ADVERSE SELECTION UNDER COMPLETE IGNORANCE*

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WP-AD 97-18

* The first version of this paper was done in D.E.L.T.A. (Paris). This research has been supported by DGICYT under Project PB92-0342.

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Editor: **Instituto Valenciano de Investigaciones Económicas, S.A.**
Primera Edición Junio 1997.
ISBN: 84-482-1519-2
Depósito Legal: V-2221-1997
Impreso por Key, S.A.
C/. Cardenal Benlloch, 69, 46021-Valencia.
Impreso en España.

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A B S T R A C T

We examine an adverse selection relationship in which the principal is unaware of the ex ante distribution of the agent's types. We show that the minimax regret mechanism, which is an incentive compatible and individually rational mechanism that minimizes the maximal principal's regret, requires the efficient agent to realize the corresponding first-best action and demands an action lower than the first-best one from the inefficient type. We prove also that the value of the minimal informational rent affects both, the optimal regrets and the distortion induced by the minimax regret mechanism.

KEYWORDS: Principal-Agent Problem; Adverse Selection; Minimax Regret Criterion.

1. Introduction

The aim of this paper is to examine the principal-agent relationship of adverse selection when the principal is unaware of the ex ante distribution of the agent's type, and uses a non-Bayesian criterion to choose the direct mechanism. For example, if the cost to obtain information about the productivity of a regulated firm is very high, a regulator may make decisions being ignorant of the efficiency of the firm. There are several theories of behaviour under uncertainty that use other than probability statements in their description (see Arrow (1951)). In this paper we use the argument put forward by Savage (1951) according to which some decision makers (statisticians or businessperson) are only responsible of making decisions as better as they can under the actual circumstances. Therefore, in our mechanism design problem, we assume that the principal uses the minimax regret criterion to choose the mechanism, and we obtain the best mechanism, from the principal's viewpoint, in that case. We also compare the properties of the agent's actions for that optimal mechanism with those of the usual adverse selection Bayesian model in which the principal maximizes his expected utility concerning an ex ante distribution of types.

There are two main differences between our approach and the standard one. On the one hand, mechanism design literature assumes commonly a Bayesian setting in which there exists a probability distribution of the agent's types representing the truthful ex ante distribution or common believes about the occurrence of types (see, for instance, Guesnerie and Laffont (1984)). In opposition to that assumption, our model assumes a stronger asymmetry of information: before contracting, the agent knows his proper type but the principal is only familiar with the support of types. On the other hand, standard models assume that the principal maximizes his expected utility. In opposition, we suppose that the principal uses the minimax regret criterion (suggested by Savage (1951)) to make his decision under complete ignorance. Such a criterion, which may be deduced from reasonable axioms (see Milnor (1954)) lies in minimizing the maximal decision maker's regret (see the chapter 13 of Luce and Raiffa (1957)).[1] To explain the minimax regret criterion in a general decision making context, assume that a decision maker has to make a decision, but his utility level for each decision depends on which state of the nature prevails. When the state is unobservable before the choice, the decision maker's regret associated with a decision at a given state is defined by the difference between the maximal utility that he would obtain under the given state if known, and the utility that he actually gets for the decision under the given state. This difference measures the regret that the

[1] Regret functions are also considered in remarkable works in Decision Theory as, for instance, in Kahneman and Tversky (1979) and Loomes and Sudgen (1982).

decision maker can suffer under a state when he has already made a decision. So, each feasible decision has a maximal regret for the decision maker's, and the minimax regret decision is the one that minimizes the maximal value of the regrets.

In our adverse selection setting, the principal, being ignorant of the agent's true type, offers contracts that are based on the verifiable agent's action (the agent's decision or performance). According to the general context of individual decision making under uncertainty, which we have described above, the principal would be the decision maker, the agent's type would correspond to the unobservable state of nature, and contracts would be the decisions. Since the taxation and revelation principles, in the mechanism design literature, do not depend on the principal's criterion to choose contracts, we consider, without loss of generality, that the principal proposes direct revelation mechanisms. We assume also that the principal is interested in hiring the agent and, therefore, feasible mechanisms verify individual rationality and incentive compatibility constraints. Following the above individual decision framework, we define the principal's regret, given a mechanism and a type, as the difference between the maximal utility, which the principal could get for that type, and the utility obtained with the mechanism, when the agent has the given type. Of course, the maximal utility that the principal may achieve, under a given type, is the level of his utility corresponding to the optimal mechanism under complete information. Therefore, in our individual decision making setting, in which the principal has to choose a mechanism under "complete ignorance," the principal will choose the mechanism that minimizes his maximal regret among all the mechanisms verifying the incentive compatibility and individual rationality constraints.

The agent's utility function is supposed to be separable. It is the difference between the agent's remuneration and a disutility function that depends only on his action and his type. We also assume the principal's utility function being the difference between a function, which depends on the agent's action and the agent's type, and the agent's remuneration multiplied by a positive parameter that represents the principal's preferences about the agent's welfare. The principal's utility function may depend on the agent's type in settings, as for example, in which the principal is a regulator and there is a shadow cost of public funds.

For simplicity, we assume a support of types with only two points. Since the agent's disutility increases with type, the lower point and the higher point are respectively denominated as "efficient type" and "inefficient type." So, for any feasible mechanism, the principal has two regrets, one at the efficient type and another one at the inefficient type. We also suppose conditions that guarantee the existence of an interior (first-best) solution under complete information.

Two important elements in the analysis are the principal's regrets, at the efficient and the inefficient type, under complete information. Each complete information regret is the difference between the corresponding first-best principal's utility level and the one obtained, under complete information, for an action and the respective type. Under complete information, the minimax regret criterion consists in minimizing the maximum of the two complete information regrets. So, under complete information, the minimax regret actions are the first-best ones and the optimal values of the complete information regrets are null. The essential fact for the analysis is that, under incomplete information, the principal's regret at a given type is the sum of the corresponding complete information regret with the corresponding agent's rent perceived by the principal. Therefore, under incomplete information, the principal's objective is to minimize the bigger of the principal's two regrets in the class of the incentive compatible and individually rational mechanisms.

