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Countervailing incentives in multi-agent environments*

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Preliminary version

Abstract

We consider a principal who signs a centralized grand-contract with two risk-neutral and limitedly liable agents behaving non-cooperatively. Technological features are privately known to each agent and give rise to countervailing incentives to misrepresent costs. We first assess that, with uncorrelated information, the principal can induce the full information outcome, as both Bayesian and dominant strategy equilibria, thanks to the presence of countervailing incentives. We then show that, with correlated information, yardstick competition helps implement the full information outcome more often in the Bayesian setting, while it does not under dominant strategies. Yet, in either case, it allows to contain distortions and rents whenever the full information outcome is beyond reach. However, the benefits from benchmarking tail off as agents' pockets become less deep and some of them eventually disappear.

Keywords: Countervailing incentives; Limited liability; Correlation; Yardstick competition

J.E.L. Classification Numbers: D82

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1 Introduction

The economic literature has shown that, in principal/agent(s) relationships with correlated private information, limited liability on the agents' side prevents the principal from implementing the efficient allocation and/or fully retain surplus (Demougin and Garvie [9]; Robert [24], Demski and Sappington [10]). However, when in those same environments agents' performance is *contingent on the realized state of nature*, under some circumstances, the principal implements the full information outcome even if agents are protected by limited liability (Gary-Bobo and Spiegel [12]).

Based on the finding illustrated above, it can be conjectured that countervailing incentives, *i.e.* agents' temptation to overstate/understate private information *depending upon its specific realization*, may represent a powerful tool for tackling asymmetric information issues when agents are wealth constraints. This conjecture is further backed by the result that countervailing incentives enhance agency problems in single-agent environments with usual break-even concerns (Lewis and Sappington [16], among others).

The following questions can thus be raised. In principal/multi-agent hierarchies with limited liability on the agents' side, can the principal induce the first-best outcome if individual pieces of information are independent but agents display countervailing incentives? Provided this is the case, which are the benefits from correlation, if any? Which is the impact of wealth constraints and how do the latter interact with correlation?

The purpose of this article is to reply these questions. We study centralized mechanism design in principal/agents hierarchies in which agents are protected by limited liability and each of them may have countervailing incentives to misrepresent private information on his own technology. We first shed light on the principal's strategies and achievements in such situations, whether private information is correlated or not across agents. We then assess whether and how resorting to yardstick competition benefits the principal when individual pieces of information are indeed correlated.

Our investigation applies to a wide range of contexts. To fix ideas, consider the regulated oligopolies emerging from recently restructured public utilities. In those sectors, both countervailing incentives and limited liability are typically relevant. On one side, countervailing incentives result from firms' technologies that involve inversely related variable and fixed costs. On the other side, regulators secure firms' participation in the market by preventing financial distress. Further pertinent illustrations can be found in regulation of local monopolies operating under a unique authority (for instance, regional markets for power generation, power distribution, water and sanitation services), procurement agreements, employer/employees negotiations.

In the various contexts, the principal may have different preferences in terms of incentive power. To account for this possibility, the analysis is developed ranging from

Bayesian to dominant strategy environments. As usual, in Bayesian environments, the principal designs the mechanism so that truthtelling is a Bayesian-Nash equilibrium. This means that each agent is induced to reveal his private information, given his conjectures about the behaviour of privately informed partners. In dominant strategy environments, the principal designs the mechanism requiring that truthful reporting be optimal for each agent, whatever the partners' behaviour. Because agents do truthtell, reports and realized states of nature coincide, at equilibrium, in either setting. The advantage of moving from Bayesian to dominant strategies is that the behaviour of each agent becomes independent of the beliefs he holds about peers' private information. Clearly, this comes along with the need of satisfying a larger set of constraints. In the context of our interest, specific benefits and costs ensue, which we explore by comparing the principal's achievements in the two settings.

The first prediction of our analysis is that, whether Bayesian or dominant strategies are played, in multi-agent environments with countervailing incentives, to some extent, the principal can implement the first-best outcome when private information is independent, even if agents are protected by limited liability. This shows that countervailing incentives enhance welfare more than so does information correlation. Indeed, while correlation alone drives efficiency and rent extraction in frictionless environments (Crémer and McLean [7], Riordan and Sappington [23], McAfee and Reny [20]), it does not in the presence of wealth constraints, as already recalled. When first best is too ambitious a goal, allocative distortions and expected rents appear. Like in single-agent settings, the former move from the bottom to the top of the type distribution, the latter from the top to the bottom as the outside options available to efficient agents become increasingly more attractive and so the principal's offer targeted to those agents increasingly more appealing to inefficient agents.

With uncorrelated information, limits on liability impose no structure on the optimal incentive mechanism. This follows from the conflict between limited liability and *interim* participation constraints. The conflict rests on the impossibility, for the principal, to discriminate across states of nature and pin down the one in which assigning the minimum admissible payoff would be more convenient. This impossibility further involves that no important difference arises, in terms of optimal mechanism, between Bayesian and dominant strategy frameworks, a result that is in line with Mookherjee and Reichelstein [21]. Independence of information thus softens the principal's ability to provide incentives of different strength to agents.

The finding that correlation is not essential for implementing the full information outcome when agents' pockets are not deep does not mean that correlation is of no value to the principal in the presence of countervailing incentives. On the opposite, it emerges that yardstick competition does ameliorate the principals' achievements, as compared to the case in which it cannot be adopted because agents' information is uncorrelated. This means that, when both countervailing incentives and correlation exist, the principal has two instruments at disposal for enhancing welfare.

Information correlation fosters the principal's ability to provide incentives of different strength to agents. Hence, the improvements yardstick competition generates depend upon the incentive power the principal requires and are not equally important in all settings. Noticeably, in the Bayesian setting, correlation allows the principal to decentralize the full information outcome more often than she would through the effect of the sole countervailing incentives. Yardstick competition does not yield analogous benefit when agents are required to play dominant strategies. Nevertheless, in either case, it helps contain the allocative inefficiencies the principal is forced to induce and the rents she concedes whenever first best is beyond reach. Importantly, the basic structure of distortions and rents in correlated environments is similar to that in uncorrelated environments, provided it rests on the very nature of agents' incentives.

By allowing the principal to screen states of nature and identify those in which incentives to cheat are more intense, the presence of correlation makes limited liability relevant, while it is not with independent information, as previously remarked. Specifically, we assess that the benefits from yardstick competition progressively reduce as agents' pockets become less deep. Many such benefits vanish in the extreme case in which the principal cannot retain more than the surplus generated within the relationship.

Our findings help us disclose the relation between information structure, liability and countervailing incentives. On one hand, when information is independent, a deep pocket is not a substitute for correlation. Instead, countervailing incentives do represent an alternative to correlation, to the extent they allow the principal to induce the full information outcome. On the other hand, when information is correlated, liability appears to complement correlation, provided the principal benefits more from correlation the deeper the agents' pockets and may benefit very little if wealth constraints are especially tight. In turn, correlation complements countervailing incentives, the best illustration being that it allows the principal to achieve first best more often in the Bayesian framework. In any setting, correlation would be a substitute for countervailing incentives only if it were perfect.

The remainder of the paper is organized as follows. In Section 2, we revise the mainly related literature. The model is presented in Section 3. Section 4 and 5 are respectively devoted to characterizing the optimal centralized mechanism in environments where private information is independent and correlated across agents. We compare results and discuss implications in Section 6. Section 7 concludes[1].

[1] All mathematical proofs are here omitted and available with the author.

2 Related literature

First of all, our work fits in with the line of research about countervailing incentives. We owe this expression to Lewis and Sappington [16], who show that the existence (or the creation) of countervailing incentives enhances efficiency in principal/agent hierarchies by introducing state-dependence in the optimal mechanism. The issue of countervailing incentives in agency problems is further tackled in various other works. For instance, Lewis and Sappington [17] and Maggi and Rodriguez-Clare [19] look at inflexible rules that enhance incentive problems. Brainard and Martimort [5] investigate the implications of asymmetric information for strategic trade policy by modelling a type-dependent reservation utility. Spiegel and Spulber [29] study how countervailing incentives affect the choice of capital structure by regulated firms. Jullien [14] provides a theory of state-dependent participation constraints under adverse selection. Bontems and Bourgeon [3] explore how countervailing incentives can be created by allowing agents to select type-dependent monitoring instruments. Saha [25] investigates corruption in a model in which the benefits from private information depend upon the level of the red tape.

In all the studies aforementioned, the principal negotiates with one sole agent, an assumption that is relaxed in our work. From the model of monopoly regulation elaborated by Lewis and Sappington [16], we specifically inherit the stylization of agents' technologies, *i.e.* negatively correlated fixed and marginal cost components[2]. Our environment is otherwise richer because of the correlation and liability aspects. Our results replicate those found in Lewis and Sappington [16] only as far as uncorrelated information environments are concerned. The reason for this analogy is that, when types are independent and agents' participation is to be secured at *interim*, each agent's information brings no news about the second agent's and limited liability imposes no structure on the optimal mechanism.

Our study further fits in with the domain of literature about mechanism design in the presence of correlated information. With regard to both dominant strategy and Bayesian settings, Crémer and McLean [7], Riordan and Sappington [23], McAfee and Reny [20] and others thereafter show that even "coarse" information may suffice to eliminate distortions ensuing from informational asymmetries between principal and agent(s). This requires that the principal be able to condition an agent's payment on some *ex post* observable and costless signal correlated with the agent's private information, which can also be the report about a second agent's private information. Under these circumstances, yardstick competition and benchmarking practices appear to be powerful rent-extraction tools, unless some kind of friction is present[3].

[2] In turn, the model Lewis and Sappington [16] build is a reconsideration of the model Baron and Myerson [2] use to study optimal regulation of a monopolist under adverse selection about costs.

[3] In the class of papers to which we refer in the text, authors look at *report*-based mechanisms. Other

One such friction is the impossibility that agents bear unbounded penalties. The impact of limited liability on the principal's achievements in correlated information settings is analyzed, for instance, in Demougin and Garvie [9]. Our work is thus related to theirs. The authors focus on a situation in which the principal faces a single agent whose type is correlated with a purely informational signal that is publicly observed *ex post*[4]. Thus, in their case, information is exogenously conveyed. By contrast, we consider an environment in which the principal deals with two agents whose types are correlated, so that information is endogenously conveyed through agents' reports. Furthermore, Demougin and Garvie [9] tackle a standard adverse selection problem in a purely Bayesian framework. Instead, in the framework we look at, agents display countervailing incentives and the principal induces information revelation either as a Bayesian-Nash or as a dominant strategy equilibrium. In Demougin and Garvie [9], it emerges that non-negative payoff constraints prevent the principal from implementing the first-best allocation and/or fully extracting information rents, despite the contract can be conditioned on an *ex post* observable signal[5]. In a similar vein, we find that wealth constraints trigger distortions and make rents available to agents. However, as long as countervailing incentives are at work, first-best implementation remains feasible, to some extent. Thus, while in Demougin and Garvie [9] private information becomes more and more relevant as the informativeness of the signal reduces, in our framework it is possible to make private information is irrelevant, to some extent, even when information is uncorrelated.

