Auction Design with Interdependent Valuations: The Generalized Revelation Principle, Efficiency, Full Surplus Extraction and Information Acquisition

Claudio Mezzetti
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Claudio Mezzetti, *Department of Economics, University of North Carolina at Chapel Hill and Department of Applied Mathematics, University of Venice*

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Summary

Agents' valuations are interdependent if they depend on the signals of all agents. Previous literature has claimed that with interdependent valuations and multidimensional, but independent, signals, efficient auction design is impossible. This paper shows that, on the contrary, it is always possible to find efficient auction mechanisms. Furthermore, it characterizes the conditions under which it is possible to extract the full surplus from the agents. Finally, it shows that it is also possible to provide agents with the incentives for the efficient, ex-ante acquisition of information. All these results rest on the application of a generalized version of the revelation principle, which requires that the designer uses two reporting stages.

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Address for correspondence:

Claudio Mezzetti
University of North Carolina
Department of Economics
Chapel Hill, NC 27599-3305
Phone: 919-966-5377
Fax: 919-966-4986
E-mail: mezzetti@email.unc.edu

1 Introduction

In the last 10 years there has been a burst of renewed interest in auctions and auction design. From the sale of new assets and the privatization of old companies, to the design of new markets, many important practical problems have provided empiricists with new data to study and theorists with interesting, open problems to solve.

From a theoretical standpoint, auction design should be viewed as part of mechanism design with transferable utility. The difference is that auctions typically deal with a discrete set of assets to be assigned to agents, while mechanism design allows more general decision sets. All the results in this paper apply to auction as well as to more general mechanism design problems; hence, I will use the terms 'auction' and 'mechanism' design interchangeably.

Consider the following basic setup. (1) There is a set of possible decisions affecting all the individuals (e.g., assets to be allocated); allocative externalities are allowed. (2) Each individual receives private signals (has private information) about his own characteristics, or type. An agent's type can be multidimensional, but it only affects the agent in question; that is, there are no informational externalities. (3) An agent's payoff depends on the decision and his own type in a general fashion and it also depend, linearly, on his own monetary transfer. The seminal contributions of Vickrey (1963) and later Clarke (1971) and Groves (1973) showed that in such a world efficient decisions (the ones that maximize the sum of agent's payoffs) can be implemented by using appropriate monetary transfers. The Vickrey-Clarke-Groves (VCG) mechanism accomplishes this by aligning every agent's payoff with social welfare. This is done, essentially, by using transfers that make each agent the residual claimant of the social surplus and then cover any deficit with additional charges that do not depend on his own behavior.

In many practical instances the assumption of private values, or no informational externalities, is violated. Informational externalities are present if the payoff of an agent depends not only on his own type, but also on the types (or informational signals) of the other agents. Following common usage, I will call this case the case of interdependent valuations. Among the many possible examples of interdependent valuations, consider the following three situations. First, a procedure must be set up to assign the mineral rights for a tract of land. Second, an existing company is either being acquired by one of several rivals, or it is going to be split among them. Third, a state-owned enterprise is being privatized. In all cases, it is highly likely that different parties have access to different informational signals that are relevant in making an efficient decision, some of which affect, possibly in different ways, all parties. Note also that in all these cases it is quite likely that the informational signals are multidimensional. For example, a firm bidding for a tract of land may have signals about the quantity and quality of the minerals to be found and about its own cost of extraction.

Interdependent valuations have been extensively studied in the auction literature that followed from Milgrom and Weber (1982). This literature, however, for the most part has restricted attention to symmetric bidders with a single dimensional informational signal and a single unit to be allocated among them. Furthermore, the focus has been more on the properties of specific auction procedures, than on the general design problem.

Recently, Maskin (1992), Dasgupta and Maskin (2000), and Jehiel and Moldovanu (2001) have generalized the VCG setup, by allowing for informational externalities. They demonstrated, in increasing generality, that if informational signals are multidimensional (or, if they are single dimensional but a single crossing condition is violated), statistically independent, and there are informational externalities, then the efficient decision rule cannot be implemented by any *standard* mechanism: incentive compatibility and efficiency are mutually exclusive.

Bergemann and Välimäki (2002) have looked at the case in which valuations are interdependent, but signals are single dimensional and a single crossing condition is satisfied. In this case there are *standard* mechanisms that implement the efficient decision rule. However, they showed that no such mechanism provides agents with the incentives for efficient ex-ante acquisition of information; agents either under-acquire, or over-acquire information.

The word *standard* is italicized for a good reason. In all these papers the mechanism designer is allowed to ask agents to report their types, as in a standard mechanism design problem with private values, but he is not allowed to ask agents to report their (pre-monetary transfer) payoffs from the decision *after* a decision has been taken. Clearly, at some point an agent will have to observe his payoff from a decision. With private values, an agent cannot extract any new information from the observation of his own payoff. On the contrary, with interdependent valuations observing his realized payoff provides the agent with new information about the types, or informational signals, of the other agents. The designer, then, should collect this information and use it. The transfers made to the agents should depend not only on the agents' reports of their types, but also on their reports of the decision payoffs. Restricting attention to standard mechanisms, with only type reports, is not without loss of generality when valuations are interdependent. This insight is the starting point of this paper.

I allow the mechanism designer to set up two reporting stages. In the first stage the designer asks about the agents' types. On the basis of these reports, the designer selects a decision. After the decision has taken effect, the designer asks the agents to report their realized payoffs in a second reporting stage. Then transfers are finalized that depend on reports in both stages. It turns out that allowing the transfers to depend on the payoff reports completely changes the conclusions of the model with interdependent valuations and multidimensional signals.

First, it is always possible to implement an efficient decision (it is also possible to balance the budget). Second, under some conditions the designer can extract the full surplus from the agents. A necessary and sufficient condition for full surplus extraction is provided in the paper. Third, it is always possible to implement the efficient decision and to provide agents with the correct incentives for efficient ex-ante acquisition of information.

A first pass at the intuition for my efficiency results is the following. The designer should implement the decision that is efficient given the signal reports of the agents in the first reporting stage. Each agent should be given as a transfer the sum of the reported payoffs by all other agents in the second reporting stage. This is sufficient to make the agent a residual claimant, and hence gives him the incentive to truthfully report his signals in the first reporting stage. We will see that the deficit so created can be covered by imposing charges on each agent that do not depend on his behavior. Furthermore, if there is an ex-ante stage when agents can aquire information, then they will acquire the efficient level, since each agent's incentives are aligned with the social good. In a sense that will be made precise later, the introduction of the payoff reporting stage after a decision has been made allows us to generalize the VCG mechanism to the case of interdependent valuations.

The condition that guarantees that the designer can extract the full surplus essentially says that any potentially profitable lie by an agent about his type in the first reporting stage should be detectable with positive probability from the payoff reports of the other agents. If this is so, then, when a lie is detected, the agent can be severely punished, making lying unprofitable.

It is important to emphasize that in this paper, as well as in the previous work by Maskin (1992), Dasgupta and Maskin (2000), Jehiel and Moldovanu (2001), and Bergemann and Välimäki (2002) (see also Ausubel (1997) and Perry and Reny (2002)) the agents' signals are statistically independent. The focus on independent types can be easily explained. We already know from Crémer and McLean (1985, 1988), McAfee and Reny (1992), and more recently McLean and Postlewaite (2001), that efficiency and full surplus extraction are possible under general conditions when there is correlation of types across agents.

The paper is organized as follows. The next section introduces the model and explains the inadequacy of standard mechanisms, by using three simple examples. Section 3 shows that the appropriate version of the revelation principle in a world with informational externalities requires that the designer ask agents to report their types in the first reporting stage, and ask them to report realized payoffs after a decision has been made, but before transfers are finalized. Section 4 shows that it is always possible to implement efficient mechanisms. Section 5 provides the necessary and sufficient condition for full surplus extraction. It also presents two versions of a model due to Jehiel and Moldovanu (2001), which show that full surplus extraction requires that no signal be purely private. Section 6 shows that it is possible to have both efficient ex-post decisions and efficient ex-ante acquisition of information. Section 7 concludes.

2 Inadequacy of the Standard Revelation Mechanisms

I study an auction, or, more generally, a mechanism design model with n agents. Each agent has private information about his own type $\theta_i \in \Theta_i$, where Θ_i is a closed and bounded subset of $\mathbb{R}^{m_i}$. Let $\Theta = \times_{i=1}^n \Theta_i$ be the set of type profiles and $\theta = (\theta_1, \ldots, \theta_n)$ be a generic element of Θ. Type θ_i is drawn from the cumulative probability distribution F_i with support Θ_i. In Section 3, I will derive a generalized version of the revelation principle without imposing any restriction on the distributions F_i; that is, I will allow for correlation across types of different agents. In all other sections I will assume that the distributions F_i are independent. Let X be the set of possible decisions, or outcomes (e.g., X could be a subset of an Euclidean space and represent the set of possible allocations of private and public goods). Agent i's payoff function $U_i : X \times \Theta \times \mathbb{R} \to \mathbb{R}$ depends on the decision x, the type profile θ and his monetary transfer t_i; we have

$$U_i(x, \theta, t_i) = u_i(x, \theta) + t_i.$$

I assume that the payoff function is linear in money and that it depends on the types of all agents. This latter assumption is what distinguishes the interdependent valuations case from that of private values, in which U_i only depends on θ_i. (Gresik (1991) was one of the first to study a mechanism design problem with interdependent valuations; Maskin (1992) and Dasgupta and Maskin (2000) use the terms "common values" and "interdependent valuations" interchangeably.)

To gain a simple intuitive understanding of this paper's contributions, it is best to start from the following examples.