Our first result concerns the levels of the agent's utility at the efficient and inefficient types. As in standard models, the minimax regret mechanism pays the inefficient agent the reservation utility because the principal may decrease his two regrets, at the efficient and the inefficient types, by diminishing the corresponding agent's utilities and keeping the validity of incentive compatibility constraints. Therefore, for the minimax regret mechanism, the principal's regret at the inefficient type coincides with the corresponding complete information regret.

The second result suggests that the minimax regret mechanism pays the efficient type the lower bound of the agent's utility that appears in the incentive compatibility constraint corresponding to the efficient type. As in standard models, this produces an informational rent (which depends only on the agent's action at the inefficient type) that is only received by the efficient agent. Therefore, for the minimax regret mechanism, the principal's regret at the efficient type is the corresponding complete information regret plus the informational rent perceived by the principal.

Then, our analysis shows that, under incomplete information, the principal has to consider essentially a distortion of the principal's objectives corresponding to complete information. The distortion induced by the hidden information consists in adding the informational rent perceived by the principal only to the complete information regret at the efficient type. We show that the minimization of the maximum of these principal's two (distorted) regrets is carried out in the space of the agent's actions for which the action at the inefficient type is lower than the one at the efficient type because feasible mechanisms are incentive compatible.

We prove that for the minimax regret mechanism there is not distortion at the top: the efficient type is asked for the optimal agent's action under complete information. On the contrary, it entails, for the inefficient type, an agent's action that is lower than the first-best one. The intuition is the following. Recall that, for the minimal regret mechanism, the principal's regret at the efficient type is equal to the corresponding complete information regret plus the respective agent's informational rent perceived by the principal, and his regret at the inefficient type coincides with the corresponding complete information regret. The minimax regret mechanism demands the first-best action from the efficient agent because, given an action for the inefficient agent, the principal's regret at the efficient type is the lowest possible if he requires the efficient type to perform the first-best action. After equalizing the action for the efficient type with the corresponding first-best one, the principal compares two elements: the perceived informational rent —which now is equal to the regret at the efficient type— and the complete information regret at the inefficient type —which coincides with the principal's regret. Since the informational rent function is positive and strictly increasing, the minimum of the maximal value of the above two elements is attained at an action that is strictly lower than first-best action at the inefficient type.

When the minimal informational rent is high enough, the distortion is the greater: for the minimax regret mechanism, the inefficient type is required to perform a null action. Moreover, for this mechanism, the principal's regret at the efficient type is strictly bigger than the one at the inefficient type. When the minimal informational rent is low enough, a positive action is demanded from the inefficient type. Now, for the minimax regret mechanism, the principal's regrets at the efficient and the inefficient type are the same and they are equal to the informational rent perceived by the principal. The intuition concerns the above two elements that the principal considers. If the minimal informational rent is very high, the first (informational rent) element prevails and the principal minimizes the informational rent function obtaining a null action for the inefficient type. This strong distortion is not so big as to suppress the very high principal's regret at the efficient type. Whenever the minimal information rent is very low, the sufficient distortion is lower. The principal's regret is the lowest if he selects the action (lower than the first-best one at the inefficient type) that equalizes the values of the above two elements because he tries to minimize the maximum of them.

Finally, in this paper we also compare the distortion —in the agent's action at the inefficient type— produced by the minimax regret mechanism with the corresponding one of the optimal mechanism for Bayesian settings. When the minimal informational rent is high enough, the minimax regret mechanism produces a distortion greater sometimes, or smaller in other cases, than the one usually obtained concerning an ex ante distribution of types. In an example of regulation, the reason is that if the probability of the efficient type is small, the Bayesian distortion has to be low and it may be lower than the minimax regret one. On the contrary, if the minimal informational rent is low enough, the produced distortion, in the minimax regret setting, is always strictly greater because the inefficient type is required to perform a null action.

The paper is organized as follows: In Section 2 the general model is presented. In Section 3 we obtain the minimax regret mechanism and we analyze its properties. Section 4 contains our conclusions.

2. The Model

The agent's utility function is:

$$V(x,t,\theta) = t - v(x,\theta) \tag{1}$$

where $x \geq 0$ is his action, $\theta \in \mathcal{R}$ is his type and $t \in \mathcal{R}$ is the transfer. We assume $\theta \in \{\theta_1, \theta_2\} \subset \mathcal{R}$ with $\theta_1 < \theta_2$. The agent's reservation utility is V_0.

The principal's utility function is:

$$U(x,t,\theta) = u(x,\theta) - \lambda t \tag{2}$$

where $\lambda > 0$ represents the principal's preferences about the agent's welfare or, in the regulation setting, for instance, reflects the cost of public funds.

In our setting, the revelation principle —see, for instance, Myerson (1981)— is satisfied because the principal criterion to select contracts is independent from the information revelation problem. So we can consider, without loss of generality, that the principal proposes direct revelation mechanisms for which the agent announces his true type.

Under complete information, for each θ observed by the principal, he maximizes the function (2) subject to the individual rationality constraint $V(x,t,\theta) \geq V_0$. This is equivalent to the pointwise maximization of the function

$$\Psi(\cdot,\theta) := u(\cdot,\theta) - \lambda v(\cdot,\theta) \tag{3}$$

Under incomplete information, the principal will propose mechanisms that verify incentive compatibility and individual rationality constraints. For notational simplicity, let $[x,t] \equiv [x_1, x_2, t_1, t_2]$, denote a feasible mechanism where the action asked for the agent is x_i if he announces θ_i ($i = 1, 2$), and t_i ($i = 1, 2$) are the corresponding transfers. We will denote de the agent's action function by $[x] \equiv [x_1, x_2]$. In this way, the principal offers mechanisms verifying the following constraints, for $i, j = 1, 2$, with $i \neq j$:

$$t_i - v(x_i, \theta_i) \geq t_j - v(x_j, \theta_i) \qquad (IC_i)$$

$$t_i - v(x_i, \theta_i) \geq V_0 \qquad (IR_i)$$

The first constraints prevent the agent from lying when he announces his type. The second ones are necessary for the participation of the agent.