In line with Demougin and Garvie [9], Robert [24] and Demski and Sappington [10] challenge the result on the irrelevance of private information with regard to correlated environments where the principal faces more than one agent. In an auction context, Robert [24] shows that a principal dealing with several agents is unable to fully retain surplus when private information is nearly independent and agents are protected by limited liability and/or they are risk-averse[6]. On the other hand, Demski and Sappington [10] find that, in correlated frameworks, private information yields rents to risk-averse agents. Similarly to Robert [24] and Demski and Sappington [10], we consider hierarchies in which

works focus on *performance*-based mechanisms. Recall, for instance, Shleifer [28] who shows that, if franchise monopolists receive a price that depends on the costs of identical firms, each such firm engages in the socially efficient amount of cost reduction. See Armstrong and Sappington [1] for a survey of the literature about yardstick-reporting and yardstick-performance settings.

[4] Limited liability in hierarchies in which the principal faces one sole agent is also studied by Sappington [26] with regard to situations in which both principal and agent only know the distribution of a random state of nature when the contract is signed. At later stage, the sole agent observes the actual state realization and chooses an action that determines his performance. The author shows that, in such situations, the optimal contract induces efficient performance only in the most productive state of nature (and, possibly, in very unproductive states).

[5] Nevertheless, under some circumstances, first best is attainable when *transfer payments* are constrained to be non-negative.

[6] Risk aversion can be approached similarly to limited liability. Indeed, an alternative interpretation of limited liability is that agents are risk-neutral over all payoffs larger than the maximum loss and infinitely risk-averse over all payoffs smaller than that threshold.

the principal is able to commit to a unique grand-mechanism that ties all her agents. However, while Robert [24] focuses on environments in which information revelation is induced as a Bayesian equilibrium only, we also look at dominant strategy equilibria. From this perspective, our approach is closer to Demski and Sappington [10]. Specifically, searching for the equilibrium the principal would prefer among all possible truthtelling Pareto-undominated equilibria, the latter conclude that this is the asymmetric equilibrium in which one agent reveals private information as a dominant strategy and the other as a Nash best reply[7]. Instead, we evidence the role of correlation comparing Bayesian and dominant strategy environments in the presence of countervailing incentives and, when possible, we rank them in terms of contract performance from the principal's viewpoint.

The result on the irrelevance of private information in correlated settings is partially restored in Gary-Bobo and Spiegel [12]. These authors consider a situation in which the principal (a regulator) deals with an agent (a firm) protected by limited liability. The agent's type is subject to random shocks, the distribution of which is (known to be) correlated with the type itself. Within this framework, under some circumstances, first best is found to be at hand despite limited liability. From this perspective, the contribution by Gary-Bobo and Spiegel [12] is closest to ours, among those concerning mechanism design with correlated information and limited liability. The similarity, which essentially regards our Bayesian approach, rests on two main aspects. Firstly, the second agent's report in our model is the counterpart for the observable signals in theirs, as in Demougin and Garvie [9]. Secondly, signals in Gary-Bobo and Spiegel [12] are not purely informational, they do affect the agent's performance. This drives state-contingency (*i.e.* adjustments to the specific shock realizations) in their setting, in the same vein that the specific cost structure triggers countervailing incentives in our model. Noticeably, here is the root to first-best implementation. Gary-Bobo and Spiegel [12] further find that, when first best is beyond reach, the classical adverse selection solution is optimal. In our setting, this is only one of the relevant cases, which arises only as long as outside opportunities available to agents are negligible. After looking at the two-type situation as a preliminary step, Gary-Bobo and Spiegel [12] extend the analysis to the case of a continuum of types, for which they develop the technique within the context of their interest. By contrast, sticking to the simple two-type case, we fully explain how contractual features vary as outside options raise, so that agents move from classical to countervailing incentives. We can thus compare allocations, rents, the impact of limited liability and the role of correlation across the various settings we are concerned with.

[7] A specification of the result in Demski and Sappington [10] can be found in Dana [8]. Recalling Demski and Sappington [10] for a general proof, the author points that, in correlated multi-agent settings, private information yields rents under *ex post* participation constraints. Dana [8] further compares a multi-agent situation with a single-agent situation so as to identify the organizational form that benefits more the principal *ex ante*.

3 The model

We consider a risk-neutral principal who deals with two risk-neutral agents, namely agent 1 and agent 2. The task of agent $i = 1, 2$ is to provide one unit of a good of quality q_i. Production costs are given by

$$C_i (q_i; \theta_i) = c (\theta_i) + \theta_i q_i. \tag{1}$$

Agent i bears a cost $c(\theta_i)$ to produce the basic good, *i.e.* the good of quality $q_i = 0$. This cost depends upon θ_i, the additional cost agent i incurs per quality unit, when he provides a better good, *i.e.* a good of (finite) quality $q_i > 0$.

An obvious alternative interpretation would be that provided by Lewis and Sappington [16], from which we inherit the formulation in (1). In that case, q_i would be the quantity produced by agent i, θ_i the latter's marginal cost/productivity and $c(\theta_i)$ the fixed cost of production. Yet, we choose to stick to the quality interpretation because yardstick competition, to be introduced in the sequel of the analysis, seems to be adopted quite systematically for quality control. As an illustration, in water services, which are provided by local monopolies subject to benchmarking practices in a plurality of countries, regulated tariffs are typically set based on the quality of raw water or sewage for disposal[8].

Agent i receives a transfer s_i for his production. His profits are written

$$\pi_i (q_i, s_i) = s_i - [c(\theta_i) + \theta_i q_i]. \tag{2}$$

At later stage, we shall require that profits not fall below the threshold $-l$, with $l > 0$, *i.e.* we will take agents to be protected by limited liability. Provision of the goods yields gross surplus $\sum_{i=1,2} V(q_i)$, with $V(0) = 0$, $V' > 0$, $V'' < 0$, $V'(0) = +\infty$ and $V'(+\infty) = 0$. Welfare is given by gross surplus net of the transfers made to the agents

$$W(q_1, q_2, s_1, s_2) = \sum_{i=1,2} [V(q_i) - s_i]. \tag{3}$$

3.1 The informational structure

At the contracting stage, the principal faces an adverse selection problem. Each agent is privately informed about his own cost characteristics, not about those of his partner. However, it is commonly known that, for any $i = 1, 2$, $\theta_i \in \Theta = \{\underline{\theta}, \overline{\theta}\}$, with $\overline{\theta} > \underline{\theta}$. Moreover, $c(\underline{\theta}) = \overline{c}$ and $c(\overline{\theta}) = \underline{c}$, with $\overline{c} > \underline{c}$. This means that the type whose basic technology is expensive finds it less costly to upgrade its product quality, as compared to the type whose basic technology is cheap. In the sequel of the work, we sometimes refer

[8] See, for instance, Haarmeyer and Mody [13], who report that this is the case in England and Wales, Malaysia, Argentina, Mexico, Turkey, Australia.

to type $\underline{\theta}$ as the (quality-)*efficient* type and to type $\overline{\theta}$ as the (quality-)*inefficient* type. Furthermore, for future reference, we denote $\Delta c = \overline{c} - \underline{c}$ and $\Delta\theta = \overline{\theta} - \underline{\theta}$ the spread of basic and quality costs respectively.

The two possible types are drawn from the distribution of prior beliefs

$$\begin{aligned}\nu_{11} &\equiv \Pr\left(\theta_1 = \underline{\theta}, \theta_2 = \underline{\theta}\right) \\ \nu_{22} &\equiv \Pr\left(\theta_1 = \overline{\theta}, \theta_2 = \overline{\theta}\right) \\ \nu_{12} &\equiv \Pr\left(\theta_1 = \underline{\theta}, \theta_2 = \overline{\theta}\right) = \Pr\left(\theta_1 = \overline{\theta}, \theta_2 = \underline{\theta}\right).\end{aligned}$$

ν_{11} (resp.ly, ν_{22}) is the joint probability that both agents are of type $\underline{\theta}$ (resp.ly, $\overline{\theta}$). Moreover, in our symmetric model, ν_{12} is the probability that agents are heterogeneous. The degree of correlation between types is denoted $\rho \equiv \nu_{11}\nu_{22} - \nu_{12}^2$ and posterior beliefs are given by $\underline{\nu} \equiv \frac{\nu_{11}}{\nu_{11}+\nu_{12}}$ and $\overline{\nu} \equiv \frac{\nu_{12}}{\nu_{12}+\nu_{22}}$. When agents' types are independent, $\rho = 0$ and $\underline{\nu} = \overline{\nu} \equiv \nu$.

Lastly, quality is observable and verifiable to all parties.

3.2 Centralized contracting

Informed agents non-cooperatively send messages $(m_1, m_2) \in M = M_1 \times M_2$ to the uninformed principal. The latter offers a grand-contract GC that ties all her agents mapping the pair (m_1, m_2) into a quadruplet of qualities and profits (q_1, q_2, π_1, π_2). Restricting attention to direct mechanisms, so that $M = \Theta^2$, qualities and profits are based on both agents' announcements about their types. GC specifies a lottery with two quality-profits pairs for each type, namely $\left(\left\{\underline{q}, \underline{\pi}\right\}, \left\{\widehat{q}_1, \widehat{\pi}_1\right\}\right)$ and $\left(\left\{\widehat{q}_2, \widehat{\pi}_2\right\}, \left\{\overline{q}, \overline{\pi}\right\}\right)$, with $\underline{q} \equiv q_1\left(\underline{\theta}, \underline{\theta}\right) = q_2\left(\underline{\theta}, \underline{\theta}\right)$, $\overline{q} \equiv q_1\left(\overline{\theta}, \overline{\theta}\right) = q_2\left(\overline{\theta}, \overline{\theta}\right)$, $\widehat{q}_1 \equiv q_1\left(\underline{\theta}, \overline{\theta}\right) = q_2\left(\overline{\theta}, \underline{\theta}\right)$ and $\widehat{q}_2 \equiv q_1\left(\overline{\theta}, \underline{\theta}\right) = q_2\left(\underline{\theta}, \overline{\theta}\right)$ and similarly for profits. Thus, for instance, $\underline{q}$ and $\underline{\pi}$ are respectively the quality and the profits designed for agent 1 and 2 when the latter both announce $\underline{\theta}$.

3.3 The full information outcome

Suppose the principal can directly observe agents' costs. In this ideal setting, where the principal enjoys full information, first best is implemented. Specifically, qualities in GC are pinned down such that marginal benefit and marginal cost are equal

$$V'(\underline{q}^{fi}) = V'(\widehat{q}_1^{fi}) = \underline{\theta} \tag{4a}$$

$$V'(\widehat{q}_2^{fi}) = V'(\overline{q}^{fi}) = \overline{\theta}, \tag{4b}$$

with ranking $\underline{q}^{fi} = \widehat{q}_1^{fi} \equiv \underline{q}^* > \widehat{q}_2^{fi} = \overline{q}^{fi} \equiv \overline{q}^*$. Profits are set so as to retain all surplus from agents. In the sequel of the work, we sometimes refer to this as the *full information* *outcome* (which explains the apex fi).

4 Uncorrelated information

Let us now concentrate on situations where the principal faces adverse selection.

We begin the analysis by assuming that agents' types are uncorrelated, so that information about an agent's type brings no news about the partner's type. Focusing on this framework allows us to first evidence what the principal can achieve when she cannot resort to benchmarking practices in the presence of countervailing incentives, both without and with wealth constraints on the agents' side. At later stage, the role of correlation will emerge by comparison with settings where types are indeed correlated.