Example 1. The first example is a simple modification of an example in Maskin (1992) and Dasgupta and Maskin (2000). There is an item for sale and two potential buyers (e.g., the item could be the right to drill oil on a tract of land and the buyers could be two wildcatters). The two buyers' valuations for the item are

$$\begin{aligned} u_1 &= 2\theta_1 \\ u_2 &= 4\theta_1 - 2 \end{aligned}$$

where $\theta_1 \in [0, 2]$ is a private signal of buyer 1 (his type). We can think of θ_1 as the expected quantity of oil in the tract, 2 and 4 as player 1 and 2's marginal revenues, and 0 and 2 as their fixed costs. Efficiency requires that buyer 1 get the item if $\theta_1 < 1$ and that buyer 2 get it if $\theta_1 > 1$. As in a standard mechanism design model, suppose that the transfers and the decision depend on the players' reports about their types. Let $t_1 : [0, 2] \to \mathbb{R}$ be buyer 1's transfer function and suppose that the decision rule is efficient; that is, the probability δ of giving the object to player 2 when θ_1^r is the reported type is

$$\delta^*(\theta_1^r) = \begin{cases} 0 & \text{if } \theta_1^r < 1 \\ 1 & \text{if } \theta_1^r > 1 \end{cases}$$

Letting $\theta_1' < 1 < \theta_1''$, incentive compatibility requires

$$2\theta_1' + t_1(\theta_1') \geq t_1(\theta_1'')$$

$$t_1(\theta_1'') \geq 2\theta_1'' + t_1(\theta_1')$$

which implies

$$\theta_1' \geq \theta_1'',$$

a contradiction. Maskin (1992) and Dasgupta and Maskin (2000) point out that the cause of the incompatibility between efficiency and incentive compatibility in this example is that $\partial u_1/\partial\theta_1 < \partial u_2/\partial\theta_1$. They show that if players types are single-dimensional, $\partial u_i/\partial\theta_i > 0$ for all i, and the "single crossing" condition $\partial u_i/\partial\theta_i > \partial u_j/\partial\theta_i$ holds for all i and $j \neq i$, then efficient standard mechanisms exist. (See also Ausubel (1997), Jehiel and Moldovanu (2001), Bergemann and Välimäki (2002), and Perry and Reny (2002).)

The next example shows that with multi-dimensional types there are no natural conditions that guarantee the existence of efficient standard mechanisms.

Example 2. As before, there are two players and one item for sale. The two players could be two bidders for a good, or a buyer and a seller. Player 1 has private information about two signals, $q \in [1, 2]$ and $c \in [0, 2]$ (e.g., q could be the quantity of oil in the tract whose drilling rights are for sale and c could be player 1's fixed cost of extraction; see Dasgupta and Maskin (2000) for a similar example). Player 2 has no private information. Let t_1 and t_2 be the transfers to the two players. The realized payoffs if player 2 gets the item with probability δ are

$$\begin{aligned} u_1 &= (1-\delta)(2q-c) + t_1 \\ u_2 &= \delta q + t_2. \end{aligned}$$

Again, in a standard mechanism the transfers and the decision depend on the reported types. Suppose that the decision rule is efficient. Ex-post efficiency requires that player 1 get the item if $q > c$ and that player 2 get it if $q < c$; that is, the probability

δ of giving the object to agent 2 when q^r and c^r are the reported quality and cost is

$$\delta^*(q^r, c^r) = \begin{cases} 1 & \text{if } q^r < c^r \\ 0 & \text{if } q^r > c^r \end{cases}$$

Let q_1, q_2, c_1, c_2 satisfy the following inequalities

$$\begin{aligned} c_1 \;\; &> \;\; q_1 \;\; > \;\; q_2 \;\; > \;\; c_2 \\ q_1 - q_2 \;\; &> \;\; (c_1 - q_1) + (q_2 - c_2) \,. \end{aligned}$$

Then the transfer function $t_1 : [1, 2] \times [0, 2] \rightarrow \mathbb{R}$ of an efficient standard mechanism must satisfy the following incentive compatibility constraints:

$$\begin{aligned} t_1(q_1, c_1) \;\; &\geq \;\; t_1(q_2, c_2) + 2q_1 - c_1 \\ t_1(q_2, c_2) + 2q_2 - c_2 \;\; &\geq \;\; t_1(q_1, c_1); \end{aligned}$$

adding up the constraints we obtain a contradiction:

$$(c_1 - q_1) + (q_2 - c_2) \geq q_1 - q_2.$$

Maskin (1992), Dasgupta and Maskin (2000) and Jehiel and Moldovanu (2001) show, at different levels of generality, that with multi-dimensional types this example corresponds to the generic case; that is, it is impossible to construct efficient standard mechanisms.

I now show that an efficient mechanism can be found in both examples if the mechanism designer can ask the players to report their realized payoffs. Denote by u_i^r the payoff reported by player i prior to the monetary transfer. The designer should set up two reporting stages. In the first stage players report their types and a decision is implemented according to their reports. In the second stage payoffs (u_i^r) are reported and transfers made that depend on both type and payoff reports. As we shall see, in both examples it is sufficient to ask only player 2 to report his realized payoff; however, in the general case the designer should ask all players to make such a report.

In example 1, the following transfer functions implement the ex-post efficient decision rule:

$$
\begin{aligned}
t_1(\theta_1^r, u_2^r) &= \begin{cases} h_1 & \text{if } \theta_1^r < 1 \\ u_2^r + h_1 & \text{if } \theta_1^r > 1 \end{cases} \\
t_2(\theta_1^r, u_2^r) &= \begin{cases} h_2 & \text{if } \theta_1^r < 1 \\ h_2 - (4\theta_1^r - 2) & \text{if } \theta_1^r > 1 \end{cases}
\end{aligned}
$$

where h_1 and h_2 are constants. Note that these transfers are quite similar to the transfers in a Vickrey-Clarke-Groves (VCG) mechanism (see Vickrey (1961), Clarke (1971) and Groves (1973)) except that they depend on reported payoffs. Clearly, the incentive compatibility constraint for agent 2 is satisfied, since t_2 does not depend on the reported payoff of player 2; truthful payoff reporting is optimal for agent 2. Thus, if agent 2 gets the item he reports a payoff

$$u_2^r = 4\theta_1 - 2$$

Hence, agent 1's payoff from reporting θ_1^r when his type is θ_1 is

$$u_1(\theta_1; \theta_1^r, u_2^r) = \begin{cases} 2\theta_1 + h_1 & \text{if } \theta_1^r < 1 \\ 4\theta_1 - 2 + h_1 & \text{if } \theta_1^r > 1 \end{cases}$$

which is maximized at $\theta_1^r = \theta_1$. Telling the truth is a Bayesian equilibrium (actually a perfect Bayesian equilibrium).

In example 2, the following transfers implement the ex-post efficient decision rule:

$$t_1(q^r, c^r, u_2^r) = \begin{cases} h_1 & \text{if } q^r > c^r \\ u_2^r + h_1 & \text{if } q^r < c^r \end{cases} \tag{1}$$

$$t_2(q^r, c^r, u_2^r) = \begin{cases} h_2 & \text{if } q^r > c^r \\ h_2 - q^r & \text{if } q^r < c^r \end{cases}$$

where h_1 and h_2 are constants. As in the previous example, these transfers are similar to the transfers in a VCG mechanism. Since t_2 does not depend on the reported payoff, truthful reporting of his realized payoff is incentive compatible for agent 2, so that if he gets the item his report is

$$u_2^r = q.$$

Hence, agent i's payoff from reporting q^r, c^r when his type is q, c is

$$u_1(q, c; q^r, c^r, u^r) = \begin{cases} 2q - c + h_1 & \text{if } q^r > c^r \\ q + h_1 & \text{if } q^r < c^r \end{cases}$$

which is maximized at $q^r = q$ and $c^r = c$. Telling the truth is a perfect Bayesian equilibrium.

Two remarks are in order. First, in both examples telling the truth is not a dominant strategy equilibrium. If one player deviates from truthtelling, the other may also want to deviate. Telling the truth, however, is a best reply for agent i independently of his beliefs about the other players. That is, telling the truth is an ex-post equilibrium: it remains a perfect Bayesian equilibrium for any prior distribution over types. Second, telling the truth is not the unique equilibrium of the mechanisms discussed in the examples and of the more general mechanisms we will construct in Section 4. These are features common to most papers in the literature. For example, Dasgupta and Maskin (2000) propose an auction procedure that is efficient for single-dimensional types (and valuations satisfying a single crossing condition);

in their auction "truthful bidding" is an ex-post equilibrium (see also Bergemann and Välimäki (2002)), but it is not a dominant strategy, and it is not necessarily the unique equilibrium. However, as they point out, it should be possible to use the literature on full Bayesian implementation surveyed by Palfrey (1992) to construct more complex mechanisms without the untruthful equilibria.

The crucial feature in the examples is that by observing his payoff an agent acquires new information. In particular, agent 2 learns one of the private signals of agent 1. It is not necessary for the payoff to perfectly reveal a signal of the other agent for efficiency to be possible. To see this, suppose that in example 2 u_2 is a random variable that depends on the true value of q. In particular, assume that q is the expected value of u_2 if agent 2 gets the item. Given the assumption of risk neutrality of agent 2, it is clear that the transfers in (1) implement the efficient decision in this case as well. As we shall see in Section 4, efficiency can be achieved in the general case, and does not require that the private signal of any agent becomes known after the payoff realizations. Since valuations are interdependent, the decision payoff provides an agent with new information; extracting this information from all agents is sufficient for the designer to design transfers that implement the efficient decision.

Let me now take up the issue of balancing the budget. In an auction setup one should require that for all possible type realizations the transfers to the agents add up to at most zero (so that the auctioneer doesn't need to transfer money to the agents). In a setup in which there is no auctioneer (e.g., a buyer-seller relationship), the appropriate (ex-post) budget balancing condition is that the transfers add up exactly to zero for all type realizations. This second condition is more stringent than the first and amounts to

$$t_1(\theta_1^r, u_2^r) = -t_2(\theta_1^r, u_2^r)$$

in the first example and to

$$t_1(q^r, c^r, u_2^r) = -t_2(q^r, c^r, u_2^r)$$

in the second example. By setting $h_1 = -h_2$, one obtains that in equilibrium the budget is balanced for all possible realizations of θ_1 in the first example and all realizations of q and c in the second example. (Note, however, that off the equilibrium path the budget need not balance.)

