judges optimal, it is still interesting for her to think about delegating authority. The consequences of that delegation are now studied.

4. Incentives and delegation

If there is a Common Agricultural Policy in Europe, most of policies are implemented via local authorities, to which the European Commission has delegated power. Here, we study the consequences of the potential creation of local *ad hoc* institutions, based in each revealed agro-ecozone. The authorities will be in charge of designing and implementing the contracts, and enforcing the results. Consequently, a third level is introduced in the principal-agent relationship.

As said in introduction, delegation can have positive or negative impacts in terms of efficiency, according to the assumptions chosen. We will not settle this dispute in this document. The aim is only to mix the impacts of delegation with the question of finer informational structure. Then, we will be able to reveal the more sensitive agroecozones to the impact of delegation on efficiency. In a first attempt to mix theory of incentives and transaction costs, Malin and Martimort (2000) model the impacts of a delegated authority as an alteration in the marginal costs of information. In fact, they see delegation as one among many transaction costs as soon as the Revelation Principle is not assumed. So, a new parameter, λ, modifies Equation 12 as follows:

$$B'(a) = \frac{\partial V}{\partial a} + \frac{G(\theta)}{g(\theta)}(1+\lambda)\frac{\partial^2 V}{\partial\theta\partial a} \tag{34}$$

When λ is positive, the delegated authority increases the marginal costs of information, and then favors the distribution of rents. When λ is negative, distortions are lowered. For a given effort, more or less rents are needed, according to the real value of delegation. λ is influenced by elements already mentioned in introduction:

$$\lambda = \Phi(\rho, \Delta\theta a) - \Psi(\mu, \nu, \omega) \tag{35}$$

where negative impacts of delegation in a revelation principle framework are reflected in the Φ function (ρ is the risk aversion of each sub-principal and $\Delta\theta a$ the relative importance of delegation, represented by the number of farmers and the amount of subsidies under the responsibility of the sub-principal). Conversely, Ψ will represent the impacts of delegation when the revelation principle cannot be applied, with μ taking into account the possibility of renegotiation, ν the reduction in communication costs and ω representing the loss of control for the principal.

However, impacts of delegation cannot be restricted to information rents. Choosing to introduce a third level in the principal-agent relationship can introduce a "deadweight loss of delegation" (**?** (?)). Therefore, we model delegation as an impact on each unit of transfer given to agents. We study the conditions under which delegation *and* subdivisions are worth the trouble for the principal. The trade-off is between contracting from the initial available information or delegating contracts to local institutions bringing more information.

First, we study the impact of delegation on the efforts asked to each type of farmers. We know that the marginal benefit of efforts is decreasing. So, asking more efforts to the agents imply $B'(a)$ lower than with the initial distribution. Using Equation 12, delegation increases efforts if and only if:

$$(1+\lambda)\left\{\frac{\partial V}{\partial a}+\frac{G_i(\theta)}{g_i(\theta)}\frac{\partial^2 V}{\partial\theta\partial a}\right\}<\frac{\partial V}{\partial a}+\frac{G(\theta)}{g(\theta)}\frac{\partial^2 V}{\partial\theta\partial a} \tag{36}$$

For the sake of simplicity, the results are presented using a a uniform distribution on the interval $[\underline{\theta};\overline{\theta}]$. We also suppose the regulator only splits the initial distribution into two sub-distributions. So, $\alpha\%$ of farmers from the former distribution belong to the first subdivision and $(1-\alpha)\%$ belong to the second one.

Because $\underline{\theta}$ does not change in the first subdivision compared with the initial situation, then the hazard rate does not change either. This means that in that subdivision, additional information do not help to increase efforts. Then, the only way of increasing efforts of the efficient farmers will be a positive impact from delegation.