4.1 Unlimited liability

For the time being, we neglect limits on liability. We let

$$\begin{aligned}\underline{\underline{q}} &\equiv \nu\underline{q} + (1-\nu)\,\widehat{q}_1 \quad \text{and} \quad \underline{\Pi} \equiv \nu\underline{\pi} + (1-\nu)\,\widehat{\pi}_1 \\ \overline{\overline{q}} &\equiv \nu\widehat{q}_2 + (1-\nu)\,\overline{q} \quad \text{and} \quad \overline{\Pi} \equiv \nu\widehat{\pi}_2 + (1-\nu)\,\overline{\pi}\end{aligned}$$

the expected qualities and payoffs of the two agents' types. In the Bayesian environment, the principal's programme, denoted (IT), amounts to maximizing expected welfare

$$\begin{aligned}E_{(c,\theta)}[W] &= 2\nu^2\left[V(\underline{q}) - (\overline{c}+\underline{\theta}\underline{q})\right] + 2(1-\nu)^2\left[V(\overline{q}) - (\overline{c}+\underline{\theta}\overline{q})\right] \\ &\quad +2\nu(1-\nu)\left[V(\widehat{q}_1) + V(\widehat{q}_2) - (\overline{c}+\underline{\theta}\widehat{q}_1) - \left(\underline{c}+\overline{\theta}\widehat{q}_2\right)\right] \\ &\quad -2\left[\nu\underline{\Pi} + (1-\nu)\,\overline{\Pi}\right],\end{aligned}$$

subject to the incentive and participation constraints

$$\underline{ITIC} \;:\; \underline{\Pi} \geq \overline{\Pi} + \Delta\theta\overline{\overline{q}} - \Delta c \tag{5a}$$

$$\overline{ITIC} \;:\; \overline{\Pi} \geq \underline{\Pi} + \Delta c - \Delta\theta\underline{\underline{q}} \tag{5b}$$

$$\underline{ITPC} \;:\; \underline{\Pi} \geq 0 \tag{5c}$$

$$\overline{ITPC} \;:\; \overline{\Pi} \geq 0. \tag{5d}$$

Looking at (5a) and (5b), it becomes clear that, *ceteris paribus*, the incentive constraint of a $\underline{\theta}-$agent ($\underline{ITIC}$) relaxes and that of a $\overline{\theta}-$agent $\left(\overline{ITIC}\right)$ tightens as Δc increases. This is relevant in that basic costs can alternatively be viewed as the outside opportunities agents forego while staying in the relationship with the principal (compare Lewis and Sappington [16]). This means that the wedge Δc is not only a measure of basic cost uncertainty. It also represents the outside opportunities available to efficient agents (relatively to those faced by inefficient agents). Therefore, how difficult it is for the principal to solicit self-selection depends upon the specific realization of agents' types.

The principal's programme is the same in the dominant strategy framework, except that incentive constraints (5a) and (5b) are replaced by

$$\begin{aligned}
\underline{DIC} &: \underline{\pi} \geq \widehat{\pi}_2 + \Delta\theta\widehat{q}_2 - \Delta c && \text{(6a)}\\
\widehat{DIC}_1 &: \widehat{\pi}_1 \geq \overline{\pi} + \Delta\theta\overline{q} - \Delta c && \text{(6b)}\\
\widehat{DIC}_2 &: \widehat{\pi}_2 \geq \underline{\pi} + \Delta c - \Delta\theta\underline{q} && \text{(6c)}\\
\overline{DIC} &: \overline{\pi} \geq \widehat{\pi}_1 + \Delta c - \Delta\theta\widehat{q}_1, && \text{(6d)}
\end{aligned}$$

which ensure that truthtelling is optimal for each agent, whatever the report his peer sends. In this case, as Δc raises, both incentive constraints associated with type $\underline{\theta}$ (namely, $\underline{DIC}$ and $\widehat{DIC}_1$) relax. Both of those associated with type $\overline{\theta}$ (namely, $\widehat{DIC}_2$ and $\overline{DIC}$) tighten.

Despite incentive constraints are not the same in the two environments, the sole relevant difference resides in the implementability condition. In the Bayesian setting, the latter calls for $\underline{\theta}-$agents' *expected* quality to be at least as large as $\overline{\theta}-$agents' ($\underline{\underline{q}} \geq \overline{\overline{q}}$). Under dominant strategies, it requires that $\underline{\theta}-$agents' quality be at least as large as $\overline{\theta}-$agents' *in either state of nature* ($\underline{q} \geq \widehat{q}_2$ and $\widehat{q}_1 \geq \overline{q}$). It follows that the programme has the same solution in the two environments, provided the optimal Bayesian quality schedule satisfies the dominant strategy monotonicity condition. This finding replicates the result, obtained by Mookherjee and Reichelstein [21], that dominant strategy implementation yields no loss of generality in structured environments such as those characterized by uncorrelated information.

The solution to (IT) is summarized in the proposition hereafter.

Proposition 1. *With independent types, the optimal grand-contract* $(GC - IT)$ *implements the full information outcome (namely,* $\underline{q} = \widehat{q}_1 = \underline{q}^*$, $\widehat{q}_2 = \overline{q} = \overline{q}^*$ and $\underline{\Pi} = \overline{\Pi} = 0$) *as a Bayesian-Nash equilibrium as long as* $\Delta c \in (\Delta\theta\overline{q}^*,\ \Delta\theta\underline{q}^*)$[9]. *Four further regions are relevant, in which qualities and payoffs are characterized as follows.*

$IT1$) $\Delta c \in \left[0,\ \Delta\theta\widetilde{\overline{q}}\right)$, *with* $\widetilde{\overline{q}} \equiv \widehat{q}_2 = \overline{q}$ *as pinned down by* (7b) *below:*

$$\begin{aligned}
\underline{q} &= \widehat{q}_1 = \underline{q}^* && \text{(7a)}\\
V'\left(\widehat{q}_2\right) &= V'\left(\overline{q}\right) = \overline{\theta} + \frac{\nu}{1-\nu}\Delta\theta && \text{(7b)}\\
\underline{\Pi} &= \Delta\theta\widetilde{\overline{q}} - \Delta c && \text{(7c)}\\
\overline{\Pi} &= 0. && \text{(7d)}
\end{aligned}$$

[9] For future reference, we denote this region $IT3$.

*IT*2) $\Delta c \in (\Delta\theta\widetilde{\overline{q}},\, \Delta\theta\overline{q}^{*})$:

$$
\begin{aligned}
\underline{q} &= \widehat{q}_1 = \underline{q}^{*} && \text{(8a)}\\
\overline{\overline{q}} &= \frac{\Delta c}{\Delta\theta} && \text{(8b)}\\
\underline{\Pi} &= 0 && \text{(8c)}\\
\overline{\Pi} &= 0. && \text{(8d)}
\end{aligned}
$$

*IT*4) $\Delta c \in (\Delta\theta\underline{q}^{*},\, \Delta\theta\widetilde{\underline{q}})$, *with* $\widetilde{\underline{q}} \equiv \underline{q} = \widehat{q}_1$ *as pinned down by* (10a) *below:*

$$
\begin{aligned}
\underline{\underline{q}} &= \frac{\Delta c}{\Delta\theta} && \text{(9a)}\\
\widehat{q}_2 &= \overline{q} = \overline{q}^{*} && \text{(9b)}\\
\underline{\Pi} &= 0 && \text{(9c)}\\
\overline{\Pi} &= 0. && \text{(9d)}
\end{aligned}
$$

*IT*5) $\Delta c > \Delta\theta\widetilde{\underline{q}}$:

$$
\begin{aligned}
V'\left(\underline{q}\right) &= V'\left(\widehat{q}_1\right) = \underline{\theta} - \frac{1-\nu}{\nu}\Delta\theta && \text{(10a)}\\
\widehat{q}_2 &= \overline{q} = \overline{q}^{*} && \text{(10b)}\\
\underline{\Pi} &= 0 && \text{(10c)}\\
\overline{\Pi} &= \Delta c - \Delta\theta\widetilde{\underline{q}}. && \text{(10d)}
\end{aligned}
$$

$GC-IT$ is the optimal centralized mechanism also under dominant strategies, provided qualities in (8b) *and* (9a) *are set such that* $\underline{q} \geq \widehat{q}_2$ *and* $\widehat{q}_1 \geq \overline{q}$.

4.1.1 Description of $GC - IT$

With independent types, the full information outcome is achieved when agents' desire to cheat can be made sufficiently weak that types are separated at no agency cost (region *IT*3). This means that the presence of countervailing incentives allows the principal to get rid of the informational problem, to some extent. Even without wealth constraints, countervailing incentives are essential for implementation of the full information outcome.

As long as Δc is sufficiently small ($\Delta c < \Delta\theta\overline{q}^{*}$), the principal faces classical adverse selection, with type $\underline{\theta}$ prone to overstate costs. She thus causes *downward* distortions in the quality commended for type $\overline{\theta}$. Initially (in *IT*1), single qualities $\widehat{q}_2$ and $\overline{q}$ are equally reduced below the efficient level to contain the information rent that is given up to efficient agents (namely, $\underline{\Pi} = \Delta\theta\widetilde{\overline{q}} - \Delta c$). As Δc raises (in *IT*2), allocative efficiency is enhanced. In the Bayesian framework, rents are avoided by fixing *expected* quality $\overline{\overline{q}}$ as small as just needed to make cheating unattractive to inefficient agents. Provided single qualities satisfy

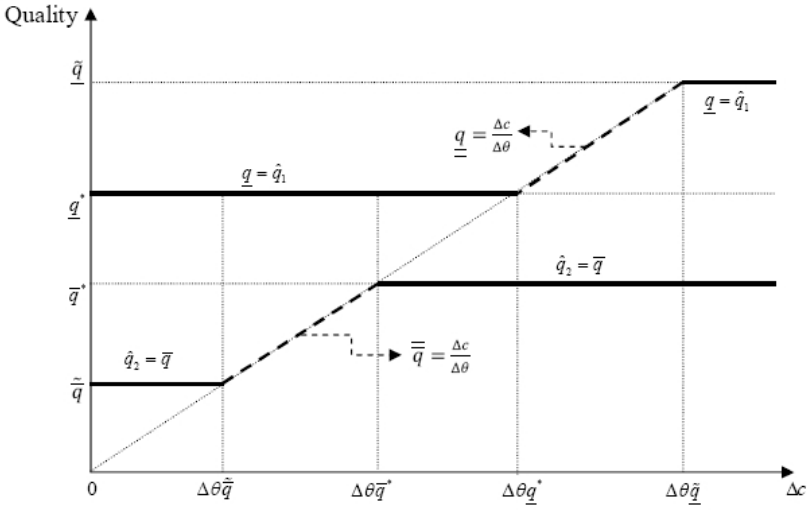

Figure 1: Quality path in $GC - IT$

the implementability conditions, this is convenient also under dominant strategies.

Symmetrically, for Δc sufficiently large ($\Delta c > \Delta\theta \underline{q}^*$), type $\overline{\theta}$ becomes prone to understate costs, *i.e.* countervailing incentives appear. The principal induces *upward* distortions in the quality commended for type $\underline{\theta}$. Initially (in $IT4$), in the Bayesian framework, it suffices to fix *expected* quality $\underline{\underline{q}}$ as large as exactly needed to prevent cheating by inefficient agents. If single qualities meet the implementability conditions, this is the best way to proceed under dominant strategies too. All surplus can be retained. As Δc further raises (in $IT5$), inefficiencies become more important. Single qualities $\underline{q}$ and $\widehat{q}_1$ are equally increased above the optimal level, trading off welfare loss and rent extraction from inefficient agents (who get $\overline{\Pi} = \Delta c - \Delta\theta \underline{\widetilde{q}}$).