Finally, by setting $h_1 = 0$ one can guarantee participation by all types of both agents (i.e., individual rationality). This suggests that interdependent valuations make it easier to achieve not only ex-post efficiency, but also budget balancing and individual rationality (e.g., contrast these examples with the impossibility result in Myerson and Satterthwaite (1983)).

Example 3. Consider now the following special case of the auction model in Myerson (1981). There is a single item for sale and two bidders (potential buyers). Each bidder is privately informed about his own type θ_i; the other players regard θ_i as a random variable with uniform distribution over the interval $[0, 1]$. Buyer i's valuation for the object is

$$u_i = \theta_i + \alpha\theta_j \qquad i \neq j,\, i, j = 1, 2,$$

where $\alpha \in (0, 1)$ is a known parameter. The seller valuation for the object is

$$u_0 = \alpha\left(\theta_1 + \theta_2\right).$$

Among standard revelation mechanisms, Myerson (1981) shows that the optimal auction is any common auction (e.g., a first-price, a second-price (Vickrey), or an ascending auction) with a reserve price R_0 given by

$$R_0 = \frac{1}{2-\alpha}.$$

Let $\theta^{(1)} = \max\{\theta_1, \theta_2\}$ and $\theta^{(2)} = \min\{\theta_1, \theta_2\}$. If the optimal auction is implemented either by a Vickrey or by an ascending auction with reserve price R_0, then bidder i wins the object if $\theta_i = \theta^{(1)} \geq R_0$, and pays a price p equal to

$$p = \max\{R_0, (1+\alpha)\theta^{(2)}\}.$$

It is clear that by using this standard optimal auction the seller does not extract the full surplus. In particular, if $\theta^{(1)} < R_0$, an event having probability $(R_0)^2$, the object goes unsold and the seller obtains a lower payoff than either buyer's valuation for the object.

I now show that the seller could exploit the interdependence of valuations and design a mechanism, or auction, that extracts the full surplus. Consider the following "shoot the liar" mechanism. Bidders are first asked to report their types (in the first reporting stage). The bidder who reports the highest type wins the object and then he is asked to report the value obtained from the object (in the second reporting stage). The payment to the seller from bidder i, as a function of the reports, is as follows:

$$p_i(\theta_1^r, \theta_2^r, u_1^r, u_2^r) = \begin{cases} \theta_i^r + \alpha\theta_j^r & \text{if } \theta_i^r > \theta_j^r \\ L & \text{if } \theta_i^r < \theta_j^r \quad \text{and} \quad u_j^r \neq \theta_j^r + \alpha\theta_i^r \\ 0 & \text{if } \theta_i^r < \theta_j^r \quad \text{and} \quad u_j^r = \theta_j^r + \alpha\theta_i^r \end{cases} \tag{2}$$

where $L > 2$ is a constant. To see that the incentive compatibility constraints for the bidders are satisfied (i.e., that bidder i wants to report truthfully), note first that p_i does not depend on i's reported valuation u_i^r (of course, i only needs to report his valuation if he wins the object). Hence, truthful reporting of his realized payoff is optimal for the winning bidder in the second reporting stage. Suppose that bidder j truthfully reports his type in the first reporting stage and if he wins he then truthfully reports his realized valuation in the second reporting stage. The expected payoff to player i from reporting $\theta_i^r \neq \theta_i$, while his type is θ_i, then is

$$U_i(\theta_i^r;\theta_i) = \int_0^{\theta_i^r} (\theta_i - \theta_i^r)\, d\theta_j - \int_{\theta_i^r}^1 L d\theta_j = (\theta_i - \theta_i^r)\,\theta_i^r - L\,(1-\theta_i^r)\,,$$

while i's expected payoff from truthfully reporting $\theta_i^r = \theta_i$ is zero. Clearly, for $L > 2$, U_i is maximized by reporting truthfully in the first stage, $\theta_i^r = \theta_i$ (telling the truth is a strict maximum). In this generalized revelation mechanism each bidder obtains a zero payoff and the seller extracts the full surplus.

The "shoot the liar" mechanism contains a discrete penalty jump for being discovered lying. One could also construct continuous penalties by setting the payments $p_i(\theta_1^r, \theta_2^r, v_1^r, v_2^r)$ to the seller as follows

$$p_i(\cdot) = \begin{cases} \theta_i^r + \alpha\theta_j^r & \text{if} \quad \theta_i^r > \theta_j^r \\ \frac{1}{\alpha^2}\gamma\left(u_j^r - \theta_j^r - \alpha\theta_i^r\right)^2 + \frac{1}{\alpha}\frac{\theta_i^r}{1-\theta_i^r}\left(u_j^r - \theta_j^r - \alpha\theta_i^r\right) & \text{if} \quad \theta_i^r < \theta_j^r \end{cases}$$

where $\gamma > 0$ is a constant. Suppose again that bidder j truthfully reports his type in the first reporting stage and if he wins he then truthfully reports his valuation in the second reporting stage. The expected payoff to player i from reporting θ_i^r, while his type is θ_i, then is

$$\begin{aligned} U_i(\theta_i^r;\theta_i) &= \int_0^{\theta_i^r} (\theta_i - \theta_i^r)\, d\theta_j - \int_{\theta_i^r}^1 \left[\gamma\,(\theta_i - \theta_i^r)^2 + \frac{\theta_i^r}{1-\theta_i^r}\,(\theta_i - \theta_i^r)\right] d\theta_j \\ &= -\gamma\,(\theta_i - \theta_i^r)^2\,(1-\theta_i^r)\,. \end{aligned}$$

Again, U_i is maximized by reporting truthfully in the first stage, $\theta_i^r = \theta_i$.

In Section 5, I will provide a necessary and sufficient condition for the designer to be able to extract the full surplus from the agents in the general model. As we shall see, this condition requires, roughly speaking, that potentially profitable lies in the first reporting stage be detected with positive probability if agents truthfully report their payoffs in the second stage.

Before discussing efficiency, full surplus extraction, and information acquisition, in the next section I will introduce a generalized version of the revelation principle that is appropriate for the case of interdependent valuations.

3 The Generalized Revelation Principle

A fundamental difference between interdependent valuations and the private values model is that with interdependent valuations the observation of the payoff from the decision conveys information to an agent. As we saw in examples 1-3, this information is potentially useful to the designer and a general model should allow him to use it. Thus, the designer should collect messages from the agents in two stages. In the first stage the messages collected should help determine the decision to be made. The second stage should take place after the agents have observed their payoffs from the decision; messages from both stages should be used to determine the monetary transfers to the agents. In most practical applications, the fact that monetary transfers should not be fully completed until after a decision has been made is not a limitation.

Formally, the designer should choose a game form composed of first and second stage message spaces M_i^1 and M_i^2 for each agent i, a decision function, and a transfer function. The game should unfold as follows. After observing his own type each agent i sends a message from M_i^1 to the designer. After receiving the first-stage messages the designer implements a decision according to the decision function. After the decision has been implemented and he has observed his own payoff, agent i sends a message from M_i^2 to the designer. After receiving all second-stage messages, the designer executes the monetary transfers according to the transfer function. The appropriate equilibrium concepts for the games generated by this game form are perfect Bayesian equilibrium and its refinements. In this paper I will use perfect Bayesian equilibrium.

In this section, I will assume that we can decompose the decision as follows: $x = (z_1, \dots, z_n, y)$ where z_i is only observed by player i and y is publicly observable; thus, $X = \times_{i=1}^n Z_i \times Y$ where Z_i is the set of privately observable decisions of agent i and Y is the set of publicly observable decisions. Let $M^\tau = \times_{i=1}^n M_i^\tau$, $\tau = 1, 2$. A deterministic mechanism is a quadruple (M^1, M^2, d, t) where $d : M^1 \to X$ is the decision rule and $t : M^1 \times M^2 \to \mathbb{R}^n$ is the transfer function. A mechanism is a quadruple $(M^1, M^2, \widetilde{d}, \widetilde{t})$ where the decision rule and the transfer functions are allowed to be stochastic.

Let $\Pi_i = u_i(X, \Theta)$ be the range of the function u_i. If $M_i^1 = \Theta_i$ and $M_i^2 = \Pi_i$ for all i, then I say that the designer is using a *generalized revelation mechanism.* If, on the other hand, $M_i^1 = \Theta_i$ and $M_i^2 = \emptyset$ for all i, then I say that the designer is using a *standard revelation mechanism.* In a standard revelation mechanism agents are not asked to report their payoffs from the decision. Under private values (i.e., if $u_i(x, \theta) = u_i(x, \theta_i)$ for all i) there is no loss of generality in assuming that the designer only uses standard revelation schemes. More precisely, the *standard revelation principle* says that with private values any perfect Bayesian equilibrium outcome of any mechanism can be implemented as a Bayesian equilibrium outcome of a standard revelation mechanism in which reporting his true type is an equilibrium strategy for each player. (Clearly, all Bayesian equilibria of a standard revelation mechanism are also perfect Bayesian equilibria.) Intuitively, in a set-up with private values, observing one's own payoff conveys no new information to an agent and thus the designer has no need to collect second-stage messages from the agents.

As I showed in the previous section, with interdependent valuations, restricting the designer to use standard revelation schemes is not without loss of generality. I now present the version of the revelation principle, that I call the *generalized revelation principle,* that is appropriate for a setting with interdependent valuations.

Proposition 1 (The Generalized Revelation Principle) *Any perfect Bayesian equilib-*

rium outcome of any mechanism can be implemented as a perfect Bayesian equilibrium outcome of a generalized revelation mechanism in which reporting his true payoff in the second stage and reporting his true type in the first stage is an equilibrium strategy for each player.