We will assume that functions $u(\cdot, \cdot)$ and $v(\cdot, \cdot)$ are three times continuously differentiable and that they satisfy the following *regularity assumptions*:

$$\partial_\theta v(\cdot, \cdot) > 0, \quad \partial_{x\theta} v(\cdot, \cdot) > 0, \quad \partial_{xx\theta} v(\cdot, \cdot) \geq 0 \qquad (RA1)$$

$$\partial_\theta u(\cdot, \cdot) \leq 0, \quad \partial_{x\theta} u(\cdot, \cdot) \leq 0, \quad \partial_{xx\theta} u(\cdot, \cdot) \leq 0 \qquad (RA2)$$

$$\partial_{xx} \Psi(\cdot, \cdot) < 0, \quad \exists\, x_i^{CI} > 0 \; i = 1, 2 \quad / \quad \partial_x \Psi(x_i^{CI}, \theta_i) = 0 \qquad (RA3)$$

Assumption RA1 is composed of three conditions. The first one is the monotonicity of the agent's welfare in types (involving that any mechanism, which satisfies constraints IC_1 and IR_2, verifies IR_1). The second one is the Spence-Mirrlees condition —involving the compensation for a low-type agent must be lower than the corresponding one to a high-type agent, given a required increase in the agent's action. In the standard model, the third condition in RA1 implies that (with RA2) the solution of the substitute program is decreasing and then, implementable by means of a truthful direct-revelation mechanism —see, for instance, Fudenberg and Tirole (1991).

Assumption RA2 guarantees that the objective function of complete information, $\Psi(\cdot, \cdot)$, has the suitable properties for the good behaviour of optimization programs that we will define later. Note that RA2 is satisfied when $u(\cdot, \cdot)$ does not depend on types.

Assumption RA3 says that the optimal agent's action under complete information exists, is unique and interior. Such an action is denoted by $[x^{CI}] \equiv [x_1^{CI}, x_2^{CI}]$. We will write $\Psi_i^{CI} = \Psi(x_i^{CI}, \theta_i)$, $i = 1, 2$. Under RA3, the principal's optimal utility under complete information is $\Psi_i^{CI} - \lambda V_0$ when the realized type is θ_i, $i = 1, 2$.

For simplicity of the analysis, we will consider the following functions:

$$G_i(\cdot) := \Psi_i^{CI} - \Psi(\cdot, \theta_i), \quad i = 1, 2.$$

We can interpret the functions $G_i(\cdot),\ i = 1, 2$, as the complete information principal's regrets at types $\theta_i,\ i = 1, 2$, because each one is the difference between the maximal principal's utility for a given type and his utility, under complete information, when he demands an action from the agent with the given type. We will later see how these functions are related to the principal's regrets in the incomplete information setting. The informational rent function is given by:

$$\rho(\cdot) = v(\cdot, \theta_2) - v(\cdot, \theta_1).$$

Regularity assumptions are natural enough in the regulatory setting. The following example formulates the regulation, through the output, of a nonmarketed good.

Example 1 *Consider a firm producing a public good with a cost function*

$$C(x, \theta) = \theta x + f(\theta)$$

where θ is the marginal cost and the fixed cost $f(\theta)$ depends on the type θ. Let $S(x)$ be the consumers' surplus when the produced quantity is $x \geq 0$.

The regulator's objectives are

$$S(x) - t + (1 - \lambda)[t - C(x, \theta)],$$

i.e., the sum of the consumers' surplus net of transfers and the firm's utility multiplied by the coefficient $1 - \lambda$ $(0 < \lambda \leq 1)$ that represents distributional considerations (see, for example, Caillaud, Guesnerie, Rey and Tirole (1988)). We can adapt this problem to the general setting by using the following functions:

$$u(x, \theta) = S(x) - (1 - \lambda)C(x, \theta), \quad v(x, \theta) = C(x, \theta), \quad \Psi(x, \theta) = S(x) - C(x, \theta).$$

Thus, if the willingness to pay of consumers $P(\cdot) = S'(\cdot)$ verifies $\theta_1 < \theta_2 < P(0)$, $P'(\cdot) < 0$, $P(+\infty) = 0$, and if $f'(\cdot) > 0$ holds, the regularity assumptions are satisfied. We can easily obtain, for the present example, the first-best productions:

$$x_i^{CI} = P^{-1}(\theta_i), \ i = 1, 2,$$

the informational rent function:

$$\rho(x) = \Delta\theta x + \Delta f, \quad \textit{with } \Delta\theta = \theta_2 - \theta_1 > 0, \ \Delta f = f(\theta_2) - f(\theta_1) > 0,$$

and the complete information regulator's regrets:

$$G_i(x) = S(P^{-1}(\theta_i)) - \theta_i P^{-1}(\theta_i) - S(x) + \theta_i x \quad i = 1, 2.$$

In this example we can see that if the fixed cost is heavily increasing in types, the informational rent may be very high whereas the complete information regrets are independent of the fixed cost. This implies that, in the general setting, the minimal informational rent may be very high compared with the values of the complete information regrets.

The regularity assumptions imply "good" properties for the functions in the model. The following proposition gathers them.

Proposition 1 *Under the regularity assumptions, we have:*

(a) The optimal agent's actions under complete information $[x_1^{CI}, x_2^{CI}]$ *satisfy* $x_1^{CI} > x_2^{CI}$. *The principal's optimal expected utilities are* $\Psi_i^{CI} - \lambda V_0$, $i = 1, 2$ *verifying* $\Psi_1^{CI} > \Psi_2^{CI}$.

(b) $\rho(\cdot) > 0$, $\rho'(\cdot) > 0$, $\rho''(\cdot) \geq 0$.

(c) The functions $G_i(\cdot)$, $i = 1, 2$ *are* C^2 *and strictly convex, and they achieve its minimal values at* x_i^{CI}, $i = 1, 2$ *respectively, with* $G_i(x_i^{CI}) = 0$, $i = 1, 2$. *Moreover, they only intersect once.*

(d) The function $G_2(\cdot) - \lambda\rho(\cdot)$ *is strictly convex and* C^2 *and achieves its unique minimal value, which is negative, at a point* $z^* \in]x_2^{CI}, x_1^{CI}]$. *Moreover, there is a unique point* $q > z^*$ *such that* $G_2(q) - \lambda\rho(q) = 0$. *If* $G_2(0) \geq \lambda\rho(0)$, *there is a unique point* $p \geq 0$ *satisfying* $p < x_2^{CI}$, $G_2(p) - \lambda\rho(p) = 0$.