The variations of efforts on the second sub-division is the result of a trade-off between delegation and segmentation. A few calculations lead to the following condition:

$$\frac{\lambda}{1+\lambda}<\alpha(\overline{\theta}-\underline{\theta})\left(\frac{\frac{\partial^2 V}{\partial\theta\partial a}}{\frac{\partial V}{\partial a}+(\theta-\underline{\theta})\frac{\partial^2 V}{\partial\theta\partial a}}\right) \tag{37}$$

This condition emphasizes, for a given λ, the variables decreasing the constraints on delegation and the ones increasing them. It can be shown that these variations would remain the same with more subdivisions. Consequently, we present the main results in the following proposition:

PROPOSITION 3. *For a given impact of delegation λ on the second sub-division, efforts increase more easily (i) the higher α; (ii) the wider the initial distribution; (iii) the lower*

θ. However, for a given θ, the impact of delegation is not changed whatever the initial efforts are.

The fact that initial efforts do not change the impacts of delegation is shown by deriving the term into brackets by a. The derivative is equal to zero whatever the disutility function.

What are the intuitions behind the results ? They all follow from the initial distortions. A wide initial distribution meant that farmers have very different opportunity costs. Therefore, being able to isolate some of them is very interesting for the principal, because the first set of contracts were designed to avoid imitative behavior from very different farmers. It is also straightforward to see that on the new sub-division, the contracts to the most efficient farmers will be close to the first-best. For those farmers, the indirect effect of delegation has to be huge to compensate the direct effect of increased information. At last, increasing α tends to reduce the width of the second sub-division. Therefore, distortions do not need to be so important. Once again, the direct effect dominates more easily the indirect one. On the other hand, the higher α, the wider the first subdivision will be. As efforts are not intrinsically increased in the first subdivision and as this subdivision gathers farmers with the highest potentials to sequester carbon, the size and the grouping of agroecozones will be a key issue about the efficiency (at least in terms of efforts) of the policy.

In order to generalize the previous conditions, it is possible to present the argument with n subdivisions ($[\underline{\theta}, \theta_1, ..., \theta_{n-1}, \overline{\theta}]$). So, gathering information and delegating authority will increase the efforts implemented by farmers if and only if[14]:

$$\lambda < (\underline{\theta}_i - \underline{\theta})\left(\frac{\frac{\partial^2 V}{\partial\theta\partial a}}{\frac{\partial V}{\partial a} + (\theta - \underline{\theta}_i)\frac{\partial^2 V}{\partial\theta\partial a}}\right) \tag{38}$$

If we assume that subdivisions are all of the same size, and when looking at the condition for the least efficient type in each subdivision, then it is immediate that the higher $\underline{\theta}_i$, the less restrictive the condition.

PROPOSITION 4. *As gathering information does not imply a similar impact on distortions between subdivisions, the optimal size and grouping of delegated authorities is the result of a trade-off between two antagonistic effects. First, the partition of the less efficient farmers in small groups can be done with a relatively costly delegation without interfering with the efficiency of the policy but this implies to leave in the same subdivision farmers with the highest potentials without being able to increase the efforts asked to those farmers.*

Despite the simplicity of the model and the number of assumptions (uniform distribution, segmentation in subdivisions without overlapping and equal in size), this text highlights some interesting features. For instance, we can see that conditions on the value of λ soften as we get further from the lowest opportunity cost farmers. This can be explained

[14] This condition follows from 36 but without explicitly presenting θ_i as a function of $(\underline{\theta}, \overline{\theta})$

by the fact that originally an important distortion had to be made for the highest ranks of opportunity costs to avoid an imitative behavior from other farmers. As it is now possible to discriminate, it becomes possible to increase the efforts asked to the highest categories. Then, the cost of delegation can be important without questioning the efficiency of the policy. The impact of the improved information furnishes a sufficient benefit compared with delegation costs.

We can infer that the regulator should focus on the lowest ranks where the most important efforts are asked. It is on those subsections that the cost of delegation will be a decisive criteria to evaluate the relative efficiency of segmentation and delegation. The impacts of delegation should be controlled strictly. On the other hand, the power on the agro-ecozones gathering the farmers with the highest opportunity costs could be delegated without having to worry about the potential negative consequences of delegation.