Remark. From the description above, it emerges that $GC - IT$ displays strong similarities with the optimal mechanism Lewis and Sappington [16] and others characterize with regard to situations where the principal deals with a single agent. In fact, in the presence of countervailing incentives, multi-agent environments with independent types basically replicate single-agent environments. Indeed, for each type of agent, qualities and payoffs commended with two agents coincide with those designed with one agent[10] (see Figure 1 for an illustration of the quality path). The similarity with single-agent settings does not come as a surprise. It has root in that, in multi-agent settings with uncorrelated information, the principal is forced to behave as if she were facing one agent only, provided there is no informational externality between agents' announcements.

[10] In Bayesian settings, *expected* qualities in $IT2$ and $IT4$ coincide with the *single* qualities that would be commended with one agent. Single qualities are the same anywhere else. Under dominant strategies, there is perfect coincidence everywhere with the single qualities that would be commended with one agent. In particular, $\widehat{q}_2 = \overline{q} = \frac{\Delta c}{\Delta \theta}$ in $IT2$ and $\underline{q} = \widehat{q}_1 = \frac{\Delta c}{\Delta \theta}$ in $IT4$. Moreover, $\underline{\pi} = \widehat{\pi}_1 = \underline{\Pi}$ and $\widehat{\pi}_2 = \overline{\pi} = \overline{\Pi}$ in all regions, equal to the payoffs that would be assigned to a single agent.

4.2 Limited liability

When agents are unable to sustain unbounded losses, the optimal grand-contract has to additionally satisfy a set of limited liability constraints. The latter are written

$$\underline{LL} \quad : \quad \underline{\pi} \geq -l \tag{11a}$$
$$\widehat{LL}_1 \quad : \quad \widehat{\pi}_1 \geq -l \tag{11b}$$
$$\widehat{LL}_2 \quad : \quad \widehat{\pi}_2 \geq -l \tag{11c}$$
$$\overline{LL} \quad : \quad \overline{\pi} \geq -l, \tag{11d}$$

with l commonly known.

In fact, it turns out that limited liability never constrains the principal's programme. To see why, suppose it did. In that case, the optimal contract would yield the maximum admissible penalty to some agent's type in any state of nature, *i.e.* whatever the peer's announcement. This rests on that, absent correlation, at *interim*, the principal is unable to discriminate across possible states of nature for either type. Yet, such a contractual offer would not be individually rational, hence it would never be accepted. Therefore, wealth constraints on the agents' side impose no structure on the optimal grand-contract and the following proposition can be stated.

Proposition 2. *With independent types, in both Bayesian and dominant strategy environments, $GC-IT$ is the optimal grand-contract even when agents are protected by limited liability.*

Proposition 1 and 2 jointly channel a positive message. No matter how deep agents' pockets are, by creating countervailing incentives for her agents, the principal can implement the full information outcome in uncorrelated information settings, as both Bayesian and dominant strategy equilibria.

Remark. The literature has shown that first best is attained with correlation and state-contingency even when agents are protected by limited liability (Gary-Bobo and Spiegel [12]). Our analysis highlights that, when agents cannot bear unbounded losses, first best is at hand with countervailing incentives even if private information is independent. We thus enucleate situations where private information is (or can be made) irrelevant in uncorrelated environments, while the literature has identified various difficulties that make private information irrelevant in correlated information environments (Demougin and Garvie [9], Robert [24], Demski and Sappington [27], Bose and Zhao [4], Dequiedt and Martimort [11][11]).

[11] Bose and Zhao [4] explore situations in which correlated signals are fewer than types, so that surplus cannot be fully extracted from every type of agent. Dequiedt and Martimort [11] focus on a setting in which the principal can only sign bilateral contracts with each of her agents and the benefits from correlated information are reduced by the presence of non-manipulability constraints on the principal's side.

5 Correlated information

We now move to explore situations where private information is correlated. Under this circumstance, the principal can adopt benchmarking practices and/or induce yardstick competition between agents.

For sake of shortness, we restrict attention to the case of positive correlation since results are analogous, *mutatis mutandis*, with negative correlation. Specifically, it is $\rho > 0$ when, for either agent, the probability of finding a partner of some given type is higher when the agent himself is of that type.

5.1 Unlimited liability

The first step of the analysis consists in studying the optimal grand-contract when agents have infinitely deep pockets and their types are (imperfectly) correlated. Let

$$\begin{aligned} \underline{\widehat{q}} &\equiv \underline{\nu q} + (1-\underline{\nu})\,\widehat{q}_1 \quad \text{and} \quad \widehat{\overline{q}} \equiv \overline{\nu}\widehat{q}_2 + (1-\overline{\nu})\,\overline{q} \\ \underline{\widehat{\Pi}} &\equiv \underline{\nu \pi} + (1-\underline{\nu})\,\widehat{\pi}_1 \quad \text{and} \quad \widehat{\overline{\Pi}} \equiv \overline{\nu}\widehat{\pi}_2 + (1-\overline{\nu})\,\overline{\pi} \end{aligned}$$

the expected quality and payoff of each type. In the Bayesian framework, the principal offers the quadruplet of qualities and profits that maximize expected welfare

$$\begin{aligned} E_{(c,\theta)}[W] = \; & 2\nu_{11}\left[V\left(\underline{q}\right) - \left(\overline{c} + \underline{\theta q}\right) - \underline{\pi}\right] \\ & +2\nu_{12}\left[V\left(\widehat{q}_1\right) + V\left(\widehat{q}_2\right) - \left(\overline{c} + \underline{\theta}\widehat{q}_1\right) - \widehat{\pi}_1 - \left(\underline{c} + \overline{\theta}\widehat{q}_2\right) - \widehat{\pi}_2\right] \\ & +2\nu_{22}\left[V\left(\overline{q}\right) - \left(\underline{c} + \overline{\theta q}\right) - \overline{\pi}\right] \end{aligned} \tag{12}$$

subject to the incentive and participation constraints

$$\underline{BIC} : \underline{\widehat{\Pi}} \geq \underline{\nu}\widehat{\pi}_2 + (1-\underline{\nu})\,\overline{\pi} + \Delta\theta\widehat{\overline{q}} - \Delta c \tag{13a}$$

$$\overline{BIC} : \widehat{\overline{\Pi}} \geq \overline{\nu}\underline{\pi} + (1-\overline{\nu})\,\widehat{\pi}_1 - \Delta\theta\underline{\widehat{q}} + \Delta c \tag{13b}$$

$$\underline{PC} : \underline{\widehat{\Pi}} \geq 0 \tag{13c}$$

$$\overline{PC} : \widehat{\overline{\Pi}} \geq 0, \tag{13d}$$

Let us name this programme (B). Instead, under dominant strategies, the principal seeks to maximize (12) subject to (6a) to (6d), (13c), (13d) and (6a) to (6d). We denote this programme (D).

The solution to both (B) and (D) is known to be the full information outcome. From Crémer and McLean [7] we learn that, as long as types are correlated, the full information allocation is implemented and surplus entirely retained, provided agents are offered properly structured lotteries such that $\underline{\widehat{\Pi}} = \widehat{\overline{\Pi}} = 0$. This result holds true here as it does not rest on the agents' cost characteristics, which drive countervailing incentives in our

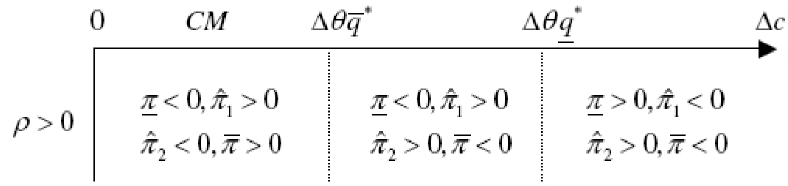

Figure 2: Summary scheme with positively correlated types in Bayesian settings

model. Therefore, with correlated types and unlimited liability, the presence (and/or the creation) of countervailing incentives is of no special value to the principal, provided she can circumvent the informational problem by simply exploiting type correlation. From Proposition 1, recall instead that, with independent information, countervailing incentives are essential for first best to arise (also) with unlimited liability.

To see how lotteries might be designed in correlated Bayesian frameworks when countervailing incentives arise, consider the case where the principal exactly saturates all constraints[12]. Then the profile of profits is given by

$$\underline{\pi} = -\frac{\nu_{12}}{\rho}(\nu_{12}+\nu_{22})\left(\Delta\theta\underline{q}^* - \Delta c\right) \tag{14a}$$

$$\widehat{\pi}_1 = \frac{\nu_{11}}{\rho}(\nu_{12}+\nu_{22})\left(\Delta\theta\underline{q}^* - \Delta c\right) \tag{14b}$$

$$\widehat{\pi}_2 = -\frac{\nu_{22}}{\rho}(\nu_{11}+\nu_{12})\left(\Delta\theta\overline{q}^* - \Delta c\right) \tag{14c}$$

$$\overline{\pi} = \frac{\nu_{12}}{\rho}(\nu_{11}+\nu_{12})\left(\Delta\theta\overline{q}^* - \Delta c\right). \tag{14d}$$

Looking at (14a) to (14d), it is straightforward to remark that profits sign depends upon the magnitude of Δc. This means that not only the profits of each type of agent are made contingent on the announcement about (and so, at equilibrium, on the realization of) the other agent's type. It is also found to depend on the specific realization of the agent's type itself. Because of this, the structure of *ex post* payoffs does not generally replicate the one that would result in the standard environment *à la* Crémer and McLean [7]. It solely does when cost uncertainty is small enough, in which case the way the principal assigns punishments and rewards is unaffected. Figure 2 provides a summary scheme of the signs profits take under positive correlation. The first region to the left (CM) is that within which profits take the same sign as in Crémer and McLean [7].

Similar considerations can be made as for dominant strategy environments. According to Demski and Sappington [27], with regard to classical two-agent two-type settings, dominant strategy implementation requires that a proper wedge be introduced between the two profits tailored on the two types an agent can have, for a given partner's type. For instance, the principal needs to fix $\underline{\pi}$ larger than $\widehat{\pi}_2$, so as to make cheating unattractive

[12] This requires that the matrix of prior beliefs be invertible, which is indeed the case with $\rho \neq 0$.

to efficient agents in the good state of nature. In the solution to (D), this strategy is optimal only for $\Delta c < \Delta\theta\overline{q}^*$, *i.e.* as long as efficient agents are prone to misrepresent private information as in standard adverse selection problems. By contrast, for $\Delta c > \Delta\theta\underline{q}^*$, the principal should rather set $\widehat{\pi}_2 > \underline{\pi}$, which makes cheating unappealing to inefficient agents. For $\Delta c \in (\Delta\theta\overline{q}^*, \Delta\theta\underline{q}^*)$, incentives to lie are sufficiently weak in either direction and it suffices to pool all profits at zero.

By now it should be clear that, in contexts where countervailing incentives may appear, offering properly structured lotteries to agents amounts to designing profits that exhibit state-dependence, *i.e.* profits that are contingent on the specific type realizations (and so on the magnitude of Δc). The following proposition can thus be stated to summarize results.

Proposition 3. *With correlated types and unlimited liability, the optimal grand-contract* $(GC - B/D)$ *implements the full information outcome for any value of* Δc, *both as a Bayesian-Nash and as a dominant strategy equilibrium, with state-dependent ex post payoffs.*

In what follows we take agents to be protected by limited liability and characterize the optimal grand-mechanism with regard to Bayesian and dominant strategy frameworks where private information is correlated.