Proof: See Appendix 1.

It is known that (see, for instance, Guesnerie and Laffont (1984)) a given profile of actions is implementable (i.e., there is a transfer function such that, with the profile, forms an incentive compatible mechanism) if and only if the profile is a monotonic function of types, provided that both the type and the agent's actions are unidimensional. So, proposition 1(a) implies that the first-best solution is implementable. Moreover, it suggests that the first-best principal's utility at the efficient type be strictly greater than the one at the inefficient type. Proposition 1(b) shows that, as in standard adverse-selection models with a finite number of types, the informational rent function is positive, strictly increasing and convex. Proposition 1(c) points out that, under complete information, the minimax regret criterion leads to the first-best actions. In proposition 1(d), we can see that there always exists an action, which is higher than the complete information optimal action at the inefficient type, equalizing the corresponding complete information regret with the informational rent perceived by the principal. Moreover, there is another action that verifies also that equality, but it is lower than the above first-best action, when the minimal informational rent is low enough. These actions are important in the analysis.

The principal's regret functions and the minimax regret mechanisms are defined below.

Definition 1 *For the mechanism* $[x,t]$*, the principal's regret at the type* θ_i $(i = 1, 2)$ *is*

$$R_i([x,t]) = \Psi_i^{CI} - \lambda V_0 - [\, u(x_i, \theta_i) - \lambda t_i \,]$$

Definition 2 *A mechanism* $[x,t]$ *is a minimax regret mechanism if it is a solution of the program* MRP_0 *below.*

$$(MRP_0) \begin{cases} \min\limits_{[x,t]} \Big\{ \; \max\{\; R_1([x,t]), \; R_2([x,t]) \;\} \; \Big\} & \\ \qquad s.t. & \\ \qquad t_1 - v(x_1, \theta_1) \geq t_2 - v(x_2, \theta_1) & (IC_1) \\ \qquad t_2 - v(x_2, \theta_2) \geq t_1 - v(x_1, \theta_2) & (IC_2) \\ \qquad t_1 - v(x_1, \theta_1) \geq V_0 & (IR_1) \\ \qquad t_2 - v(x_2, \theta_2) \geq V_0 & (IR_2) \end{cases}$$

3. The minimax regret mechanism

In this section we will find the minimax regret mechanism, i.e., the solution of program MRP_0. To simplify, we will use the variables $V_i = t_i - v(x_i, \theta_i)$, $i = 1, 2$, and the functions $G_i(\cdot)$, $(i = 1, 2)$ and $\rho(\cdot)$. It is immediate that program MRP_0 is equivalent to the program MRP_1 below. Note that, as in the usual adverse selection models, constraint IR_1 is implied by constraints IC_1 and IR_2.

$$(MRP_1) \quad \begin{cases} \min\limits_{[x,V]} \max\Big\{G_1(x_1) + \lambda(V_1 - V_0),\ G_2(x_2) + \lambda(V_2 - V_0)\Big\} & \\ \qquad \text{s.t.} & \\ \qquad V_1 \geq V_2 + \rho(x_2) & (IC_1) \\ \qquad V_2 \geq V_1 - \rho(x_1) & (IC_2) \\ \qquad V_2 \geq V_0 & (IR_2) \end{cases}$$

Here it is important to remark that regrets and complete information regrets are related by the equalities:

$$R_i([x,t]) = G_i(x_i) + \lambda(V_i - V_0), \quad i = 1, 2. \tag{4}$$

This is the fundamental fact for the analysis.

We will denote $F(P)$ the set of feasible points of a general program P. The set of solutions of a program P will be denoted $S(P)$. The optimal value of a program P will be denoted $\Gamma(P)$. Trivially, we have $F(MRP_1) \neq \emptyset$. Lemma 1 below shows that program MRP_1 is equivalent to the program:

$$(MRP_2) \quad \begin{cases} \min\limits_{[x,V_1]} \max\Big\{G_1(x_1) + \lambda(V_1 - V_0),\ G_2(x_2)\Big\} & \\ \qquad \text{s.t.} & \\ \qquad V_1 \geq V_0 + \rho(x_2) & (IC_1) \\ \qquad V_1 \leq V_0 + \rho(x_1) & (IC_2) \end{cases}$$

The reason is that, as in standard models, constraint IR_2 is binding at the optimum. We can always decrease the agent's utility at the inefficient type up to the reservation utility, by diminishing in the same amount the agent's utilities V_1 and V_2, and keeping the validity of constraints IC_1 and IC_2. This procedure decreases both, the principal's regret at the efficient type and the one at the inefficient type.

Lemma 1
(a) If $[x,V] \in S(MRP_1)$, then $V_2 = V_0$ and $[x, V_1] \in S(MRP_2)$.
(b) If $[x, V_1] \in S(MRP_2)$, then $[x,V] \in S(MRP_1)$ with $V_2 = V_0$.

Proof: See Appendix 2.

Other standard result that will be verified in our model is that constraint IC_1 is binding at the optimum. Given a feasible point for program MRP_2, by decreasing the agent's utility at the efficient type up to the lower bound in constraint IC_1, the principal may maintain the validity of constraint IC_2 and decrease his regret at the efficient type. This justifies that program MRP_2 is equivalent to program MRP_3 below.

$$(MRP_3) \begin{cases} \min_{[x]} \max\Big\{G_1(x_1) + \lambda\rho(x_2),\ G_2(x_2)\Big\} \\ \quad \text{s.t.} \\ \quad x_2 \leq x_1 \end{cases}$$

The following lemma proves the above equivalence. Note that, given a solution of program MRP_2, lemma 2 implies that there is another solution for which constraint IC_1 is binding.