Proof. I will allow agents to use mixed strategies. Let $\Delta(S)$ be the set of probability distributions over the set S. A perfect Bayesian equilibrium of a given mechanism $\gamma = (M^1, M^2, \widetilde{d}, \widetilde{t})$ consists of the following functions

$$\begin{aligned} r_i^1 &: \Theta_i \to \Delta\left(M_i^1\right) \\ r_i^2 &: Z_i \times Y \times \Theta_i \times \Pi_i \to \Delta\left(M_i^2\right), \quad \text{and} \\ \beta_i &: Z_i \times Y \times \Theta_i \times \Pi_i \to \Delta(\Theta_{-i}) \end{aligned}$$

where $r_i = (r_i^1, r_i^2)$ is the (mixed) strategy of player i and β_i is the function mapping a player type and the variables he observes in the first stage into his posterior beliefs concerning the types of the other players. Let $r = (r_1^1, \dots, r_n^1, r_1^2, \dots, r_n^2)$ and $\beta = (\beta_1, \dots, \beta_n)$. Suppose (r, β) is a perfect Bayesian equilibrium of γ. Now consider the generalized revelation mechanism $\rho = (\Theta, \Pi, \delta, \tau)$, with the transfer functions $\tau_i : \Theta \times \Pi \to \Delta(\mathbb{R})$ given by the composite functions $\tau_i(\theta, \pi) = \widetilde{t}_i(r^1(\theta), r^2(\widetilde{d}(r^1(\theta)), \theta, \pi))$ and the decision function $\delta : \Theta \to \Delta(X)$ given by the composite function $\delta(\theta) = \widetilde{d}(r^1(\theta))$. Let $\alpha_i^1 : \Theta_i \to \Theta_i$ be the identity map and $\alpha_i^2 : Z_i \times Y \times \Theta_i \times \Pi_i \to \Pi_i$ be the projection map defined by $\alpha_i^2(z_i, y, \theta_i, \pi_i) = \pi_i$. Let $\alpha^\tau = (\alpha_1^\tau, \dots, \alpha_n^\tau)$, for $\tau = 1, 2$ and $\alpha = (\alpha^1, \alpha^2)$. I claim that (α, β) is a perfect Bayesian equilibrium of the generalized revelation mechanism ρ that implements the same outcome as the equilibrium (r, β) of γ. By construction, it is immediate that (α, β) in ρ implements the same outcome as (r, β) in γ. Furthermore, if a deviation from truthtelling were profitable in ρ, then we could construct an associated profitable deviation from (r, β) in γ. E.g., if reporting $\widehat{\theta}_i$ instead of θ_i were a profitable deviation for type θ_i in ρ, then reporting $\widehat{m}_i^1 = r_i^1(\widehat{\theta}_i)$ instead of $r_i^1(\theta_i)$ and using the second-stage reporting strategy $r_i^2(z_i, y, \widehat{\theta}_i, \pi_i)$ instead of $r_i^2(z_i, y, \theta_i, \pi_i)$ would be a profitable deviation in γ. ■

It is important to observe that in a generalized revelation mechanism, at the beginning of the second reporting stage, each agent's expected transfer must be independent of his payoff message; if it were not, then the agent would not want to reveal his true payoff from the decision. The other agents' transfers, however, may vary with agent i's second-stage report. It is precisely this feature of the second reporting stage that allows the designer to collect new information at no cost, and to punish deviations from truthtelling in the first stage that would not be punishable by using a standard revelation mechanism.

From now on, I will assume that types are drawn independently across agents; that is, the θ_i's are independent random variables. I will focus on the possibility of implementing efficient decision rules, on extracting the full surplus from the agents, and on efficient ex-ante information acquisition. The reason for focusing on independent types is simple. We already know from the work of Crémer and McLean (1985, 1988), McAfee and Reny (1992), and more recently McLean and Postlewaite (2001), that efficiency and full surplus extraction are possible under general conditions when there is correlation of types across agents. On the other hand, Maskin (1992), Dasgupta and Maskin (2000) and Jehiel and Moldovanu (2001) have shown that efficiency (and hence full surplus extraction) is impossible if valuations are interdependent, signals are multidimensional, *and* attention is restricted to standard revelation mechanisms.

4 Efficiency

I will apply the generalized revelation principle and use generalized revelation mechanisms. Suppose that the goal of the designer is to choose an efficient decision rule.

The deterministic decision rule $\delta^* : \Theta \to X$ is efficient if, for all $\theta \in \Theta$ it is

$$\delta^*(\theta) \in \arg\max_{x \in X} \sum_{i=1}^{n} u_i(x, \theta). \tag{3}$$

I will assume that (3) is always well defined.

Let θ_i^r and u_i^r be the type and the payoff from the decision reported by agent i in the first and second reporting stage respectively. Suppose the mechanism designer uses the decision rule δ^*, so that if θ^r is the profile of reported types, then the decision is $x = \delta^*(\theta^r)$. To induce agents to report truthfully, the designer can use the following transfer function τ_i:

$$\tau_i(\theta^r, u^r) = \sum_{j \neq i} u_j^r. \tag{4}$$

The trick, analogous to the trick used in a standard Vickrey-Clarke-Groves mechanism, is to make every agent the "residual claimant" of the full surplus (I will worry later about balancing the budget). To see that this trick works, suppose that all agents except i truthfully report their types, $\theta_{-i}^r = \theta_{-i}$, and their decision payoffs, while agent i of type θ_i falsely reports his type to be θ_i' (note that the report of his decision payoff does not affect agent i's total utility - because τ_i does not depend on it - hence it is optimal for agent i to truthfully report his payoff in the second reporting stage). Under these hypotheses, it is

$$u_j^r = u_j(\delta^*(\theta_i', \theta_{-i}), \theta_i, \theta_{-i}),$$

and agent i's total utility becomes

$$\begin{aligned} & u_i(\delta^*(\theta_i', \theta_{-i}), \theta_i, \theta_{-i}) + \sum_{j \neq i} u_j(\delta^*(\theta_i', \theta_{-i}), \theta_i, \theta_{-i}) \\ \leq \; & u_i(\delta^*(\theta_i, \theta_{-i}), \theta_i, \theta_{-i}) + \sum_{j \neq i} u_j(\delta^*(\theta_i, \theta_{-i}), \theta_i, \theta_{-i}). \end{aligned}$$

Hence, agent i will never profit from falsely reporting θ_i'; truthful reporting is a best reply to the truthful reporting of all the other agents. The two remarks made in Section 2 are still valid here, and are worth recalling. First, telling the truth is an ex-post equilibrium; that is, it remains an equilibrium for all type distributions. Second, modifications of the mechanism following techniques from the full Bayesian implementation literature should allow the elimination of the untruthful equilibria.

Making all agents "residual claimants" could be very costly. However, it is always possible to make sure that the designer collects positive revenue, by selecting the following transfer functions:

$$t_i(\theta^r, u^r) = \sum_{j \neq i} u_j^r - \max_{\theta_i \in \Theta_i,\, x \in X} \sum_{j \neq i} u_j(x, \theta_i, \theta_{-i}^r). \tag{5}$$

With these transfers, the mechanism is similar to the so-called pivot scheme in the mechanism design literature with private values (a generalization of the Vickrey auction); the agent pays for the highest possible externality he causes to others (note that here the maximum is taken not only over the decision, as in the case of private values, but also over agent i's type).

Requiring that the budget balance (i.e., that the transfers add up to zero) is a more restrictive condition than requiring that the designer collects a non-negative revenue. This is the appropriate property to require of a mechanism in which the designer is a mediator - helping out the agents to coordinate - as opposed to the case when the designer is an agent himself (e.g., an auctioneer) trying to extract surplus from the other agents. I will now show that the designer can balance the budget.

Let E_{-i} be the expectation operator over the random variable θ_{-i} and E be the expectation over θ. The designer could subtract from the transfer τ_i in equation (4) a charge h_i, thus fixing i's total transfer t_i to be equal to $\tau_i - h_i$; if the additional charge h_i is designed so that its expected value is independent from the reports of agent i, then truthful reporting remains an equilibrium. Let

$$\begin{aligned} h_i(\theta^r) &= \frac{n-1}{n}\left\{\sum_{j=1}^{n} u_j(\delta^*(\theta^r),\theta^r) - E_{-i}\left[\sum_{j=1}^{n} u_j(\delta^*(\theta_i^r,\theta_{-i}),\theta_i^r,\theta_{-i})\right] + \right. \\ &\left. +E_{-(i+1)}\left[\sum_{j=1}^{n} u_j(\delta^*(\theta_{i+1}^r,\theta_{-(i+1)}),\theta_{i+1}^r,\theta_{-(i+1)})\right]\right\} \end{aligned} \quad (6)$$

with $E_{-(n+1)} = E_{-1}$. If all other agents report truthfully, then the expected value of the charge h_i to a type θ_i that reports θ_i^r is

$$E_{-i}h_i(\theta_i^r,\theta_{-i}) = \frac{n-1}{n}E\left[\sum_{j=1}^{n} u_j(\delta^*(\theta),\theta)\right] \equiv \frac{n-1}{n}S, \quad (7)$$

where S is the ex-ante, expected (optimal) social surplus, a constant independent from θ_i and θ_i^r. Hence truthful reporting remains a perfect Bayesian equilibrium after the charges h_i are subtracted from the τ_i. Note, however, that it is not an ex-post equilibrium anymore. It is simple to check that on the equilibrium path (i.e., for $\theta_i = \theta_i^r$) the budget will be balanced (off the equilibrium path the budget need not balance):

$$\sum_{i=1}^{n} t_i(\theta,u(\theta)) = \sum_{i=1}^{n} \tau_i(\theta,u(\theta)) - \sum_{i=1}^{n} h_i(\theta) = 0.$$

Since we already know that efficient Bayesian mechanisms exist if valuations are independent (e.g., D'Aspremont and Gérard-Varet (1979)), I have proved the following result.

Proposition 2 *Whether or not valuations are interdependent, it is always possible to construct an efficient, budget balancing, perfect Bayesian mechanism.*

While with private valuations it is possible to make truthful revelation (but not budget balancing) a dominant strategy for all agents, with interdependent valuation the dominant strategy property is lost. Another minor difference is that with private values it is possible to balance the budget for all possible reports, including nontruthful reports. On the other hand, with interdependent valuations the budget can only be balanced on the equilibrium path. This is because the transfers must depend on the reported decision payoffs, and not only on the reported types.

It is important to emphasize that Proposition 2 continues to hold even if payoffs are random functions of the agents' signals; the mechanism that I have described continues to guarantee efficiency (recall the discussion of Example 2 in Section 2).