5.2 Bayesian equilibria with limited liability

In Bayesian frameworks, the principal designs the optimal grand-contract by maximizing (12) subject to (13a) to (13d) and (11a) to (11d). We denote this programme (BL). The solution to (BL) is summarized in the proposition hereafter.

Proposition 4. *With positively correlated types and limited liability, the optimal grand-contract* $(GC - BL)$ *implements the full information outcome as a Bayesian-Nash equilibrium as long as* $\Delta c \in (\Delta\theta\overline{q}^* - \frac{\rho l}{\nu_{22}(\nu_{11}+\nu_{12})}, \Delta\theta\underline{q}^* + \frac{\rho l}{\nu_{11}(\nu_{12}+\nu_{22})})$[13]. *Four further regions are relevant, in which qualities and payoffs are characterized as follows.*

BL1) $\Delta c \in [0,\ \Delta\theta\widehat{\overline{Q}} - \frac{\rho l}{\nu_{22}(\nu_{11}+\nu_{12})})$, *where* $\widehat{\overline{Q}} \equiv \overline{\nu}\widehat{Q}_2 + (1-\overline{\nu})\overline{Q}$ *with* $\widehat{Q}_2$ *and* $\overline{Q}$ *as pinned down by* (15b) *below:*

$$\underline{q} = \widehat{q}_1 = \underline{q}^* \tag{15a}$$

$$V'(\widehat{q}_2) = \overline{\theta} + \frac{\nu_{11}}{\nu_{12}}\Delta\theta; \qquad V'(\overline{q}) = \overline{\theta} + \frac{\nu_{12}}{\nu_{22}}\Delta\theta \tag{15b}$$

$$\widehat{\underline{\Pi}} = \left(\Delta\theta\widehat{\overline{q}} - \Delta c\right) - \frac{\rho l}{\nu_{22}(\nu_{11}+\nu_{12})} \tag{15c}$$

$$\widehat{\widehat{\Pi}} = 0, \tag{15d}$$

[13] For future reference, we denote this region $BL3$.

with profits

$$\widehat{\pi}_2 = -l \quad \textit{and} \quad \overline{\pi} = \frac{\nu_{12}}{\nu_{22}} l.$$

BL2) $\Delta c \in (\Delta\theta\widehat{\overline{Q}} - \frac{\rho l}{\nu_{22}(\nu_{11}+\nu_{12})}, \Delta\theta\overline{q}^* - \frac{\rho l}{\nu_{22}(\nu_{11}+\nu_{12})})$:

$$\underline{q} = \widehat{q}_1 = \underline{q}^* \tag{16a}$$

$$\widehat{\overline{q}} = \frac{1}{\Delta\theta}\left[\Delta c + \frac{\rho l}{\nu_{22}(\nu_{11}+\nu_{12})}\right] \tag{16b}$$

$$\underline{\widehat{\Pi}} = 0 \tag{16c}$$

$$\widehat{\overline{\Pi}} = 0, \tag{16d}$$

with profits

$$\widehat{\pi}_2 = -l \quad \textit{and} \quad \overline{\pi} = \frac{\nu_{12}}{\nu_{22}} l$$

BL4) $\Delta c \in (\Delta\theta\underline{q}^* + \frac{\rho l}{\nu_{11}(\nu_{12}+\nu_{22})}, \Delta\theta\underline{\widehat{Q}} + \frac{\rho l}{\nu_{11}(\nu_{12}+\nu_{22})})$, *where* $\underline{\widehat{Q}} \equiv \underline{\nu}\underline{Q} + (1-\underline{\nu})\widehat{Q}_1$ *with* $\underline{Q}$ *and* $\widehat{Q}_1$ *as pinned down by* (18a) *below:*

$$\underline{\widehat{q}} = \frac{1}{\Delta\theta}\left[\Delta c - \frac{\rho l}{\nu_{11}(\nu_{12}+\nu_{22})}\right] \tag{17a}$$

$$\widehat{q}_2 = \overline{q} = \overline{q}^* \tag{17b}$$

$$\underline{\widehat{\Pi}} = 0 \tag{17c}$$

$$\widehat{\overline{\Pi}} = 0, \tag{17d}$$

with profits

$$\underline{\pi} = \frac{\nu_{12}}{\nu_{11}} l \quad \textit{and} \quad \widehat{\pi}_1 = -l.$$

BL5) $\Delta c > \Delta\theta\underline{\widehat{Q}} + \frac{\rho l}{\nu_{11}(\nu_{12}+\nu_{22})}$:

$$V'(\underline{q}) = \underline{\theta} - \frac{\nu_{12}}{\nu_{11}}\Delta\theta; \quad V'(\widehat{q}_1) = \underline{\theta} - \frac{\nu_{22}}{\nu_{12}}\Delta\theta \tag{18a}$$

$$\widehat{q}_2 = \overline{q} = \overline{q}^* \tag{18b}$$

$$\underline{\widehat{\Pi}} = 0 \tag{18c}$$

$$\widehat{\overline{\Pi}} = \left(\Delta c - \Delta\theta\underline{\widehat{q}}\right) - \frac{\rho l}{\nu_{11}(\nu_{12}+\nu_{22})}, \tag{18d}$$

with profits

$$\underline{\pi} = \frac{\nu_{12}}{\nu_{11}} l \quad \text{and} \quad \widehat{\pi}_1 = -l.$$

5.2.1 Description of $GC - BL$

As long as Δc is sufficiently small $(BL1)$, outside opportunities are irrelevant and the principal faces the classical adverse selection problem. That is, $\underline{\theta}-$agents would like to *overstate* costs and pretend to be inefficient. Hence, quality is set at the full information efficient level for type $\underline{\theta}$, whatever the partner's type. However, an expected rent is given up to provide incentives to this type of agent. As the rent increases with the qualities commanded from type $\overline{\theta}$, both $\widehat{q}_2$ and $\overline{q}$ are downward distorted. With positive correlation, the optimal distortion is smaller for a pair of $\overline{\theta}-$agents than it is when the $\overline{\theta}-$agent is coupled with a $\underline{\theta}-$agent[14]. Indeed, this allows to minimize expected inefficiency. Since agents are more likely to be of the same type, the principal gives up more efficiency in the less probable states of nature, *i.e.* when agents' differ in type. One thus has $\widehat{Q}_2 < \overline{Q} < \underline{q}^*$. All *ex ante* surplus is extracted from the quality-inefficient agent. This is made by assigning the minimum possible payoff $(-l)$ to a $\overline{\theta}-$agent that is coupled with a $\underline{\theta}-$agent. To see why, recall that, for Δc small, the type that has incentive to cheat is $\underline{\theta}$. Now suppose agent 1 has this type and does mimic type $\overline{\theta}$. Then, as long as agent 2 truthtells, under positive correlation, the principal is more likely to face a $\left(\overline{\theta}_1, \underline{\theta}_2\right)-$pair than a $\left(\overline{\theta}_1, \overline{\theta}_2\right)-$pair. In the former state, the limited liability constraint binds because the principal would like to inflict a penalty larger than $-l$. Under limited liability, this is unfeasible and the best the principal can do is to assign the maximum admissible punishment. Clearly, under the requirements of *interim* participation, this involves that the *ex post* payoff is positive for a $\overline{\theta}-$agent who is coupled with a $\overline{\theta}-$agent. More precisely, it is given by the complement to $-l$ that allows the agent to break even in expectation.

For Δc larger but not too big $(BL2)$, the optimal contract still entails no distortion at the top of the type distribution. That is, a $\underline{\theta}-$agent is required to provide efficient qualities in any state of nature. However, because the outside opportunities he faces are now more attractive, the principal finds it harder to keep this agent in the contract. Yet the principal can still hold him at his reservation utility level by distorting the $\overline{\theta}-$agent's *expected* quality just enough to prevent cheating. Once *interim* participation is secured in an incentive-compatible way, single qualities $\widehat{q}_2$ and $\overline{q}$ are irrelevant and remain here undefined.

For intermediate values of Δc $(BL3)$, incentives to cheat are sufficiently weak that the full information outcome entails. That is, all qualities are fixed at the efficient level and expected surplus entirely retained. Profits (14a) to (14d) remain feasible as long as

$$\Delta\theta(\underline{q}^* - \overline{q}^*) \leq \frac{\rho^2 l}{\nu_{22}\nu_{12}\left(\nu_{11}+\nu_{12}\right)\left(\nu_{12}+\nu_{22}\right)}. \tag{19}$$

The left-hand side of (19) can be interpreted as a measure of uncertainty about quality

[14] With $\rho > 0$, it is $\left(\nu_{11}/\nu_{12}\right) > \left(\nu_{12}/\nu_{22}\right)$.

costs, with qualities efficiently set. Condition (19) requires that such a measure be sufficiently small. *Ceteris paribus*, (19) relaxes when *(i)* type correlation is high, so that enough information is conveyed about agents' types, and *(ii)* agents' pockets are deep, so that the principal enjoys more freedom at designing lotteries. On the opposite, (19) is never satisfied when $l = 0$, *i.e.* when agents' participation is to be ensured *ex post* rather than at *interim*[15].

As Δc grows enough $(BL4)$, agents of type $\overline{\theta}$ start being attracted by the contractual offer the principal designs for type $\underline{\theta}$, whose outside options are now particularly good. Incentives to cheat begin to arise for $\overline{\theta}-$agents, who are tempted to *understate* costs and pretend to be efficient. The principal is still able to hold both types of agents at zero expected surplus, but she has to give up some efficiency in setting qualities for type $\underline{\theta}$. More precisely, the *expected* quality commanded from a $\underline{\theta}-$agent is upward distorted as much as it is necessary to ensure that inefficient agents are unwilling to cheat, while single qualities are undefined. For $\rho > 0$, *ex ante* surplus is extracted from type $\underline{\theta}$ giving up an *ex post* benefit to a $\underline{\theta}-$agent that is coupled with an agent of analogous type. Instead, the minimum possible payoff is assigned to a $\underline{\theta}-$agent that is coupled with a peer of different type, for whom the limited liability constraint binds. The explanation for this goes along the line illustrated for region $BL1$. Suppose agent 1 has type $\overline{\theta}$ and does mimic type $\underline{\theta}$. Provided agent 2 truthtells, under positive correlation, the principal is more likely to face a $\left(\underline{\theta}_1, \overline{\theta}_2\right)-$pair than a $\left(\underline{\theta}_1, \underline{\theta}_2\right)-$pair. As above, the largest penalty accrues in the former situation, in which the principal cannot punish the liar as severely as she would like to.

Lastly, when Δc is very large $(BL5)$, *i.e.* very appealing outside opportunities are available for efficient agents, countervailing incentives intensify. Inefficient agents are prone to pretend to be efficient as they are attracted by the contractual offer the principal designs for $\underline{\theta}-$agents. The optimal strategy for the principal is to fix qualities at the efficient level for agents of type $\overline{\theta}$, while leaving them with a positive expected rent so as to prevent cheating. This rent is contained by upward distorting single qualities $\underline{q}$ and $\widehat{q}_1$, which are again both defined in region $BL5$. *Ex ante*, any surplus can be extracted from type $\underline{\theta}$. The profile of profits is kept as in region $BL4$ for the reason there illustrated.