Lemma 2

(a) If $[x, V_1] \in S(MRP_2)$, then $[x] \in S(MRP_3)$.

(b) If $[x] \in S(MRP_3)$, then $[x, V_1] \in S(MRP_2)$ with $V_1 = V_0 + \rho(x_2)$.

Proof: See Appendix 3.

The results in previous lemmas are not surprising because the agent's utility, at the efficient and the inefficient type, increases the respective principal's regrets (see equalities (4)). To decrease both regrets, the principal pays the reservation utility to the inefficient type (lemma 1) because the incentive compatibility constraints allow it. To decrease the regret at the efficient type, he pays the efficient type as little as the incentive compatibility constraint corresponding to this type (IC_1) permits it (lemma 2). The produced informational rent, which is received by the efficient type, depends on the agent's action at the inefficient type.

The objective function of program MRP_3 will be denoted

$$F(x_1, x_2) := \max[\ G_1(x_1) + \lambda\rho(x_2),\ G_2(x_2)\ ].$$

We can interpret this function in terms of a distortion, caused by the agent's hidden information, of the complete information principal's objectives. If the information were complete, the minimax regret criterion would consist in the minimization of the maximum of the two complete information regrets $G_1(x_1)$ and $G_2(x_2)$. Note —see (4)— that this procedure leads us to the first-best solution $[x^{CI}]$. The distortion induced by the hidden information consists in adding the informational rent —which increases the rent of the efficient type— perceived by the principal to the principal's objectives under complete information. The essential feature of this distortion is that the perceived informational rent is added only to the principal's regret at the efficient type.

Fortunately, the function $F(x_1, x_2)$ has a strict minimum, and this unique minimum is a feasible point of program MRP_3.

Proposition 2 *The only solution $[x_1^*, x_2^*]$ of the program MRP_3 satisfies the properties below.*
(a) If $G_2(0) \leq \lambda\rho(0)$: $x_1^* = x_1^{CI}$, $x_2^* = 0$, $\Gamma(MRP_3) = \lambda\rho(0)$.
(b) If $G_2(0) > \lambda\rho(0)$: $x_1^* = x_1^{CI}$, $x_2^* = p$, $\Gamma(MRP_3) = \lambda\rho(p) = G_2(p)$, where p is the only positive point lower than x_2^{CI} that verifies $G_2(p) = \lambda\rho(p)$.

Proof: First, we prove that the function $F(\cdot, \cdot)$ has a strict minimum in $\mathcal{R}^2$. Since $G_1(x_1^{CI}) = 0 \leq G_1(\cdot)$, we have $F(x_1, x_2) \geq \max[\ \lambda\rho(x_2),\ G_2(x_2)\ ] := J(x_2)$.

Under $G_2(0) \leq \lambda\rho(0)$, the function $J(\cdot)$ verifies: $J(x) = \lambda\rho(x)$ for $x \in [0,\ q]$, and $J(x) = G_2(x)$ for $x \geq q$ (see the properties of $G_2(\cdot) - \lambda\rho(\cdot)$ in proposition 1). Because $R'(\cdot) > 0$, we obtain $J(\cdot) \geq J(0)$. Therefore,

$$F(x_1, x_2) \geq J(0) = \lambda\rho(0) = F(x_1^{CI}, 0).$$

Under $G_2(0) > \lambda\rho(0)$, we have that $J(x) = G_2(x)$ for $x \in [0,\ p]$, $J(x) = \lambda\rho(x)$ for $x \in [p,\ q]$, and $J(x) = G_2(x)$ for $x \geq q$ (see the properties of $G_2(\cdot) - \lambda\rho(\cdot)$ in proposition 1). Since $p < x_2^{CI} < q$ it follows that $J(\cdot) \geq J(p)$ and thus

$$F(x_1, x_2) \geq J(p) = \lambda\rho(p) = G_2(p) = F(x_1^{CI}, p).$$

Since $G_2''(\cdot) > 0$ and $R'(\cdot) > 0$, the function $J(\cdot)$ is strictly convex and the minimum of $F(\cdot, \cdot)$ is unique.

We can check immediately that points $(x_1^{CI}, 0)$ and (x_1^{CI}, p) satisfy the constraint of program MRP_3 in the cases $G_2(0) \leq \lambda\rho(0)$ and $G_2(0) > \lambda\rho(0)$ respectively.
Q.E.D.

Theorem 1 below shows that for the minimax regret mechanism there is not distortion at the top: the first-best action at the efficient type is demanded from the efficient type. On the contrary, for the minimax regret mechanism, the agent's action at the inefficient type is lower than the respective optimal one under complete information. The intuition is the following. If the information were complete the principal would minimize the maximum of the two complete information regrets, obtaining the first-best solution. For this solution, the agent's action at the efficient type is strictly greater than the one at the inefficient type and, therefore, it is incentive compatible. When the information is incomplete, only the efficient type receives the informational rent and, therefore, this rent increases only the principal's regret at the efficient type. So, for the minimax regret mechanism, the principal requires the first-best agent's action from the efficient type, because, given an action for the inefficient type, the principal's regret at the efficient type is the lowest possible if the agent's action at the efficient type is the respective first-best action. Next, the principal compares two factors: the perceived informational rent —which now coincides with the principal's regret at the efficient type— and the complete information regret at the inefficient type. If the minimal informational rent is high enough $[G_2(0) < \lambda\rho(0)]$ the first factor prevails and the principal chooses a null agent's action at the inefficient type (recall that the informational rent function is strictly increasing). When the minimal informational rent is low enough $[G_2(0) \geq \lambda\rho(0)]$ the principal chooses an action equalizing both factors because he tries to minimize the maximum value of them.