5. Concluding remarks

In this work, the links between information and efficiency in the case of a carbon sequestration policy are highlighted. The results show the key importance of endogenizing the informational structure in an optimal contractual policy. Gathering of *ex ante* information can thus be a strategic variable to reach an efficient eco-environmental policy. More field work, or more studies on carbon sequestration potential, could be, to some extent, a way to increase the efficiency of the policy even in a theory of incentives framework. We have also dealt with the impacts of a more complicated hierarchical structure and notably the necessity to split the effects according to the kind of agroecozone we observe. The setting-up of *ad hoc* institutions is a question that should be raised, notably in comparison with using existing ones, like national or regional administrations.

Further research is needed in several directions. First, using the same methodology than De Cara et al. (2004) in the case of greenhouse gas emissions, a spatial assessment of the costs of carbon sequestration should be done. This would help revealing the marginal cost curves of a sample of farmers and could provide a realistic calibration estimate of the distributions of the opportunity costs for building the optimal contract. Moreover, more work is needed in order to clarify the issue of enforcement of such a policy. Following the methodology proposed by Florens and Foucher (1999) in the case of oil pollution, further research could investigate the issue of optimal investment policy to control farmers. Various instruments are available to measure carbon sequestration, like remote sensing or sampling, and it would be relevant to endogenize farmers' responses to these instruments. Finally, Andersson and Richards (2001) recall that the carbon sequestration issue cannot be isolated from the treatment of emissions. A modification in the agent's behavior will have impacts on the efficiency of other policies. As an illustration, the effect of carbon-sequestration oriented policies on other sources of emissions (methane or nitrous oxide) remains unclear. Climate change is by nature a multi-pollutant issue that require multi-dimensional and comprehensive answers.

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Annex 1

To simplify the incentive constraint, we need to explicit the agents' program. They want to maximize the following expression:

$$\max_{\tilde{\theta}}\{t(\tilde{\theta}) - V(a(\tilde{\theta}), \theta)\} \tag{39}$$

As the regulator seeks to create the conditions under which the agents reveal their true types, and because she knows the program of the agent, she will want that:

$$\theta \in \arg\max_{\tilde{\theta}}\{t(\tilde{\theta}) - V(a(\tilde{\theta}), \theta)\} \tag{40}$$

The contract will then *reveal* the farmer's type. We suppose the functions $t(\theta)$, $a(\theta)$ and $R(\theta)$ are fully differentiable. We know that the first order condition of the agent's profit maximization is:

$$t'(\theta) - \frac{\partial V}{\partial a}(a(\theta), \theta)a'(\theta) = 0 \tag{41}$$

We also know that by definition of $R(\theta)$:

$$\begin{aligned}\frac{dR}{d\theta} &= [t'(\tilde{\theta}) - \frac{\partial V}{\partial a}(a(\tilde{\theta}), \theta)a'(\tilde{\theta})]_{\tilde{\theta}=\theta} \\ &- [\frac{\partial V}{\partial \theta}(a(\tilde{\theta}), \theta)]_{\tilde{\theta}=\theta}\end{aligned} \tag{42}$$

According to the first order condition of the profit maximization, the first term on the right hand side of this equation equals zero at the equilibrium. We then have:

$$\dot{R}(\theta) = -\frac{\partial V}{\partial \theta}(a(\theta), \theta) \tag{43}$$

The first order condition (41) should be true for each value of θ, which means:

$$\frac{d}{d\theta}[\frac{\partial \pi}{\partial \tilde{\theta}}]_{\tilde{\theta}=\theta} = 0 \tag{44}$$

which is equivalent to:

$$\frac{\partial^2 \pi}{\partial \theta^2} + \frac{\partial^2 \pi}{\partial \tilde{\theta}\partial \theta} = 0 \tag{45}$$

As the first term of the left hand side of this equation is necessarily negative (second order condition of profit maximization), we want the second one to be positive. We have:

$$\frac{\partial^2 \pi}{\partial \tilde{\theta} \partial \theta} = -\frac{\partial^2 V}{\partial a \partial \theta} a'(\theta) > 0 \tag{46}$$