Remark. In some respect, $GC - BL$ is reminiscent of the optimal single-agent contract characterized by Gary-Bobo and Spiegel [12]. In their model, the principal either implements first best (as here in $BL3$) or induces the classical adverse selection solution (as here in $BL1$). Which situation actually materializes depends upon how the efficient type's reservation utility compares with the expected payoff this type would obtain by lying, provided the inefficient type's performance were set at the first-best level. First best is decentralized when this payoff does not exceed the zero reservation utility. This

[15] Having $l = 0$ is tantamount to replacing *interim* participation and limited liability constraints with *ex post* participation constraints.

requires that the degree of correlation and/or the maximum admissible loss, which is assigned to prevent the efficient type from cheating, be large enough. In our framework, these requirements are needed for implementation of profits (14a) to (14d)[16], while they are not for first-best implementation. Indeed, in $GC-BL$, the full information outcome unconditionally arises when outside opportunities are sufficiently appealing that agents are turned between opposite incentives. Under those circumstances, agents' liability is irrelevant and profits remain undefined. The classical adverse selection solution appears in $GC-BL$ only when outside options are insignificant. In that case, punishments are necessary to contrast efficient agents' desire to lie in the good state, in which the biggest feasible penalty is indeed assigned.

5.3 Dominant strategy equilibria with limited liability

We now move to investigate environments where the principal seeks to induce information revelation as a dominant strategy under limited liability on the agents' side. In this setting, the optimal grand-contract is the one that maximizes (12) subject to (13c), (13d), (6a) to (6d) and (11a) to (11d). The solution to this programme, denoted (DL), is summarized in the proposition hereafter.

Proposition 5. *With positively correlated types and limited liability, the optimal grand-contract* $(GC-DL)$ *implements the full information outcome in dominant strategies as long as* $\Delta c \in (\Delta\theta\overline{q}^*,\ \Delta\theta\underline{q}^*)$[17]. *Eight further regions are relevant, in which qualities and payoffs are characterized as follows.*

*DL*1) $\Delta c \in [0,\ \Delta\theta\widehat{Q}_2)$:

$$\underline{q} = \widehat{q}_1 = \underline{q}^* \tag{20a}$$

$$\widehat{q}_2 = \widehat{Q}_2; \quad \overline{q} = \overline{Q} \tag{20b}$$

$$\underline{\widehat{\Pi}} = (\Delta\theta\widehat{\overline{q}} - \Delta c) - \frac{\rho l}{\nu_{22}(\nu_{11}+\nu_{12})} \tag{20c}$$

$$\widehat{\overline{\Pi}} = 0 \tag{20d}$$

with profits

$$\underline{\pi} = \Delta\theta\widehat{q}_2 - \Delta c - l \quad \textit{and} \quad \widehat{\pi}_1 = \Delta\theta\overline{q} - \Delta c + \frac{\nu_{12}}{\nu_{22}} l$$

$$\widehat{\pi}_2 = -l \quad \textit{and} \quad \overline{\pi} = \frac{\nu_{12}}{\nu_{22}} l.$$

[16] Recall condition (19).

[17] For future reference, we denote this region $DL5$.

$DL2)\quad \Delta c \in (\Delta\theta\widehat{Q}_2,\, \Delta\theta\overline{Q} - \frac{\rho l}{\nu_{12}\nu_{22}}):$

$$\begin{aligned} \underline{q} &= \widehat{q}_1 = \underline{q}^* && (21a)\\ \widehat{q}_2 &= \frac{\Delta c}{\Delta\theta}; \quad \overline{q} = \overline{Q} && (21b)\\ \widehat{\underline{\Pi}} &= (1-\underline{\nu})\left(\Delta\theta\overline{q} - \Delta c\right) - \frac{\rho l}{\nu_{22}\left(\nu_{11}+\nu_{12}\right)} && (21c)\\ \widehat{\overline{\Pi}} &= 0 && (21d) \end{aligned}$$

with profits

$$\begin{aligned} \underline{\pi} &= -l \quad \textit{and} \quad \widehat{\pi}_1 = \Delta\theta\overline{q} - \Delta c + \frac{\nu_{12}}{\nu_{22}}l\\ \widehat{\pi}_2 &= -l \quad \textit{and} \quad \overline{\pi} = \frac{\nu_{12}}{\nu_{22}}l. \end{aligned}$$

$DL3)\quad \Delta c \in (\Delta\theta\overline{Q} - \frac{\rho l}{\nu_{12}\nu_{22}},\, \Delta\theta\overline{q}^* - \frac{\rho l}{\nu_{12}\nu_{22}}):$

$$\begin{aligned} \underline{q} &= \widehat{q}_1 = \underline{q}^* && (22a)\\ \widehat{q}_2 &= \frac{\Delta c}{\Delta\theta}; \quad \overline{q} = \frac{1}{\Delta\theta}\left(\Delta c + \frac{\rho l}{\nu_{12}\nu_{22}}\right) && (22b)\\ \widehat{\underline{\Pi}} &= 0 && (22c)\\ \widehat{\overline{\Pi}} &= 0 && (22d) \end{aligned}$$

with profits

$$\begin{aligned} \underline{\pi} &= -l \quad \textit{and} \quad \widehat{\pi}_1 = \frac{\nu_{11}}{\nu_{12}}l\\ \widehat{\pi}_2 &= -l \quad \textit{and} \quad \overline{\pi} = \frac{\nu_{12}}{\nu_{22}}l. \end{aligned}$$

$DL4)\quad \Delta c \in (\Delta\theta\overline{q}^* - \frac{\rho l}{\nu_{12}\nu_{22}},\, \Delta\theta\overline{q}^*):$

$$\begin{aligned} \underline{q} &= \widehat{q}_1 = \underline{q}^* && (23a)\\ \widehat{q}_2 &= \frac{\Delta c}{\Delta\theta}; \quad \overline{q} = \overline{q}^* && (23b)\\ \widehat{\underline{\Pi}} &= 0 && (23c)\\ \widehat{\overline{\Pi}} &= 0 && (23d) \end{aligned}$$

with profits

$$\begin{aligned} \underline{\pi} &= -l \quad \textit{and} \quad \widehat{\pi}_1 = \frac{\nu_{11}}{\nu_{12}}l\\ \widehat{\pi}_2 &= -l \quad \textit{and} \quad \overline{\pi} = \frac{\nu_{12}}{\nu_{22}}l. \end{aligned}$$

$DL6)\quad \Delta c \in (\Delta\theta \underline{q}^*,\, \Delta\theta \underline{q}^* + \frac{\rho l}{\nu_{11}\nu_{12}}):$

$$\underline{q} = \underline{q}^*; \quad \widehat{q}_1 = \frac{\Delta c}{\Delta\theta} \tag{24a}$$
$$\widehat{q}_2 = \overline{q} = \overline{q}^* \tag{24b}$$
$$\widehat{\underline{\Pi}} = 0 \tag{24c}$$
$$\widehat{\overline{\Pi}} = 0, \tag{24d}$$

with profits

$$\underline{\pi} = \frac{\nu_{12}}{\nu_{11}} l \quad \textit{and} \quad \widehat{\pi}_1 = -l$$
$$\widehat{\pi}_2 = \frac{\nu_{22}}{\nu_{12}} l \quad \textit{and} \quad \overline{\pi} = -l$$

$DL7)\quad \Delta c \in (\Delta\theta \underline{q}^* + \frac{\rho l}{\nu_{11}\nu_{12}},\, \Delta\theta \underline{Q} + \frac{\rho l}{\nu_{11}\nu_{12}}):$

$$\underline{q} = \frac{1}{\Delta\theta}\left(\Delta c - \frac{\rho l}{\nu_{11}\nu_{12}}\right); \qquad \widehat{q}_1 = \frac{\Delta c}{\Delta\theta} \tag{25a}$$
$$\widehat{q}_2 = \overline{q} = \overline{q}^* \tag{25b}$$
$$\widehat{\underline{\Pi}} = 0 \tag{25c}$$
$$\widehat{\overline{\Pi}} = 0 \tag{25d}$$

with profits

$$\underline{\pi} = \frac{\nu_{12}}{\nu_{11}} l \quad \textit{and} \quad \widehat{\pi}_1 = -l$$
$$\widehat{\pi}_2 = \frac{\nu_{22}}{\nu_{12}} l \quad \textit{and} \quad \overline{\pi} = -l.$$

$DL8)\quad \Delta c \in (\Delta\theta \underline{Q} + \frac{\rho l}{\nu_{11}\nu_{12}},\, \Delta\theta \widehat{Q}_1):$

$$\underline{q} = \underline{Q}; \quad \widehat{q}_1 = \frac{\Delta c}{\Delta\theta} \tag{26a}$$
$$\widehat{q}_2 = \overline{q} = \overline{q}^* \tag{26b}$$
$$\widehat{\underline{\Pi}} = 0 \tag{26c}$$
$$\widehat{\overline{\Pi}} = \overline{\nu}\left(\Delta c - \Delta\theta \underline{q}\right) - \frac{\rho l}{\nu_{11}\left(\nu_{12} + \nu_{22}\right)} \tag{26d}$$

with profits

$$\underline{\pi} = \frac{\nu_{12}}{\nu_{11}} l \quad \textit{and} \quad \widehat{\pi}_1 = -l$$
$$\widehat{\pi}_2 = \Delta c - \Delta\theta \underline{q} + \frac{\nu_{12}}{\nu_{11}} l \quad \textit{and} \quad \overline{\pi} = -l.$$

$DL9)\quad \Delta c > \Delta\theta \widehat{Q}_1:$

$$\begin{aligned} \underline{q} &= \underline{Q}; \quad \widehat{q}_1 = \widehat{Q}_1 && (27a)\\ \widehat{q}_2 &= \overline{q} = \overline{q}^* && (27b)\\ \widehat{\underline{\Pi}} &= 0 && (27c)\\ \widehat{\overline{\Pi}} &= \left(\Delta c - \Delta\theta \widehat{\underline{q}}\right) - \frac{\rho l}{\nu_{11}\left(\nu_{12}+\nu_{22}\right)} && (27d) \end{aligned}$$

with profits

$$\begin{aligned} \underline{\pi} &= \frac{\nu_{12}}{\nu_{11}} l \quad \textit{and} \quad \widehat{\pi}_1 = -l\\ \widehat{\pi}_2 &= \Delta c - \Delta\theta \underline{q} + \frac{\nu_{12}}{\nu_{11}} l \quad \textit{and} \quad \overline{\pi} = \Delta c - \Delta\theta \widehat{q}_1 - l. \end{aligned}$$

5.3.1 Description of $GC - DL$

For very small and very large values of Δc, the mechanism that solves (DL) is the one that has been found to solve (BL). More precisely, qualities and rents in $DL1$ and $DL9$ replicate those in $BL1$ and $BL5$ respectively[18]. The sole specificity to $GC - DL$ is that *ex post* payoffs are defined also for the type that wishes to cheat, provided both incentive constraints bind for this type of agent. This signals that, both when outside opportunities are negligible and when they are greatly attractive, eliciting self-selection is so hard for the principal, that the nature of agents' strategies becomes irrelevant and the two programmes pin down the same solution, up to profits determination.