Theorem 1 *The minimax regret mechanism* $[x^{MR}, V^{MR}]$ *exists and is unique. It verifies*

(a) if $G_2(0) < \lambda\rho(0)$*:*

$$x_1^{MR} = x_1^{CI}, \quad x_2^{MR} = 0$$
$$V_1^{MR} = V_0 + \rho(0), \quad V_2^{MR} = V_0$$
$$R_1([x^{MR}, V^{MR}]) = \lambda\rho(0) > G_2(0) = R_2([x^{MR}, V^{MR}]).$$

(b) if $G_2(0) \geq \lambda\rho(0)$*:*

$$x_1^{MR} = x_1^{CI}, \quad x_2^{MR} = p$$
$$V_1^{MR} = V_0 + \rho(p), \quad V_2^{MR} = V_0$$
$$R_1([x^{MR}, V^{MR}]) = \lambda\rho(p) = G_2(p) = R_2([x^{MR}, V^{MR}]).$$

Proof:

(a) Assume $G_2(0) < \lambda\rho(0)$. Previous lemmas show that a solution $[x^{MR}, V^{MR}]$ of program MRP_1 has to verify $[x^{MR}] \in S(MRP_3)$ and, therefore, we have $x_1^{MR} = x_1^{CI}$ and $x_2^{MR} = 0$. From lemma 1, the equality $V_2^{MR} = V_0$ holds. From lemma 2, we obtain that $[x^{MR}, V_1]$ is also a solution of program MRP_2 if $V_1 = V_0 + \rho(0)$. Therefore, we have:

$$\max[\lambda(V_1^{MR} - V_0),\ G_2(0)] =$$
$$= \max[\lambda R(0),\ G_2(0)] = \lambda\rho(0) \geq$$
$$\geq \lambda(V_1^{MR} - V_0).$$

Since $[x^{MR}, V_1^{MR}]$ is feasible for program MRP_2, we have $V_1^{MR} - V_0 \geq \rho(0)$ and then, $V_1^{MR} = V_0 + \rho(0)$ holds. From the relation (4) between the regrets and the complete information regrets, we show easily that $R_1([x^{MR}, V^{MR}]) = \lambda\rho(0) > G_2(0) = R_2([x^{MR}, V^{MR}])$.

On the other hand, there is a unique solution of program MRP_3. This is $[x]$ such that $x_1 = x_1^{CI}$ and $x_2 = 0$. From previous lemmas, it follows that $[x, V]$, with $V_1 = V_0 + \lambda\rho(0)$ and $V_2 = V_0$, is a solution of MRP_1. So, the minimal regret mechanism exists, it is unique and it has the properties in the theorem.

(b) When $G_2(0) \geq \lambda\rho(0)$, there exists a point p (see proposition 1) for which $G_2(p) = \lambda\rho(p)$ and moreover $0 < p < x_2^{CI}$. By means of an argument similar to the one of part (a), we can prove that, in this second case the minimal regret mechanism also exists, it is unique and it has the properties in the theorem. **Q.E.D.**

Note that when the minimal informational rent is high enough, for the minimax regret mechanism, the principal's regret at the efficient type is strictly greater than the one at the inefficient type. The reason is that, here, the very high informational rent, which implies a very high principal's regret at the efficient type, dominates the principal's regret at the inefficient type. The principal prefers the minimal informational rent and then, he chooses a null action at the inefficient type. This strong distortion is not so big as to cancel the high principal's regret at the efficient type.

To compare the minimax regret solution with the one that is obtained in the Bayesian setting, in which the principal and the agent know the ex ante distribution of types, we will denote $\pi \in [0,\ 1[$ the probability of the efficient type.

For this later setting, the principal will maximize the expected utility

$$\pi[\ u(x_1, \theta_1) - \lambda t_1\ ] + (1 - \pi)[\ u(x_2, \theta_2) - \lambda t_2\ ]$$

under constraints IC_1, IC_2, IR_1, IR_2.

We can check easily that this is equivalent to the maximization of

$$\pi[\ \Psi(x_1, \theta_1) - \lambda\rho(x_2)\ ] + (1 - \pi)\Psi(x_2, \theta_2) - \lambda V_0$$

subject to the constraint $x_1 \geq x_2$.

Under regularity assumptions RA1, RA2 and RA3, if we suppose also

$$\partial_x \Psi(0, \theta_2) > \frac{\lambda \pi \rho'(0)}{1-\pi}, \tag{5}$$

the optimal agent's actions under incomplete information, in the Bayesian setting, exist and are interior. They are $x_1^B = x_1^{CI}$ and x_2^B verifying

$$\partial_x \Psi(x_2^B, \theta_2) = \frac{\lambda \pi \rho'(x_2^B)}{1-\pi}. \tag{6}$$

Moreover, we have $x_2^B < x_2^{CI} < x_1^{CI} = x_1^B$.

From Theorem 1, when the minimal informational rent is low enough $[G_2(0) > \lambda\rho(0)]$, the Bayesian predictions and the corresponding ones to the minimax regret mechanism are qualitatively similar. On the contrary, if the minimal informational rent is high enough, predictions are different.

Corollary 1 *Suppose the regularity assumptions, the condition (5) and a sufficiently high minimal informational rent $[G_2(0) < \lambda\rho(0)]$. Then the optimal agent's action under incomplete information, in the Bayesian setting, verifies $x_1^B = x_1^{CI}$, $x_2^B > 0$, but the minimax regret agent's action satisfies $x_1^{MR} = x_1^{CI}$, $x_2^{MR} = 0$.*

Proof: Form (6), the condition (5) implies $x_2^B > 0$. Theorem 1(a) implies the other equalities. **Q.E.D.**

Under a minimal informational rent that is low enough, the minimax regret mechanism may produce more o less distortion than the solution of incomplete information in the Bayesian setting. The following example gives an illustration of this fact.

Example 2 *Consider the particular case of Example 1 where the willingness to pay of consumers is $P(x) = S'(x) = a - x$, with $a > \theta_2 + \frac{\lambda\pi\Delta\theta}{1-\pi}$.*

We have $G_2(0) - \lambda\rho(0) = \frac{(a-\theta_2)^2}{2} - \lambda\Delta f$. Thus, in this example, $G_2(0) > \lambda\rho(0)$ suggests that the sales of the inefficient monopoly (without regulation) are greater than the social difference of fixed costs $\lambda[f(\theta_2) - f(\theta_1)] > 0$.