This is the Spence-Mirrlees condition: it means that if we assume the marginal disutility of the effort increases (resp. decreases) with the type, we should also have decreasing (resp. increasing) efforts asked to the farmers. AS it is more coherent to assume an increase in the marginal disutility, we can rewrite the constraints as follows:

$$\dot{R}(\theta) = -\frac{\partial V}{\partial \theta}(a(\theta), \theta) \tag{47}$$

$$\dot{a}(\theta) \leq 0 \tag{48}$$

$$R(\theta) \geq 0 \tag{49}$$

As the rents are decreasing with the type and as the budget is limited for the regulator, the third constraint above can be rewritten as follows:

$$R(\overline{\theta}) = 0 \tag{50}$$

Annex 2

First, we begin by neglecting the second constraint (the one on the variation of the efforts asked given the type). We will have to check that this condition is respected at the end of the process. Let us recall what the surplus' function is:

$$S = \int_{\underline{\theta}}^{\overline{\theta}} [B(a) - V(a(\theta), \theta) - R(\theta)] g(\theta) d\theta \tag{51}$$

We can rewrite the last part of this integral as follows:

$$\int_{\underline{\theta}}^{\overline{\theta}} R(\theta) g(\theta) d\theta = [R(\theta) G(\theta)]_{\underline{\theta}}^{\overline{\theta}} - \int_{\underline{\theta}}^{\overline{\theta}} \dot{R}(\theta) G(\theta) d\theta \tag{52}$$

We can substitute $\dot{R}(\theta)$ by its value according to the first constraint of the program. Then, we have:

$$\int_{\underline{\theta}}^{\overline{\theta}} R(\theta) g(\theta) d\theta = 0 + \int_{\underline{\theta}}^{\overline{\theta}} \frac{\partial V(a(\theta), \theta)}{\partial \theta} G(\theta) d\theta \tag{53}$$

So, the program of the principal is:

$$S = \int_{\underline{\theta}}^{\overline{\theta}} \{[B(a) - V(a(\theta), \theta)] g(\theta) - \frac{\partial V(a(\theta), \theta)}{\partial \theta} G(\theta)\} d\theta \tag{54}$$

The First Order Conditions, for each θ, become:

$$[B'(a) - \frac{\partial V(a(\theta), \theta)}{\partial a}]g(\theta) - \frac{\partial^2 V}{\partial a \partial \theta} G(\theta) = 0 \tag{55}$$

Rearranging this expression, we obtain:

$$B'(a) - \frac{\partial V}{\partial a} = \frac{G(\theta)}{g(\theta)} \frac{\partial^2 V}{\partial \theta \partial a} \tag{56}$$

Differentiating the expression 55, we are going to determine sufficient conditions to respect the second constraint. We need:

$$[B''(a) - \frac{\partial^2 V}{\partial a^2} - \frac{G(\theta)}{g(\theta)} \frac{\partial^3 V}{\partial a^2 \partial \theta}]da = [\frac{\partial^2 V}{\partial a \partial \theta} + \frac{G(\theta)}{g(\theta)} \frac{\partial^3 V}{\partial a \partial \theta^2} + \frac{G(\theta)}{g(\theta)}' \frac{\partial^2 V}{\partial a \partial \theta}]d\theta \tag{57}$$

As we want the level of effort decreasing in θ, sufficient conditions for a solution to 57 are:

$$\frac{\partial^3 V}{\partial a^2 \partial \theta} \geq 0, \; and \; \frac{\partial^3 V}{\partial a \partial \theta^2} \geq 0 \tag{58}$$

The last condition to be sure that the constraint neglected in the solving process is respected is the monotonicity of the hazard rate ($\frac{G(\theta)}{g(\theta)}$), condition respected for most of unimodal distributions (cf. Bagnoli and Bergstrom (1989) for further explanations).