As Δc raises (in $DL2$ to $DL4$), the principal starts reducing the distortion in the quality commanded from type $\overline{\theta}$ in the more productive state. Specifically, $\widehat{q}_2$ is distorted downward till both $\underline{DIC}$ is exactly satisfied jointly with $\underline{LL}$. Saturating these constraints ensures that an efficient agent does not gain from cheating (and is thus unwilling to do so) when coupled with an agent of analogous type and that his payoff does not fall below the minimum threshold *ex post*. It is because of correlation and limited liability that $\underline{DIC}$ is now less stringent than in $DL1$. Under positive correlation, the principal would like to decrease the $\overline{\theta}-$agent's *ex post* payoff in the more productive state, which is more likely to materialize in the event of cheating. Limited liability makes this unfeasible and rather forces the principal to reward the $\underline{\theta}-$agent in the more productive state, which is more likely to realize in case of truthtelling. Quality $\widehat{q}_2$ is then raised to reduce this reward as much as possible ($\underline{\pi} = -l$).

In $DL2$, Δc remains small enough that $\widehat{DIC}_1$ cannot be exactly satisfied, in turn. This is so because *interim* participation requires that the $\overline{\theta}-$agent get higher profits in

[18] Recall the description of $GC - BL$.

the less productive state, once payoff $-l$ is assigned in the other state. Thus the quality commanded from type $\overline{\theta}$ in the less productive state remains fixed as in $DL1$. This allows the principal to contain the rent she concedes to efficient agents, which increases with quality $\overline{q}$ only. It is thus explained why, despite positive correlation involves that agents are more likely to be of the same type, the principal starts decreasing inefficiency in the quality the $\overline{\theta}-$type is commanded in the more productive state.

As Δc grows enough $(DL3)$, the principal can induce less severe a distortion also in the quality commanded from type $\overline{\theta}$ when the partner's report is $\overline{\theta}$. Specifically, $\overline{q}$ is downward distorted till both $\widehat{\underline{DIC}}_1$ and $\underline{PC}$ are exactly met. Saturating these constraints makes sure that an efficient agent does not benefit from lying (and is thus unwilling to do so) when coupled with an inefficient agent and that he is available to participate at *interim*, provided he gets profits equal to $-l$ when the good state realizes. This strategy allows the principal to retain all expected surplus with contained allocative inefficiencies. However, given the profits assigned to agents' types in the different states, $\underline{DIC}$, $\underline{LL}$, $\widehat{\underline{DIC}}_1$ and $\underline{PC}$ can only be saturated altogether if $\overline{q}$ is set larger than $\widehat{q}_2$, the gap increasing in the degree of correlation. Hence, as compared to $\widehat{q}_2$, $\overline{q}$ attains the efficient level for a smaller value of Δc and this value is lower the higher ρ. In $DL4$, quality $\widehat{q}_2$ is still distorted so as to saturate $\underline{DIC}$ and $\underline{LL}$. Yet, this is the sole persisting distortion, which is removed in $DL5$.

As the mechanisms previously presented, $GC - DL$ exhibits mirror features in the regions to the right of that where the full information outcome attains.

In $DL6$ to $DL8$, countervailing incentives appear and become increasingly more intense. In $DL6$, Δc is still sufficiently small that $\widehat{\overline{DIC}}_2$ remains slack, but $\overline{DIC}$ starts tightening. The principal keeps $\underline{q} = \underline{q}^*$, but she begins to upward distort the quality commanded from type $\underline{\theta}$ in the less productive state till the point where $\overline{DIC}$ is exactly satisfied together with $\overline{LL}$. Saturating these constraints warrants that an inefficient agent does not gain from cheating (and is not induced to do so) when he has a partner of analogous type and that he precisely receives the minimum admissible profits. Again, this solution is convenient because, while the principal would like to decrease the $\underline{\theta}-$agent's *ex post* payoff in the less productive state, wealth constraints rather require that the $\overline{\theta}-$agent be rewarded in the less productive state. Then, raising $\widehat{q}_1$ allows to reduce this reward as much as possible $(\overline{\pi} = -l)$.

In $DL7$, outside options are sufficiently large that an incentive to cheat begins to appear for type $\overline{\theta}$ also in the bad state. Observe, however, that the larger ρ, the larger the value of Δc at which this incentive arises. At that stage, the principal distorts upward also the quality commanded from type $\underline{\theta}$ in the more productive state till the point where $\widehat{\overline{DIC}}_2$ is exactly satisfied together with $\overline{PC}$. This makes sure that an inefficient agent does not benefit from (and is thus uninterested in) lying when he has an efficient peer and that he is available to participate at *interim*, provided he is assigned profits equal to $-l$ when the bad state materializes. As above, by adopting this strategy, the principal retains all expected surplus with limited allocative inefficiencies. For $\overline{DIC}$, $\overline{LL}$, $\widehat{DIC}_2$ and $\overline{PC}$ to be saturated altogether, it is necessary that $\underline{q}$ be fixed smaller than $\widehat{q}_1$, the difference increasing in the degree of correlation. As compared to $\widehat{q}_1$, $\underline{q}$ attains its maximum distortion at a lower value of Δc, though this value increases with ρ. Thus, in $DL8$, one has $\underline{q} = \underline{Q}$, while quality $\widehat{q}_1$ is still distorted so as to saturate $\overline{DIC}$ together with $\overline{LL}$, till the latter becomes slack (in $DL9$).

6 Comparisons and discussion

So far we have characterized and described the main features of the optimal incentive mechanism in the presence of uncorrelated and correlated private information, ranging from Bayesian to dominant strategy settings. We now turn to compare the principal's strategies and achievements in the various environments so as to highlight and discuss the role of correlation and the impact of limited liability in the context of our interest, namely when agents display countervailing incentives.

6.1 The structure of the grand-contracts

Our analysis evidences that, in all considered environments, the basic structure of the optimal incentive mechanism is reminiscent of that of the optimal single-agent contract characterized by Lewis and Sappington [16], among others. This signals that the structure does not rest on number and types of agents, degree of correlation and wealth constraints. It is rather dictated by the nature of agents' incentives, which triggers state-dependence.

The presence of wealth constraints involves that, despite correlation, both $GC - BL$ and $GC - DL$ implement the full information outcome only for a restricted set of values of Δc (region $BL3$ and $DL5$ respectively). In $GC - BL$, this set is larger than it is in $GC - IT$, unless $l = 0$. Instead, in $GC - DL$, the set is as big as in $GC - IT$. This means that, in Bayesian frameworks, the presence of correlation, and thus the possibility of inducing yardstick competition between agents, allows the principal to achieve efficiency and extract rents more often than with independent information. By contrast, under dominant strategies, correlation does not deliver analogous benefit. Because incentive compatibility is to be met for each type of agent in either state of nature, more structure is imposed on the optimal mechanism. An implication of this is that first best arises equally often, whether private information is correlated or not. That is, as long as the principal seeks to solicit information revelation as a dominant strategy, she will be able to implement the full information outcome only to the extent that countervailing incentives allow for. Yardstick competition will not be useful from this perspective.

In $GC-IT$, $GC-BL$ and $GC-DL$, the full information outcome is beyond reach in all regions other than $IT3$, $BL3$ and $DL5$ respectively. The three contracts share the feature that allocative distortions move from the bottom to the top of the type distribution and expected rents from the top to the bottom as the outside options available to efficient agents become increasingly more attractive and the principal's offer targeted to those agents increasingly more appealing to inefficient agents[19].

6.2 Allocations

Despite the similarities just pointed out, quality profiles display several differences across the environments of our interest. In Bayesian frameworks, single qualities are not necessarily determined in the contract, whether information is independent or correlated. Specifically, *expected* qualities appear in $IT2$ and $IT4$ with independent types and in $BL2$ and $BL4$ with correlated information[20]. In those regions, the principal gives up the possibility of differentiating qualities across states. She only makes sure that the mimicking type's incentive constraint, which is written in expectation over the two possible states of nature, is exactly satisfied without compromising *interim* participation. This does not mean that there is no benefit from correlation in the regions under scrutiny. On the opposite, in $BL2$ and $BL4$, correlation brings expected qualities closer to the efficient level, as compared to $IT2$ and $IT4$. Indeed, one respectively has $\overline{q}^* > \widehat{\overline{q}} = \frac{\Delta c}{\Delta\theta} + \frac{\rho l}{\nu_{22}(\nu_{11}+\nu_{12})\Delta\theta} > \overline{\overline{q}} = \frac{\Delta c}{\Delta\theta}$ and $\underline{q}^* < \widehat{\underline{q}} = \frac{\Delta c}{\Delta\theta} - \frac{\rho l}{\nu_{11}(\nu_{12}+\nu_{22})\Delta\theta} < \underline{\underline{q}} = \frac{\Delta c}{\Delta\theta}$.

On the other hand, dominant strategy incentive compatibility requires that *single* qualities be always defined in the optimal grand-contract, whether information is independent or correlated. This directly results from the circumstance that, for each type of agent, two incentive constraints are to be met, one for each of the possible reports on the partner's type. While, in $IT2$ and $IT4$, the two qualities attached to the mimicking type are set equal and such that $\widehat{q}_2 = \overline{q} = \frac{\Delta c}{\Delta\theta}$ and $\widehat{q}_1 = \underline{q} = \frac{\Delta c}{\Delta\theta}$ respectively, in $DL3$ and $DL7$ those qualities are differentiated across states of nature. Once again, this is made taking advantage of information correlation. With $\rho > 0$, it pays to reduce the distortion in the more likely situation. Hence, one has $\overline{q} = \frac{\Delta c}{\Delta\theta} + \frac{\rho l}{\nu_{12}\nu_{22}\Delta\theta} > \widehat{q}_2 = \frac{\Delta c}{\Delta\theta}$ in $DL3$ and $\underline{q} = \frac{\Delta c}{\Delta\theta} - \frac{\rho l}{\nu_{11}\nu_{12}\Delta\theta} < \widehat{q}_1 = \frac{\Delta c}{\Delta\theta}$ in $DL7$. This signals that correlation is not exploited to ameliorate quality in the less likely case for either type of agent. Thus that quality remains the same as with independent types. Yet, correlation does bring quality closer to the efficient level in the more likely state. Noticeably, given the liability threshold, this benefit

[19] While in our model upward distortions arise for the efficient type, in Kessler, Lülfesmann and Schmitz [15] they appear for the inefficient type. In our environment, they are driven by the presence of countervailing incentives, in theirs by the imposition of an upper bound on the transfers from the agent to the principal.

[20] Here and in the sequel of the text, comparisons between correlated and uncorrelated environments refer to the characteristics of the contracts in the various regions. They regard size and/or location of the regions only when specified.

increases as the informational externality between agents becomes more important.