The optimal firm's productions in the Bayesian setting under

$$2\lambda\Delta f < (a-\theta_2)^2,$$

are:

$$x_1^B = a - \theta_1, \quad x_2^B = a - \theta_2 - \frac{\lambda\pi\Delta\theta}{1-\pi},$$

because, here,

$$\Psi(x,\theta) = \frac{a^2 - (a-x)^2}{2} - [\theta x + f(\theta)]$$

and, in consequence we have $\partial_x\Psi(0,\theta_2) = a - \theta_2$ *and* $\rho'(x) = \Delta\theta$, *which implies condition (5) in this particular case. The value of* x_2^B *is deduced from (6).*

The minimax regret productions, from Theorem 1(b), are:

$$x_1^{MR} = a - \theta_1, \quad x_2^{MR} = a - \theta_2 + \lambda\Delta\theta - \sqrt{(a-\theta_2+\lambda\Delta\theta)^2 - (a-\theta_2)^2 + 2\lambda\Delta f}.$$

The value of x_2^{MR} *is* p *verifying*

$$G_2(p) - \lambda\rho(p) = S(P^{-1}(\theta_2)) - \theta_2 P^{-1}(\theta_2) - S(p) + \theta_2 p - \lambda[\Delta\theta p + \Delta f] = 0,$$

considering that, here, we have $S(x) = \frac{a^2-(a-x)^2}{2}$ *and* $P^{-1}(z) = a - z$.

Therefore the minimax regret distortion is greater than the Bayesian one (i.e., $x_2^{MR} < x_2^B$*) if and only if:*

$$\pi < 1 - \sqrt{\frac{\lambda(\Delta\theta)^2}{\lambda(\Delta\theta)^2 + 2\Delta\theta(a-\theta_2) + 2\Delta f}}.$$

This example suggests the following intuition. If the probability of the efficient type is small, the Bayesian distortion has to be low because the importance of the inefficient type into the principal's objective function corresponding to the Bayesian setting decreases with this probability. Note that, from relation (6), the optimal action at the inefficient type in the Bayesian setting goes to the corresponding first-best action when π goes to zero. So, if the probability of the efficient type is low, the Bayesian distortion may be lower than the one in the minimax regret setting. If the probability is large, the distortion in the Bayesian setting will be bigger.

4. Conclusions

In this paper we examine an adverse selection relationship, between a principal and an agent, when the principal uses the minimax regret criterion to choose the mechanism under a complete ignorance of the two-point distribution of the agent's types. In this setting, the regret of a mechanism for a given type, is the difference between the maximal (complete information) utility, which the principal could obtain for that type, and the utility actually obtained with the mechanism at the given type. So, any mechanism has a maximal regret. Therefore, we assume that the principal will choose the mechanism, which satisfies the incentive compatibility and individual rationality constraints, with a minimal value for the maximum of the two regrets.

We show that for the minimax regret mechanism there is not distortion at the top: the efficient type is asked for the optimal agent's action under complete information. On the contrary, it entails an agent's action lower than the first-best one for the inefficient type.

When the minimal informational rent is high enough, we also show that the distortion is the greatest: the minimax regret mechanism asks the inefficient type for a null agent's action. Moreover, for this mechanism, the principal's regret at the efficient type is strictly bigger than the one at the inefficient type. When the minimal informational rent is low enough, for the minimax regret mechanism, a positive agent's action is required from the inefficient. Moreover, for this mechanism, the regrets at the efficient and at the inefficient type are the same and they are equal to the informational rent perceived by the principal.

If the minimal informational rent is low enough, the minimax regret mechanism may produce a distortion greater or smaller, according respectively to a low or high probability of the efficient type, than the one usually obtained concerning an ex ante distribution of types. On the contrary, if the minimal informational rent is sufficiently high, the distortion produced may be always strictly greater independently of the distribution considered in the Bayesian setting.

Appendix 1 *Proof of proposition 1*

(a) The optimal agent's actions under complete information are the solutions of the problem: $\max \Psi(\cdot, \theta)$ for $\theta = \theta_1, \theta_2$. Then, they are x_2^{CI}, x_1^{CI} from RA3. By RA1 we have $\partial_{x\theta}\Psi(\cdot,\cdot) < 0$ and therefore $0 = \partial_x \Psi(x_1^{CI}, \theta_1) > \partial_x \Psi(x_1^{CI}, \theta_2)$. This implies $x_1^{CI} > x_2^{CI}$ by RA3. From RA1 and RA2, we have $\partial_\theta \Psi(\cdot,\cdot) < 0$ and then $\Psi_1^{CI} - \Psi_2^{CI} > \Psi_1^{CI} - \Psi(x_2^{CI}, \theta_1) > 0$.

(b) From RA1, we have $\rho(\cdot) = v(\cdot, \theta_2) - v(\cdot, \theta_1) > 0$, $\rho'(\cdot) = \partial_x v(\cdot, \theta_2) - \partial_x v(\cdot, \theta_1) > 0$, $\rho''(\cdot) = \partial_{xx} v(\cdot, \theta_2) - \partial_{xx} v(\cdot, \theta_2) \geq 0$, because $\theta_2 > \theta_1$.

(c) From (a), the functions $G_1(\cdot)$ and $G_2(\cdot)$ are strictly convex, and they achieve its minimal values at x_1^{CI} and x_2^{CI} respectively, with $G_2(x_2^{CI}) = G_1(x_1^{CI}) = 0$. By RA1, we have $[G_1(\cdot)-G_2(\cdot)]' = \partial_x\Psi(\cdot,\theta_2)-\partial_x\Psi(\cdot,\theta_1) < 0$ and $G_1(x_2^{CI})-G_2(x_2^{CI}) > 0$, $G_1(x_1^{CI})-G_2(x_1^{CI}) < 0$. Then, the functions $G_1(\cdot)$ and $G_2(\cdot)$ intersect at only one point in $]x_2^{CI},\ x_1^{CI}[$.