The close similarity of the constructions in this section to the standard VCG schemes under private values needs to be emphasized (e.g., see Green and Laffont (1977), Holmström (1979) and Laffont and Maskin (1979)). In a standard VCG mechanism, the decision and the transfer functions only depend on the reported types. Under private values, this is not a restriction and the efficient decision rule can be implemented by giving each player a transfer that makes him a residual claimant. With interdependent valuations, on the other hand, making each player a residual claimant requires that his transfer depends on the reported payoffs of the other players. Thus, we can think of the mechanism constructed in this section as a *generalized VCG mechanism*.

With private values, and for sufficiently rich domains (e.g., simply connected or convex set of valuations) VCG mechanisms are the only ones that allow the designer to implement the efficient decision (e.g., see Green and Laffont (1977), Holmström (1979) and, more recently, Williams (1999)). Example 3 showed that with interdependent valuations there are other mechanisms, besides generalized VCG schemes, that implement the efficient decision rule; the "shoot the liar" mechanism is not a VCG mechanism, yet it implements the efficient outcome in that example.

I now turn to the issue of voluntary participation of the agents in the mechanism. I will restrict attention to generalized VCG mechanisms (which, as I just argued, is a real restriction) and provide a sufficient condition for a mechanism to be individually rational; that is, to induce voluntary participation. If the designer were forced to use a generalized VCG mechanism, the condition I provide is necessary and sufficient for individual rationality.

Observe that incentive compatibility is not affected if a lump-sum transfers ℓ_i is added to the transfer of agent i, so that $t_i(\cdot) = \tau_i(\cdot) - h_i(\cdot) + \ell_i$. Obviously, if $\sum_{i=1}^n \ell_i = 0$, then budget balancing is also guaranteed.

Let $U_i^O(\theta_i)$ be type θ_i of agent i's expected utility from not participating (his outside option utility). In most applied models the utility from not participating is taken to be type independent and is normalized to zero. However, allowing for the outside option utility of agent i to depend on his type is more general and entails little complication. Prior to the lump-sum transfer ℓ_i, type θ_i of agent i's expected utility in the generalized VCG mechanism constructed in the proof of Proposition 2 is

$$U_i^V(\theta_i) = E_{-i}\left[\sum_{i=1}^n u_i(\delta^*(\theta_i, \theta_{-i}), \theta_i, \theta_{-i})\right] - \frac{n-1}{n}S \equiv S_i(\theta_i) - \frac{n-1}{n}S,$$

where $S_i(\theta_i)$ is the total interim expected surplus (or gains from trade) by type θ_i. Let θ_i^* be the worst-off type of player i

$$\theta_i^* \in \arg\min_{\theta_i \in \Theta_i} U_i^V(\theta_i) - U_i^O(\theta_i)$$

and let

$$L_i = U_i^O(\theta_i^*) - U_i^V(\theta_i^*)$$

be the expected loss of the worst type of agent i from participating in the generalized VCG mechanism, prior to the issuing of the lump-sum transfer ℓ_i. If $\sum_{i=1}^n L_i \leq 0$, then it is possible to add lump-sum transfers $\ell_i \geq L_i$ such that $\sum_{i=1}^n \ell_i = 0$ and induce participation by all types of all agents. It is useful to look at this inequality in a slightly different way. Let

$$C_i = \frac{n-1}{n}S - L_i.$$

Recall that $S(n-1)/n$ is the expected value of the charge h_i to agent i. On the other hand, C_i is the expected gain above his outside utility that the worst type of agent i gets in the mechanism that makes him the "residual claimant" of the full surplus (i.e., the generalized VCG mechanism before the imposition of the charge h_i). Thus, starting from the "everybody is a residual claimant" mechanism, we can think of C_i as the maximum expected charge that can be imposed on agent i. It is clear that the following inequalities are equivalent

$$\begin{aligned}\sum_{i=1}^{n} L_i &\leq 0 \\ \sum_{i=1}^{n} C_i &\geq (n-1)S \\ \sum_{i=1}^{n} \left[S_i(\theta_i^*) - U_i^O(\theta_i^*)\right] &\geq (n-1)\,S,\end{aligned} \tag{8}$$

and that if they are satisfied then participation by all agents can be achieved.

Proposition 3 *If the inequalities in (8) hold, then it is always possible to construct an efficient, budget balancing, individually rational, perfect Bayesian mechanism.*

Makowski and Mezzetti (1994) proved the counterpart of this proposition for the case of private valuations (in their case inequalities analogous to (8) are necessary and sufficient for individual rationality).

5 Full Surplus Extraction

Crémer and McLean (1985, 1988) (see also McAfee and Reny (1992) and McLean and Postlewaite (2001)) showed that full surplus extraction is generically possible when agents' types are correlated. In their model full surplus extraction occurs at the interim level. Each type of each agent participates in a lottery which leaves him with zero expected surplus. As a consequence, at the ex-ante stage (i.e., before knowing the agents' types) the auctioneer expects to extract the full surplus, while ex-post (i.e., when the agents' types are known) he sometimes extract more and sometimes less than the full surplus. This raises potential problems. First, the mechanism is not ex-post individually rational, and hence it may not work if agents have limited liability. Second, the mechanism may not work if agents are risk averse.

In this section I will show that with interdependent valuations it is often possible for the auctioneer to fully extract the surplus ex-post (i.e., for all type realizations) even if signals are statistically independent. I will assume that the functions $u_i(x, \theta)$ are bounded.

Note that if all agents with the possible exception of agent i truthfully report their types and decision payoffs, then for all $j \neq i$ the reported decision payoff will be

$$u_j^r(\theta_i^r, \theta_i, \theta_{-i}) = u_j(\delta^*(\theta_i^r, \theta_{-i}), \theta_i, \theta_{-i})$$

where θ_i^r is the type reported by agent i and θ_i is his true type. On the other hand, on the basis of the type reports, and on the assumption that all agents are being truthful, the designer would have predicted a reported decision payoff equal to

$$u_j^p(\theta_i^r, \theta_{-i}) = u_j(\delta^*(\theta_i^r, \theta_{-i}), \theta_i^r, \theta_{-i}) \qquad \text{for } j = 1, ..., n.$$

In general, any difference between j's reported and predicted payoff provides the designer with evidence of deceit: some agent lied at the type reporting stage (assuming that agent j has no incentive to lie at the payoff reporting stage). The designer could then impose severe penalties on all but agent j. Let $\|\cdot\|$ denote the supnorm in $\mathbb{R}^{n-1}$. The distance between predicted and reported payoffs as a function of θ_{-i} and the true and reported types of agent i is

$$\left\| u_{-i}^p(\theta_i^r, \theta_{-i}) - u_{-i}^r(\theta_i^r, \theta_i, \theta_{-i}) \right\|,$$

where u_{-i}^p and u_{-i}^r are the vectors of predicted and reported payoffs by all players except i. Define the function

$$\mathbf{1}(\theta_i^r,\theta_i;\theta_{-i}) = \begin{cases} 1 & \text{if} \quad \left\| u_{-i}^p(\theta_i^r,\theta_{-i}) - u_{-i}^r(\theta_i^r,\theta_i,\theta_{-i}) \right\| > 0 \\ 0 & \text{if} \quad \left\| u_{-i}^p(\theta_i^r,\theta_{-i}) - u_{-i}^r(\theta_i^r,\theta_i,\theta_{-i}) \right\| = 0 \end{cases}$$

and the set

$$\Theta_{-i}^D(\theta_i^r,\theta_i) = \{\theta_{-i} \in \Theta_{-i} \text{ s.t. } \mathbf{1}(\theta_i^r,\theta_i;\theta_{-i}) = 0\}.$$

The set $\Theta_{-i}^D(\theta_i^r,\theta_i)$ is the set of types of the other agents for which the designer cannot detect the lie θ_i^r by type θ_i of agent i. Let $\Delta_i(\theta_i^r,\theta_i)$ measure the probability that the distance between predicted and reported payoffs, as a function of the true and reported types of agent i, is greater than zero:

$$\Delta_i(\theta_i^r,\theta_i) = E_{-i}\left[\mathbf{1}(\theta_i^r,\theta_i;\theta_{-i})\right] = 1 - \Pr\{\theta_{-i} \in \Theta_{-i}^D(\theta_i^r,\theta_i)\}.$$

I am now ready to introduce an identifiability condition which guarantees that the designer can extract all the surplus from the agents.

Assumption I: *For all i, all θ_i and all θ_i^r with $\theta_i \neq \theta_i^r$, if the inequality*

$$E_{-i}\left[u_i(\delta^*(\theta_i^r,\theta_{-i}),\theta_i,\theta_{-i}) - u_i(\delta^*(\theta_i^r,\theta_{-i}),\theta_i^r,\theta_{-i})\right] > 0$$

holds, then it must be $\Delta_i(\theta_i^r,\theta_i) > 0$.

Assumption I says that if player i of type θ_i expects the difference between his actual and his predicted payoff u_i to be positive when reporting θ_i^r, then the probability of being detected lying must be strictly greater than zero. Given that the functions u_i are bounded, Assumption I is equivalent to

Assumption I$'$: *For all i, all θ_i and all θ_i^r with $\theta_i \neq \theta_i^r$, there exists L such that*

$$E_{-i}\left[u_i(\delta^*(\theta_i^r,\theta_{-i}),\theta_i,\theta_{-i}) - u_i(\delta^*(\theta_i^r,\theta_{-i}),\theta_i^r,\theta_{-i})\right] \leq L\Delta_i(\theta_i^r,\theta_i).$$

I will now show that Assumption I is necessary and sufficient for full surplus extraction.