Annex 3

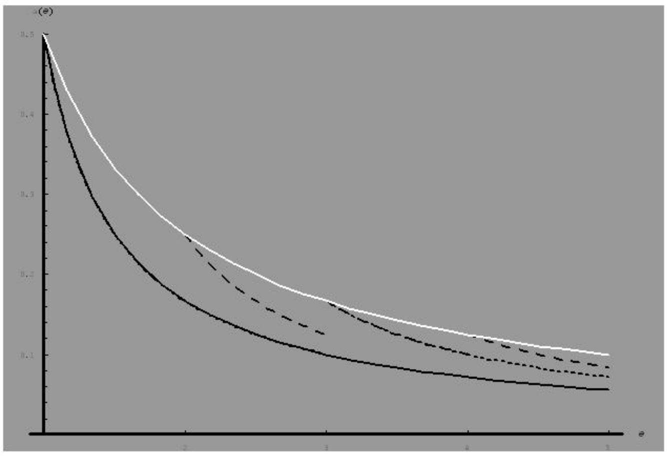

Figure 1. Efforts given types and information

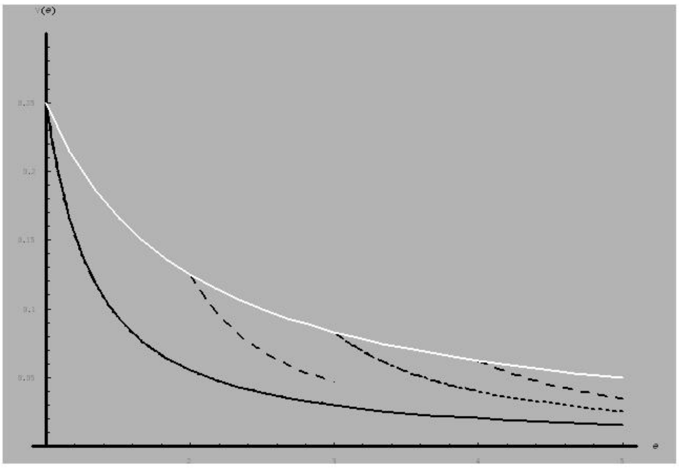

Figure 2. Disutility given types and information

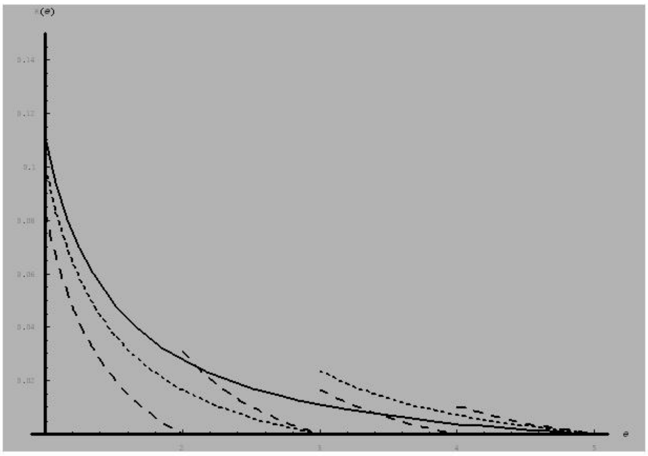

Figure 3. Informational rents given types and information

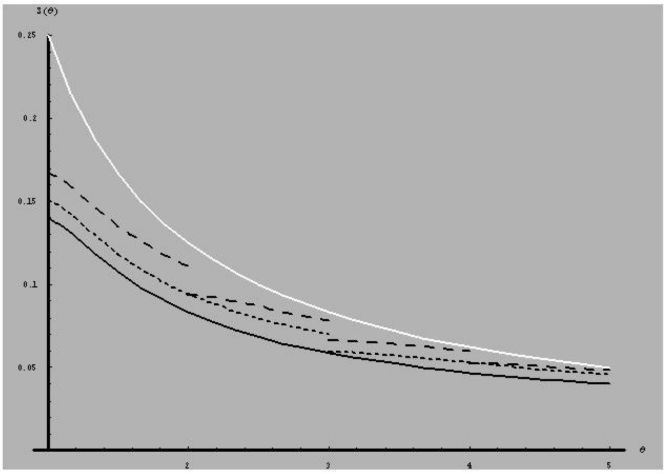

Figure 4. Surplus expected from different types and levels of information