(d) Consider the function $\Delta u(\cdot) := u(\cdot,\theta_1) - u(\cdot,\theta_2)$. By RA2 we have that $\Delta u(\cdot) \geq 0, \Delta u'(\cdot) \geq 0, \Delta u''(\cdot) \geq 0$. Since $G_2(\cdot)-\lambda\rho(\cdot) = G_1(\cdot)+\Delta u(\cdot)-\Psi_1^{CI}+\Psi_2^{CI}$, we obtain

$$[G_2(\cdot) - \lambda\rho(\cdot)]'' = G_1''(\cdot) + \Delta u''(\cdot) > 0, \quad G_2'(x_2^{CI}) - \lambda\rho'(x_2^{CI}) = -\lambda\rho'(x_2^{CI}) < 0$$
$$G_2'(x_1^{CI}) - \lambda\rho'(x_1^{CI}) = \Delta u'(x_1^{CI}) \geq 0$$

Then, there is only a point z^* verifying $G_2'(z^*) - \lambda\rho'(z^*) = 0$, and moreover, $z^* \in]x_2^{CI},\ x_1^{CI}]$. We have also $G_2(z^*) - \lambda\rho(z^*) < G_2(x_2^{CI}) - \lambda\rho(x_2^{CI}) = -\lambda\rho(x_2^{CI}) < 0$. Thus, there is a unique point $q > z^*$ such that $G_2(q) - \lambda\rho(q) = 0$. When $G_2(0) - \lambda\rho(0) \geq 0$ there is p such that $0 \leq p < z^*$ satisfying the equality $G_2(p) = \lambda\rho(p)$. Moreover, we have $p < x_2^{CI}$. **Q.E.D.**

Appendix 2 *Proof of Lemma 1*

(a) Consider $[x, V] \in S(MRP_1)$. If IR_2 were no binding for $[x, V]$, some mechanism $[x, V']$ with $V' = V - \epsilon$, $\epsilon > 0$, would be feasible for MRP_1 with a value of the objective function strictly lower than the corresponding one for $[x, V]$. Thus, $V_2 = V_0$ holds and then, $[x, V_1] \in F(MRP_2)$. If $[x, V_1] \notin S(MRP_2)$, there is $[x', V_1'] \in F(MRP_2)$ such that

$$\max[G_1(x_1') + \lambda(V_1' - V_0),\ G_2(x_2')] < \max[G_1(x_1) + \lambda(V_1 - V_0),\ G_2(x_2)].$$

So, we have $[x', V'] \in F(MRP_1)$, where $V_2' = V_0$, which contradicts that $[x, V]$ is optimal.

(b) Consider $[x, V_1] \in S(MRP_2)$. We have that $[x, V] \in F(MRP_1)$ where $V_2 = V_0$. If $[x, V] \notin S(MRP_1)$, there is $[x', V'] \in F(MRP_1)$ such that

$$\max[G_1(x_1') + \lambda(V_1' - V_0),\ G_2(x_2') + \lambda(V_2' - V_0)] <$$
$$\max[G_1(x_1) + \lambda(V_1 - V_0),\ G_2(x_2) - \lambda(V_2 - V_0)].$$

If IR_2 were no binding for $[x', V']$, applying the argument in part (a), there would be $[x'', V''] \in F(MRP_1)$ such that IR_2 would be binding and verifying the above strict inequality. Therefore, we can consider that, without loss of generality, IR_2 is binding at $[x', V']$. Since $[x', V_1'] \in F(MRP_2)$, this contradicts that $[x, V_1]$ is optimal. **Q.E.D.**

Appendix 3 *Proof of Lemma 2*

(a) Let $[x, V_1]$ be a point in $S(MRP_2)$. Evidently, we have $[x] \in F(MRP_3)$. Suppose that $[x] \notin S(MRP_3)$. Then, there exists $[x'] \in F(MRP_3)$ such that:

$$\max[G_1(x_1') + \lambda\rho(x_2'),\ G_2(x_2')] < \max[G_1(x_1) + \lambda\rho(x_2), G_2(x_2)].$$

Since $G_1(x_1) + \lambda(V_1 - V_0) \geq G_1(x_1) + \lambda\rho(x_2)$, we have:

$$\begin{aligned} &\max[G_1(x_1) + \lambda(V_1 - V_0),\ G_2(x_2)] \geq \\ \geq &\max[G_1(x_1) + \lambda\rho(x_2),\ G_2(x_2)] > \\ > &\max[G_1(x_1') + \lambda\rho(x_2'),\ G_2(x_2')] = \\ = &\max[G_1(x_1') + \lambda(V_1' - V_0),\ G_2(x_2')], \end{aligned}$$

where $V_1' = V_0 + \rho(x_2')$. Because $x_2' \leq x_1'$ and $R'(\cdot) > 0$, the relation $\rho(x_2') = V_1' - V_0 \leq \rho(x_1')$ holds and, in consequence, we obtain $[x', V_1'] \in F(MRP_2)$. This is impossible because $[x, V_1] \in S(MRP_2)$. Therefore, $[x] \in S(MRP_3)$ holds.

(b) Consider $[x] \in S(MRP_3)$. We have $[x, V_1] \in S(MRP_2)$ when $V_1 = V_0 + \rho(x_2)$ because $\rho(x_2) \leq \rho(x_1)$. Suppose $[x, V_1] \notin S(MRP_2)$. Then, there exists $[x', V_1'] \in F(MRP_2)$ such that:

$$\begin{aligned} &\max[G_1(x_1') + \lambda(V_1' - V_0),\ G_2(x_2')] < \\ < &\max[G_1(x_1) + \lambda\rho(x_2),\ G_2(x_2)]. \end{aligned}$$

Since $G_1(x_1') + \lambda(V_1' - V_0) \geq G_1(x_1') + \lambda\rho(x_2')$, we have:

$$\begin{aligned} &\max[G_1(x_1') + \lambda\rho(x_2'),\ G_2(x_2')] \leq \\ \leq &\max[G_1(x_1') + \lambda(V_1' - V_0),\ G_2(x_2')] < \\ < &\max[G_1(x_1) + \lambda\rho(x_2),\ G_2(x_2)]. \end{aligned}$$

Because $R'(\cdot) > 0$, we obtain $[x'] \in F(MRP_3)$ and this contradicts that $[x]$ is optimal. Therefore, we have $[x, V_1] \in S(MRP_2)$ with $V_1 = V_0 + \rho(x_2)$. **Q.E.D.**

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