Proposition 4 *Full surplus extraction is possible (with bounded penalties) if and only if Assumption I holds.*

Proof. First I show that I is sufficient. Consider the following mechanism. The decision rule is the efficient deterministic rule $\delta^* : \Theta \to X$; the transfer functions are given by

$$t_i(\theta_i^r, \theta_{-i}^r, u_i^r, u_{-i}^r) = \begin{cases} -u_i^p(\theta_i^r, \theta_{-i}^r) & \text{if } \left\| u_{-i}^p(\theta_i^r, \theta_{-i}^r) - u_{-i}^r \right\| = 0 \\ -u_i^p(\theta_i^r, \theta_{-i}^r) - L & \text{if } \left\| u_{-i}^p(\theta_i^r, \theta_{-i}^r) - u_{-i}^r \right\| > 0 \end{cases} \tag{9}$$

Suppose that all the other agents truthfully report their types and decision payoffs. First note that agent i's total payoff does not depend on his reported decision payoff. Furthermore, if agent i of type θ_i truthfully reports his type, then he gets a zero total payoff. On the other hand, if he reports type $\theta_i^r \neq \theta_i$ his expected total payoff is

$$E_{-i}\left[u_i(\delta^*(\theta_i^r, \theta_{-i}), \theta_i, \theta_{-i}) - u_i(\delta^*(\theta_i^r, \theta_{-i}), \theta_i^r, \theta_{-i})\right] - L\Delta_i\left(\theta_i^r, \theta_i\right),$$

which is non-positive for a sufficiently large, but bounded L, if Assumption I (or I$'$) holds.

I now need to show that Assumption I is necessary for full surplus extraction. Given any mechanism using the efficient decision rule $\delta^* : \Theta \to X$, we can write the transfer functions as follows

$$t_i(\theta_i^r, \theta_{-i}^r, u_i^r, u_{-i}^r) = -u_i^p(\theta_i^r, \theta_{-i}^r) + \gamma_i(\theta_i^r, \theta_{-i}^r, u_{-i}^r), \tag{10}$$

since i's total payoff should not depend on his reported payoff. If all the other agents truthfully report their types and decision payoffs, while agent i of type θ_i reports type θ_i^r, his expected total payoff is

$$E_{-i}\left[u_i(\delta^*(\theta_i^r,\theta_{-i}),\theta_i,\theta_{-i}) - u_i(\delta^*(\theta_i^r,\theta_{-i}),\theta_i^r,\theta_{-i})\right] \tag{11}$$
$$+E_{-i}\left[\gamma_i(\theta_i^r,\theta_{-i},u_{-i}(\delta^*(\theta_i^r,\theta_{-i}),\theta_i,\theta_{-i}))\right].$$

Full surplus extraction requires that for all θ_i it must be

$$E_{-i}\left[\gamma_i(\theta_i,\theta_{-i},u_{-i}(\delta^*(\theta_i,\theta_{-i}),\theta_i,\theta_{-i}))\right] = 0. \tag{12}$$

Suppose that Assumption I is violated. Then there exist i, θ_i, θ_i^r for which

$$E_{-i}\left[u_i(\delta^*(\theta_i^r,\theta_{-i}),\theta_i,\theta_{-i}) - u_i(\delta^*(\theta_i^r,\theta_{-i}),\theta_i^r,\theta_{-i})\right] > 0 \tag{13}$$

and $\Delta_i\left(\theta_i^r,\theta_i\right) = 0$. But $\Delta_i\left(\theta_i^r,\theta_i\right) = 0$ implies that for almost all θ_{-i}

$$u_{-i}(\delta^*(\theta_i^r,\theta_{-i}),\theta_i^r,\theta_{-i})) = u_{-i}(\delta^*(\theta_i^r,\theta_{-i}),\theta_i,\theta_{-i})).$$

Thus, for almost all θ_{-i} we have

$$\gamma_i(\theta_i^r,\theta_{-i},u_{-i}(\delta^*(\theta_i^r,\theta_{-i}),\theta_i,\theta_{-i})) = \gamma_i(\theta_i^r,\theta_{-i},u_{-i}(\delta^*(\theta_i^r,\theta_{-i}),\theta_i^r,\theta_{-i})).$$

Hence, by (12) it must be

$$E_{-i}\left[\gamma_i(\theta_i^r,\theta_{-i},u_{-i}(\delta^*(\theta_i^r,\theta_{-i}),\theta_i,\theta_{-i}))\right] = 0,$$

which, together with (13), implies that the expression in (11) is positive and hence type θ_i profits from reporting θ_i^r. As a result, full surplus extraction is not possible if Assumption I is violated. ■

In the following subsection I will apply this result to the linear model with a discrete choice set studied by Jehiel and Moldovanu (2001).

5.1 A Linear Model with a Discrete Choice Set

Suppose that the decision set X contains a finite number of elements, $X = \{x^1, \ldots, x^k\}$. In the first version of the model, the type set Θ_i of each player i is a compact subset of $\mathbb{R}^K$. If $\theta_i = (\theta_i^1, \ldots, \theta_i^K)$ is the type of player i, then we should think of θ_i^k as the signal of player i that affects the payoffs of all players if x^k is the selected decision. For all i, j and x_k, let α_{ij}^k be a scalar representing the weight of the signal θ_j^k on player i' s payoff. The payoff functions are given by

$$U_i(x_k, t_i, \theta) = u_i(x, \theta) + t_i = \sum_{j=1}^{n} \alpha_{ij}^k \theta_j^k + t_i. \tag{14}$$

In the second version of the model, the type set Θ_i of each player i is a compact subset of $\mathbb{R}^{NK}$. If $\theta_i = (\theta_{i1}^1, \ldots, \theta_{iN}^1, \ldots, \theta_{i1}^K, \ldots, \theta_{iN}^K)$ is the type of player i, then we should think of θ_{ij}^k as the signal of player i that affects the payoffs of player j if x^k is the selected decision. The payoff functions in this version are given by

$$U_i(x_k, t_i, \theta) = u_i(x, \theta) + t_i = \sum_{j=1}^{n} \alpha_{ij}^k \theta_{ji}^k + t_i. \tag{15}$$

For simplicity, in both versions of the model I will assume that the distribution functions F_i have the property that every open subset of Θ_i has positive probability measure. Jehiel and Moldovanu (2001) showed that if one restricts attention to standard revelation mechanisms, both versions of the model are incompatible with efficiency (for generic type sets). I will now show that Assumption I holds, generically, in the first version of the model, while it fails in the second. Thus, full surplus extraction is always possible in the first version, but not in the second. (As we know from Proposition 2, efficiency can be obtained in both versions of the model using a generalized VCG mechanism.)

Proposition 5 *Suppose players' payoff functions are given by (14), Θ_i is a compact subset of $\mathbb{R}^K$ for all i, and that if $\alpha_{ii}^k \neq 0$ and $x^k \in X$ is the efficient decision in* *an open subset of* Θ *then there exists* $j \neq i$ *such that* $\alpha_{ji}^k \neq 0$. *Then full surplus extraction is possible.*

Proof. I only need to show that Assumption I holds. Suppose that there exists i, θ_i *and* $\theta_i^r \neq \theta_i$ *for which*

$$E_{-i}\left[u_i(\delta^*(\theta_i^r, \theta_{-i}), \theta_i, \theta_{-i}) - u_i(\delta^*(\theta_i^r, \theta_{-i}), \theta_i^r, \theta_{-i})\right] > 0,$$

so that Assumption I requires that $\Delta_i(\theta_i^r, \theta_i) > 0$. (Otherwise Assumption I trivially holds, since it imposes no restrictions.) We have

$$E_{-i}\left[u_i(\delta^*(\theta_i^r, \theta_{-i}), \theta_i, \theta_{-i}) - u_i(\delta^*(\theta_i^r, \theta_{-i}), \theta_i^r, \theta_{-i})\right] = \sum_{k=1}^{K} \lambda^k \alpha_{ii}^k \left[\theta_i^k - \theta_i^{k^r}\right],$$

where λ^k equals the probability that θ_{-i} is such that $\delta^*(\theta_i^r, \theta_{-i}) = x^k$. Thus, it must be $\alpha_{ii}^k \neq 0$ for a k such that $\lambda^k \neq 0$. In other words, the decision x^k must be efficient for θ_i^r and all θ_{-i} in an open subset O_{-i} of Θ_{-i}. Let j be the player for which $\alpha_{ji}^k \neq 0$. Then for all $\theta_{-i} \in O_{-i}$ we have

$$u_j^p(\theta_i^r, \theta_{-i}) - u_j^r(\theta_i^r, \theta_i, \theta_{-i}) = \alpha_{ji}^k \left[\theta_i^{k^r} - \theta_i^k\right] \neq 0,$$

and, as a result, $\Delta_i(\theta_i^r, \theta_i) > 0$ (recall the assumption that any open subset of Θ_i has positive probability measure). This concludes the proof. ■

The condition that if $\alpha_{ii}^k \neq 0$ then $\alpha_{ji}^k \neq 0$ for at least another player j says that if i's signal regarding decision x^k is relevant for i, then it must be relevant for at least another player j. If this were not the case, then when the decision is x^k player i has a private signals, and an untruthful report of this signal could not be detected by the payoff observations of the other players.

In the second version of the model, each player always has private signals; e.g., i's signal θ_{ii}^k only affects the payoff of player i when the decision is x^k. This explains why in this case full surplus extraction is unobtainable; the designer has no way of ever finding out that player i untruthfully reported θ_{ii}^k.

Proposition 6 *Suppose players' payoff functions are given by (15), Θ_i is a compact subset of $\mathbb{R}^{KN}$ for all i, and for all k such that $x^k \in X$ is the efficient decision in an open subset of Θ there exist i such that $\alpha_{ii}^k \neq 0$. Then full surplus extraction is not possible.*

Proof. Let k be such that $x^k \in X$ is the efficient decision in an open subset O of Θ, let i be such that $\alpha_{ii}^k \neq 0$, and let (θ_i, θ_{-i}) be in the interior of O. Take θ_i^r so that: (i) it only differs from θ_i for the signal affecting i (i.e., for all h and all $j \neq i$, $\theta_{ij}^{h^r} = \theta_{ij}^h$); (ii) $\theta_{ii}^{k^r}$ is arbitrarily close to θ_{ii} (so that x^k remains the efficient decision) and $\alpha_{ii}^k(\theta_{ii}^k - \theta_{ii}^{k^r}) > 0$. Observe that we have

$$E_{-i}\left[u_i(\delta^*(\theta_i^r, \theta_{-i}), \theta_i, \theta_{-i}) - u_i(\delta^*(\theta_i^r, \theta_{-i}), \theta_i^r, \theta_{-i})\right] = \sum_{h=1}^{K} \lambda^h \alpha_{ii}^h \left[\theta_{ii}^h - \theta_{ii}^{h^r}\right],$$

where λ^h equals the probability that θ_{-i} is such that $\delta^*(\theta_i^r, \theta_{-i}) = x^h$. Then, Assumption I requires $\Delta_i(\theta_i^r, \theta_i) > 0$. However, we have

$$u_j^p(\theta_i^r, \theta_{-i}) - u_j^r(\theta_i^r, \theta_i, \theta_{-i}) = \alpha_{ji}^k \left[\theta_{ij}^{k^r} - \theta_{ij}^k\right] = 0;$$

as a result, $\Delta_i(\theta_i^r, \theta_i) = 0$, and Assumption I does not hold. This concludes the proof. ■

Note that the condition $\alpha_{ii}^k \neq 0$ guarantees that lying about his private type θ_{ii}^k is profitable to player i. This is sufficient to make full surplus extraction impossible in this version of the model.

6 Information Acquisition

In a recent paper, Bergemann and Välimäki (2002) posed the following question: Is it possible to construct mechanisms that (i) provide agents with the incentives to acquire the ex-ante efficient level of information, and (ii) implement the ex-post efficient decision rule? They showed that the answer is yes in the case of private values. In the case of interdependent valuations ("common values" in their terminology), they restricted attention to standard revelation mechanisms and to the case in which types are single dimensional and a single-crossing, or sorting, condition is satisfied, so that standard revelation mechanisms that implement the ex-post efficient decision rule exist. Nevertheless, they showed that no such mechanism provides agents with the incentives for efficient ex-ante information acquisition. In their words, "ex-ante and ex-post efficiency cannot be reconciled" (see also Maskin (1992) for a preliminary investigation of this issue).

In this section I will show that by allowing the designer to use generalized revelation mechanisms we can achieve both efficient ex-post decisions and efficient ex-ante acquisition of information.

6.1 The Model

To study information acquisition as in Bergemann and Välimäki (2002), I need to modify the model as follows. There are still n agents and a set X of possible decisions. However, there is now a set of possible states of the world, $\Omega = \times_{i=1}^{n} \Omega_i$, where Ω_i is a finite set for all i. The prior marginal distributions $q_i(\omega_i)$, $\omega_i \in \Omega$, are common knowledge. The q_i's are independent, so that for all $\omega \in \Omega$ the common prior is $q(\omega) = \prod_{i=1}^{n} q_i(\omega_i)$. Agent i's payoff function $U_i : X \times \mathbb{R} \times \Omega \to \mathbb{R}$ depends on the decision x, his monetary transfer t_i, and the state of the world ω; we have

$$U_i(x, t_i, \omega) = v_i(x, \omega) + t_i.$$

Each agent can acquire additional information in the form of a noisy signal about the state of the world. Agent i chooses a distribution (the noisy signal) from a parameterized family of distributions $\{F^{\alpha_i}(\theta_i)\}_{\alpha_i \in A_i}$ over the space Θ_i of posterior probability distributions over Ω_i (i.e., Θ_i is the unit simplex in $\mathbb{R}^{m_i}$, where m_i is the cardinality of Ω_i). After choosing a distribution, the agent privately observes the signal realization $\theta_i \in \Theta_i$ (note that the signal realizations of two different agents are independent). The signal realization θ_i corresponds to the posterior belief of agent i over Ω_i (i.e., $\theta_i(\omega_i)$ is the posterior probability attached to $\omega_i \in \Omega_i$). The parameter space A_i is a compact interval in $\mathbb{R}$ and each $F^{\alpha_i}(\theta_i)$ is continuous in α_i in the topology of weak convergence. The cost of acquiring information $c_i(\alpha_i)$ is a continuous function of α_i. The parameter α_i can be interpreted as the signal, or statistical experiment, chosen by agent i.

A posterior over the state of the world $\omega = (\omega_1, ..., \omega_n)$ is given by $\theta(\omega) = \prod_{i=1}^{n} \theta_i(\omega_i)$. We can then write the expected payoff of agent i from decision x, conditional on the posterior θ, as

$$u_i(x, \theta) = \sum_{\omega \in \Omega} v_i(x, \omega)\theta(\omega).$$

If u_i only depends on θ_i values are private, while if u_i depends on the whole vector θ, then valuations are interdependent. The decision rule $\delta^* : \Theta \rightarrow X$ is (ex-post) efficient if, for all $\theta \in \Theta$ it is

$$\delta^*(\theta) \in \arg\max_{x \in X} \sum_{i=1}^{n} u_i(x, \theta).$$

As before, I will assume that $\delta^*(\theta)$ is always well defined.

An ex-ante efficient allocation is a vector of statistical experiments $\alpha^* = (\alpha_1^*, ..., \alpha_n^*) \in A = \times_{i=1}^{n} A_i$ and an (ex-post) efficient decision $\delta^*(\theta)$, such that

$$\alpha^* \in \arg\max_{\alpha \in A} \int \sum_{i=1}^{n} u_i(\delta^*(\theta), \theta) dF^{\alpha}(\theta) - \sum_{i=1}^{n} c_i(\alpha_i) \qquad (16)$$

where $F^{\alpha}(\theta) = \times_{i=1}^{n} F^{\alpha_i}(\theta_i)$.

Bergemann and Välimäki (2002) showed that it is impossible to implement an ex-ante efficient allocation with standard revelation mechanisms when valuations are interdependent. In other words, with interdependent valuations no standard revelation mechanism that implements the ex-post efficient decision rule provides agents with the incentives for efficient information acquisition. To see why, it is useful to look at a simple example.

Example 4. There is an item for sale and two potential buyers, whose valuations for the item are

$$\begin{aligned} u_1 &= 3\omega_1 \\ u_2 &= 1 + \gamma\omega_1 \end{aligned}$$

where $\omega_1 \in \{0, 1\}$ is the state of the world (there are only two possible states), and $\gamma \in [-1, 1]$ is a known parameter. The prior probability that $\omega_1 = 1$ is common knowledge and equal to 1/2. Buyer 1 can choose a private signal from a set $\{F^{\alpha_1}(\theta_1)\}$ at a cost $c_1(\alpha_1)$, with $\alpha_1 \in A_1$; a privately observed signal realization θ_1 corresponds to buyer 1's posterior about the probability that $\omega_1 = 1$. An increase in α_1 corresponds to a more precise signal, and hence to a probability measure with more mass around the endpoints 0 and 1. After observing a signal realization θ_1, efficiency requires that buyer 1 get the item if $\theta_1 > 1/(3-\gamma)$ and that buyer 2 get it if $\theta_1 < 1/(3-\gamma)$. Note that $\partial u_i/\partial\theta_1 > 0$ and $\partial u_i/\partial\theta_1 > \partial u_2/\partial\theta_1$, so that, as shown by Maskin (1992) and Dasgupta and Maskin (2000), an efficient standard revelation mechanism exists. If the designer is constrained to use standard revelation mechanisms, then the efficient decision rule can be implemented by the following transfer function

$$t_1(\theta_1^r) = \begin{cases} h_1 & \text{if} \quad \theta_1^r > \frac{1}{3-\gamma} \\ h_1 + \frac{3}{3-\gamma} & \text{if} \quad \theta_1^r < \frac{1}{3-\gamma} \end{cases}$$

where h_1 is a constant. (I need not specify the transfer to agent 2, since it does not play a role in guaranteeing incentive compatibility. As in Bergemann and Välimäki (2002), at least for the time being, I will not be concerned with the issue of balancing the budget.) To check that incentive compatibility is satisfied, note that if $\theta_1 > 1/(3-\gamma)$ then misreporting his "type" only affects agent 1's payoff if he reports $\theta_1^r < 1/(3-\gamma)$ and the item goes to buyer 2. However, such a misrepresentation decreases buyer 1's payoff, since $h_1 + 3/(3-\gamma) < 3\theta_1 + h_1$. Similarly, if $\theta_1 < 1/(3-\gamma)$ reporting a type $\theta_1^r > 1/(3-\gamma)$ decreases buyer 1's payoff, since in this case $h_1 + 3/(3-\gamma) > 3\theta_1 + h_1$.

Ex-ante efficient information acquisition requires that the signal be chosen so as to solve the following maximization program

$$\max_{\alpha_1 \in A_1} \int_0^1 \max\{3\theta_1, 1 + \gamma\theta_1\} dF^{\alpha_1}(\theta_1) - c_1(\alpha_1),$$

or, equivalently,

$$\max_{\alpha_1 \in A_1} \int_0^{\frac{1}{3-\gamma}} (1 + \gamma\theta_1)\, dF^{\alpha_1}(\theta_1) + \int_{\frac{1}{3-\gamma}}^1 3\theta_1 dF^{\alpha_1}(\theta_1) - c_1(\alpha_1). \tag{17}$$

On the other hand, when choosing a signal, buyer 1 solves the following maximization program

$$\max_{\alpha_1 \in A_1} \int_0^1 \max\{3\theta_1, \frac{3}{3-\gamma}\} dF^{\alpha_1}(\theta_1) - c_1(\alpha_1),$$

or, equivalently,

$$\max_{\alpha_1 \in A_1} \int_0^{\frac{1}{3-\gamma}} \frac{3}{3-\gamma} dF^{\alpha_1}(\theta_1) + \int_{\frac{1}{3-\gamma}}^1 3\theta_1 dF^{\alpha_1}(\theta_1) - c_1(\alpha_1). \tag{18}$$

Now let $\beta \in [0,1]$ be a parameter, and consider the following program

$$\max_{\alpha_1 \in A_1} \int_0^{\frac{1}{3-\gamma}} \left[\frac{3\beta}{3-\gamma} + (1-\beta)(1+\gamma\theta_1)\right] dF^{\alpha_1}(\theta_1) + \int_{\frac{1}{3-\gamma}}^1 3\theta_1 dF^{\alpha_1}(\theta_1) - c_1(\alpha_1),$$

when $\beta = 0$, the program above corresponds to (17) and when $\beta = 1$, it corresponds to (18). Note that, by the second order conditions of (17) and (18), we have

$$sign\frac{\partial \alpha_1}{\partial \beta} = sign\frac{\partial \int_0^{\frac{1}{3-\gamma}} \left[\frac{3}{3-\gamma} - (1+\gamma\theta_1)\right] dF^{\alpha_1}(\theta_1)}{\partial \alpha_1}.$$

Note also that, for $\theta_1 < 1/(3-\gamma)$,

$$\frac{3}{3-\gamma} - (1+\gamma\theta_1) > 0 \quad \text{if and only if} \quad \gamma > 0.$$

Since an increase in α_1 puts more mass around 0 and 1 in the measure with distribution F^{α_1}, we have

$$sign\frac{\partial \alpha_1}{\partial \beta} = sign\left[\frac{3}{3-\gamma} - (1+\gamma\theta_1)\right].$$

Thus, if $\gamma > 0$, then $\partial\alpha_1/\partial\beta > 0$ and buyer 1 has an incentive to over-invest in information acquisition, while if $\gamma < 0$, then $\partial\alpha_1/\partial\beta < 0$ and buyer 1 has an incentive to under-invest in information acquisition. Only if $\gamma = 0$, the case of private values, does agent 1 have an incentive to acquire the (ex-ante) efficient level of information (in that case (17) and (18) coincide). The intuition is the following. The social surplus as a function of the posterior θ_1 is $\max\{3\theta_1, 1+\gamma\theta_1\}$, while the private payoff of agent 1 is $\max\{3\theta_1, 2/(3-\gamma)\}$. Hence, at the pivotal type $\theta_1 = 3/(3-\gamma)$, if $\gamma > 0$, then the private payoff function is more convex than the social surplus function, while the opposite is true if $\gamma < 0$. Since information is more valuable the more convex is the payoff function, if $\gamma > 0$ buyer 1 has an incentive to over-acquire information, while if $\gamma < 0$ he has an incentive to under-acquire information. Bergemann and Välimäki (2002) showed that this result holds in general if one restricts attention to standard revelation mechanisms (a first, less general, version of this inefficiency result can be found in Maskin (1992)).

I now show that this inefficiency in the ex-ante acquisition of information disappears if the mechanism designer is allowed to condition transfers on the players' reports of their realized payoffs. The following transfer functions implement the ex-post efficient decision rule in the example:

$$t_1(\theta_1^r, u_2^r) = \begin{cases} h_1 & \text{if } \theta_1^r > \frac{1}{3-\gamma} \\ u_2^r + h_1 & \text{if } \theta_1^r < \frac{1}{3-\gamma} \end{cases}$$

$$t_2(\theta_1^r, u_2^r) = \begin{cases} h_2 & \text{if } \theta_1^r > \frac{1}{3-\gamma} \\ h_2 - (1 + \gamma\theta_1^r) & \text{if } \theta_1^r < \frac{1}{3-\gamma} \end{cases}$$

where h_1 and h_2 are constants. Truthful payoff reporting in the second reporting stage is optimal for agent 2. Thus, if agent 2 gets the item he reports a payoff

$$u_2^r = 1 + \gamma\omega_1$$

and agent 1's expected payoff (conditional on his posterior θ_1) from reporting θ_1^r in the first reporting stage when his type is θ_1 is

$$u_1(\theta_1; \theta_1^r, u_2^r) = \begin{cases} 3\theta_1 + h_1 & \text{if } \theta_1^r > \frac{1}{3-\gamma} \\ 1 + \gamma\theta_1 + h_1 & \text{if } \theta_1^r < \frac{1}{3-\gamma} \end{cases}$$

which is maximized at $\theta_1^r = \theta_1$. Telling the truth is a perfect Bayesian equilibrium. Hence, the private benefit, or payoff, of agent 1 is $\max\{3\theta_1 + h_1, 1 + \gamma\theta_1 + h_1\}$ which is equal, up to the constant h_1, to the social surplus. This implies that agent 1 has the correct incentive to acquire the ex-ante efficient level of information. There is no conflict between ex-post decision efficiency and ex-ante efficient information acquisition. Note that by setting $h_1 = h_2 = 0$, the mechanism designer can also balance the budget (as we shall see, this result does not generalize).

I am now ready to show that ex-post decision efficiency and efficient ex-ante information acquisition are compatible under very general conditions.

Proposition 7 *Whether or not valuations are interdependent, it is always possible to* *construct an ex-post efficient perfect Bayesian mechanism which also provides agents with the incentives for the ex-ante efficient acquisition of information.*

Proof. Suppose the designer uses the (ex-post) efficient decision rule $\delta^*(\theta^r) \in \arg\max_{x \in X} \sum_{i=1}^n u_i(x, \theta^r)$ and the transfer functions:

$$t_i(\theta^r, u^r) = \sum_{j \neq i} u_j^r - h_i(\theta_{-i}^r),$$

where the charges h_i are independent of θ_i^r. It is simple to check that truthtelling is a Bayesian equilibrium (the reasoning is similar to the one found in the proof of Proposition 2); hence, the specified generalized revelation mechanism implements the ex-post efficient decision rule.

It remains to show that each agent has the incentive to acquire the ex-ante efficient level of information. Given the specified mechanism and truthtelling in the ex-post stage, agent i solves the following ex-ante information acquisition problem

$$\max_{\alpha_i \in A_i} \int \left(\sum_{i=1}^n u_i(\delta^*(\theta), \theta) - h_i(\theta_{-i}) \right) dF^\alpha(\theta) - c_i(\alpha_i). \tag{19}$$

Given that $F^\alpha(\theta) = F^{\alpha_i}(\theta_i) F^{\alpha_{-i}}(\theta_{-i})$, by independence in the signals, we have

$$\int h_i(\theta_{-i}) dF^\alpha(\theta) = \int h_i(\theta_{-i}) dF^{\alpha_{-i}}(\theta_{-i}),$$

a constant. Hence (19) is equivalent to

$$\max_{\alpha_i \in A_i} \int \sum_{i=1}^n u_i(\delta^*(\theta), \theta) dF^\alpha(\theta) - c_i(\alpha_i). \tag{20}$$

On the other hand, ex-ante efficient information acquisition requires that the signals be chosen so as to solve the maximization program in (16). The solutions to the maximization programs (16) and (20) coincide. ■

It is important to note that the proposition does not say anything about balancing the budget. (Bergemann and Välimäki (2002) do not address the issue of balancing the budget either.) It turns out that it is generally not possible to achieve ex-post decision efficiency, efficient ex-ante information acquisition and to balance the budget. To see why this is so, suppose that the designer uses the generalized VCG mechanism described in the proof of Proposition 2, with the transfer functions

$$t_i(\theta^r, u^r) = \sum_{j \neq i} u_j^r - h_i(\theta^r),$$

where the charges h_i are defined by equation (6). Then, given truthtelling at the ex-post stage and equation (7), at the ex-ante information acquisition stage each agent i solves the following maximization problem

$$\max_{\alpha_i \in A_i} \int \frac{1}{n} \sum_{i=1}^{n} u_i(\delta^*(\theta), \theta) dF^{\alpha}(\theta) - c_i(\alpha_i),$$

which yields a solution with less information acquisition than the socially efficient solution to the ex-ante information acquisition program in (16).

While balancing the budget is not possible, as we saw in Section 4 it is always possible to run a surplus (e.g., in the case of an auction, to make sure that the auctioneer collects positive revenue), by selecting the transfer function defined in (5). With these transfers, the charges $h_i(\theta_{-i}^r)$ used in the proof of Proposition 7 are

$$h_i(\theta_{-i}^r) = \max_{\theta_i \in \Theta_i,\, x \in X} \sum_{j \neq i} u_j(x, \theta_i, \theta_{-i}^r).$$

7 Conclusions

The general lesson of this paper is that when there are informational externalities, the options of the designer are enhanced by exploiting the informational spillovers that are associated with a decision. A related point had been made by Hansen (1985) and Crémer (1987) (see also Samuelson (1987)). They showed that if the value of an asset (e.g., a target firm) to the winning bidder (e.g., the acquiring firm) becomes publicly known ex-post, then the seller can raise its revenue by using contingent payments as opposed to cash auctions.

This lesson does not seem to have been missed in the real world. For example, firms frequently survey costumers about their level of satisfaction and then give bonuses to their employees based on these surveys. Furthermore, as pointed out by Samuelson (1987) "contingent pricing schemes are common in actual practice, where examples range from corporate acquisition via exchange of securities, to revenue sharing in oil lease auctions, and incentive contracts in defense procurement."

The generalized VCG mechanism introduced in this paper contains contingent payments, because the transfers to all bidders depend on the realized payoffs. This paper's setup is much more general, however, than the one in Hansen (1985) and Crémer (1987). More importantly, I do not require that information becomes public, but I rely instead on the agents' reports of their own realized payoffs. Thus, the payments in the generalized VCG mechanism are contingent on the reported payoffs, not on publicly observable payoffs.

Some authors (e.g., Dasgupta and Maskin (2000)) have claimed that the mechanism design methods I used in this paper are too informationally demanding, requiring the designer to have information about the signal spaces of the agents and the functional forms of the agents' payoffs. While I acknowledge that greater informational simplicity is valuable, I want to offer two arguments in defense of my approach.

First, the full force of the mechanism design methods allows us to see how far we can go in implementing outcomes. Thus, I was able to reach conclusions that are in sharp contrast with the results one obtains with standard mechanisms (i.e., if contingent payments are not allowed). I have shown that efficient decisions can always be achieved. I characterized the conditions under which one can have full surplus extraction. Finally, I have shown that the efficient ex-ante acquisition of information can also always be obtained.

Second, the general lesson of the paper, that information that follows from an outcome should be exploited to achieve efficiency, or surplus extraction, goes beyond the abstract mechanism design approach. For example, I conjecture that less informationally demanding game forms can be constructed in many situations that implement the efficient outcomes, by using payments that depend on the reported payoffs of the agents. I have undertaken some preliminary research that supports this conjecture; I hope to report its development in a future paper.

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