Correlation does appear to improve upon qualities in either setting. Yet, in general, it is unclear whether the principal prefers the allocation that arises under $GC-BL$ or $GC-DL$. To clarify this point, we represent the quality profile in $GC-DL$ and that in $GC-BL$ altogether in Figure 3, in the top and bottom graph respectively. For sake of shortness, in the top graph, we use the following notation: $\eta \equiv \Delta\theta\widehat{Q}_2$, $\iota \equiv \Delta\theta\overline{Q} - \frac{\rho l}{\nu_{12}\nu_{22}}$, $\kappa \equiv \Delta\theta\overline{q}^* - \frac{\rho l}{\nu_{12}\nu_{22}}$, $\mu \equiv \Delta\theta\overline{q}^*$, $\varpi \equiv \Delta\theta\underline{q}^*$, $\vartheta \equiv \Delta\theta\underline{q}^* + \frac{\rho l}{\nu_{11}\nu_{12}}$, $\sigma \equiv \Delta\theta\underline{Q} + \frac{\rho l}{\nu_{11}\nu_{12}}$ and $\varsigma \equiv \Delta\theta\widehat{Q}_1$. Easy to remark, in the graph, each quality has an autonomous path, as dictated by dominant strategy incentive compatibility. In the bottom graph, instead, the notation is as follows: $\alpha \equiv \Delta\theta\widehat{\overline{Q}} - \frac{\rho l}{\nu_{22}(\nu_{11}+\nu_{12})}$; $\beta \equiv \Delta\theta\overline{q}^* - \frac{\rho l}{\nu_{22}(\nu_{11}+\nu_{12})}$; $\gamma \equiv \Delta\theta\underline{q}^* + \frac{\rho l}{\nu_{11}(\nu_{12}+\nu_{22})}$; $\delta \equiv \Delta\theta\widehat{\underline{Q}} + \frac{\rho l}{\nu_{11}(\nu_{12}+\nu_{22})}$. Possible qualities are represented by dashed lines for $\Delta c \in (\alpha, \beta)$ and for $\Delta c \in (\gamma, \delta)$ because, for the reasons previously explained, $GC-BL$ solely defines *expected* qualities in those intervals (the dotted lines in the graph)[21]. One can check that, as far as allocations are concerned, the two contracts are strictly equivalent for the principal within the intervals $(0, \eta)$, (μ, ϖ) and $(\varsigma, +\infty)$. In expected terms, they are equivalent in (ι, κ) and (ϑ, σ). Moreover, $GC-DL$ dominates in (η, α) and (δ, ς), $GC-BL$ in (β, μ) and (ϖ, γ). However, in the other intervals, it is not evident how quality profiles compare in expectation.

A complete quality parallel is made more difficult by the fact that relevant regions do not coincide. Their size and location vary in the different contexts. In $GC-BL$, all regions are affected by correlation. The higher ρ, the smaller the regions in which distortions are more severe ($BL1$ and $BL5$) as well as that in which the full information outcome is implemented ($BL3$)[22]. By contrast, in $GC-DL$, neither the size of the regions in which distortions (and rents) are largest ($DL1$ and $DL9$) nor that of the region in which first best attains ($DL5$) depends upon ρ. On the other hand, the size of the regions in which qualities are first distorted and then efficiently set in the more likely state raises with correlation ($DL2$ and $DL8$ as well as $DL4$ and $DL6$ respectively).

6.3 Rents

Not only allocations but also rent profiles exhibit both similarities and differences across the environments we look at. In both Bayesian and dominant strategy settings, correlation improves on expected rents through a double channel. Firstly, it allows for a straight abatement in the amount of surplus left to agents. To see this, observe that, both in $BL1$ (resp.ly, $BL5$) and in $DL1$ and $DL2$ (resp.ly, $DL8$ and $DL9$), the rent given up to type $\underline{\theta}$ (resp.ly, $\overline{\theta}$) is diminished by $\frac{\rho l}{\nu_{22}(\nu_{11}+\nu_{12})}$ (resp.ly, $\frac{\rho l}{\nu_{11}(\nu_{12}+\nu_{22})}$)[23]. Secondly, as

[21] The overall ranking is given by $\eta < \alpha < \iota < \kappa < \beta < \mu < \varpi < \gamma < \vartheta < \sigma < \delta < \varsigma$.

[22] Instead, $BL2$ and $BL4$ move apart as correlation increases, while their size remains unaffected.

[23] Comparing the expressions of the rents in $BL1$ and $BL5$ and in $DL1$, $DL2$, $DL8$ and $DL9$ with those in $IT1$ and $IT5$, the absence of the abatement in $GC-IT$ is immediately evident.

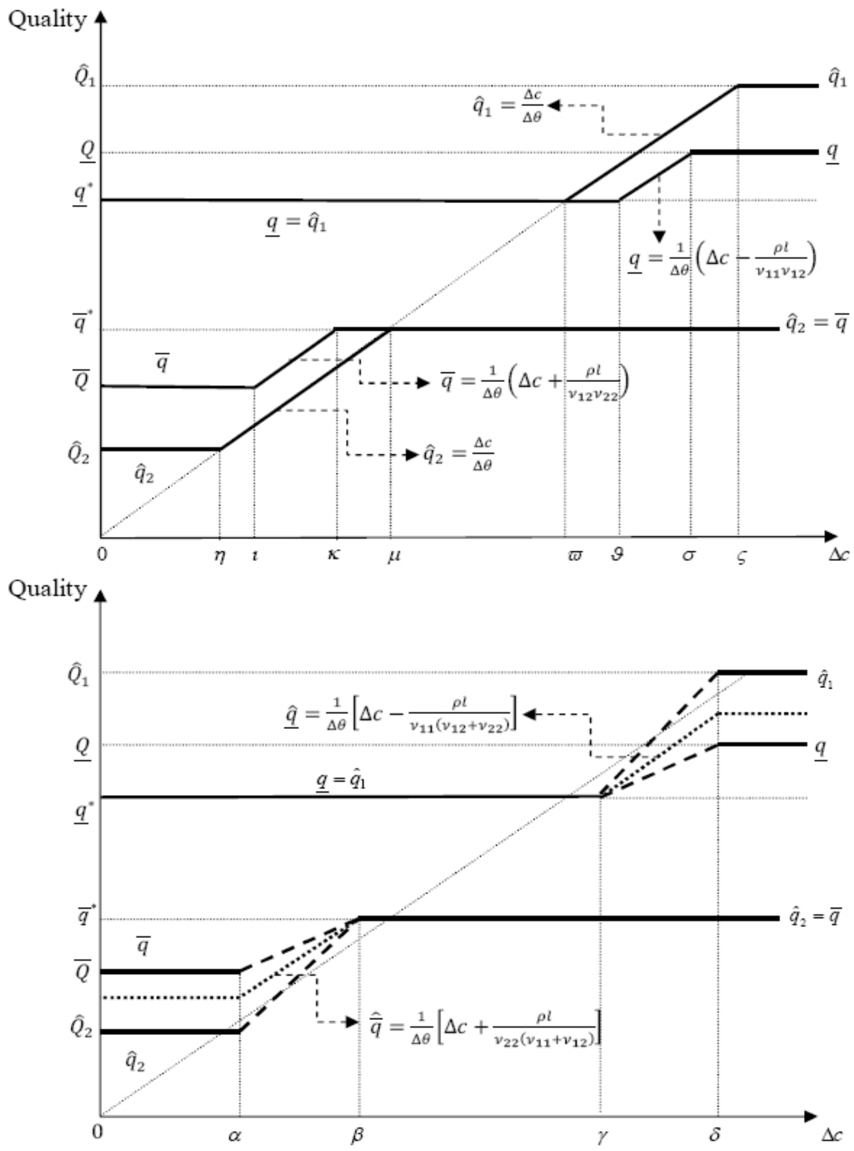

Figure 3: Quality path in $GC - DL$ (top graph) and $GC - BL$ (bottom graph)

already described, rents are contained by means of *ad hoc* quality distortions.

With regard to the latter aspect, a divergence between environments is to be pointed out. Recall that, in $DL1$ (resp.ly, $DL9$), the efficient (resp.ly, inefficient) agent receives an expected rent that depends on the quantity an inefficient (resp.ly, efficient) partner would produce both if the former were to cheat, namely $\overline{q}$ (resp.ly, $\underline{q}$), and if he were not, namely $\widehat{q}_2$ (resp.ly, $\widehat{q}_1$). This rent is exactly equal to that agents receive in $BL1$ (resp.ly, $BL5$). Instead, in $DL2$ (resp.ly, $DL8$), the efficient (resp.ly, inefficient) agent is assigned an expected rent that depends only on the quantity an inefficient (resp.ly, efficient) partner would produce if the efficient (resp.ly, inefficient) agent himself were to cheat, namely $\overline{q}$ (resp.ly, $\underline{q}$). This is explained by the fact that the incentive problem, here addressed state by state, in the good (resp.ly, bad) state is solved. It follows that, in

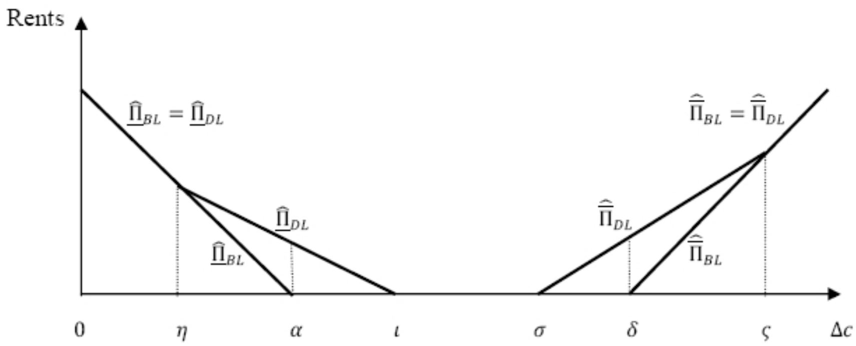

Figure 4: Rents in $GC-BL$ and $GC-DL$

$DL2$ (resp.ly, $DL8$), up to the direct abatement, the rent is obtained with conditional probability that the second agent is inefficient (resp.ly, efficient), given that the first agent is efficient (resp.ly, inefficient), namely $(1-\underline{\nu})$ (resp.ly, $\overline{\nu}$). *Ceteris paribus*, the higher this probability, the more appealing cheating becomes, the larger the rent that is needed to induce type separation.

Noticeably, *ex ante*, the principal retains less surplus in $GC-DL$ than she does in $GC-BL$. As depicted in Figure 4, where the subscripts BL and DL are appended to distinguish rents across environments, expected rents are overall bigger in $GC-DL$ and are assigned for a larger set of values of Δc. This reflects the presence of a stronger trade-off between efficiency and rent extraction under dominant strategies than in the Bayesian setting. Hence, while the comparison is not completely clear as far as qualities are concerned, in terms of expected rents the principal is unambiguously better off when she induces information revelation as a Bayesian equilibrium.

6.4 Profits and limited liability

From Proposition 2 we know that limited liability imposes no structure on $GC-IT$. On the opposite, by allowing for screening, correlation makes limited liability relevant in both (BL) and (DL). Considering these environments altogether, one realizes that the biggest admissible penalty can be assigned (i) to the type that receives no rent in the state where cheating is more likely and/or (ii) to the type that does obtain a rent in the state that is more likely to realize.

Let us begin by illustrating case (i). This case regards both $GC-BL$ and $GC-DL$. To see why it arises, consider that, once correlation enables the principal to identify the state of nature in which the type that has incentive to cheat is more likely to do so, in that state, the principal would like to punish the potential liar more deeply than it is feasible in the presence of wealth constraints. Then the limited liability constraint binds and the principal cannot do better than setting profits equal to $-l$, that is to employ the maximum penalty for incentive purposes. Instead, the payoff in the other state is dictated by *interim* participation requirements. This occurs in $B1$ and $B2$ as well as in $DL1$ to $DL4$, where profits $-l$ accrue to a $\overline{\theta}-$agent who is coupled with a $\underline{\theta}-$agent. It also occurs in $B4$ and $B5$ as well as in $DL6$ to $DL9$, where they accrue to a $\underline{\theta}-$agent who has a partner of different type. When incentives to lie are strong but the mimicking type cannot be punished deeply enough, type separation requires that the non-mimicking type be over-rewarded. It is thus explained why, given the degree of correlation, the smaller the liability and so the penalty the principal can assign, the higher the expected rent she is forced to concede. *Ceteris paribus*, the direct abatements in expected rents that correlation brings about are more important when l is large. Therefore, while liability does not seem to represent a substitute for correlation when types are independent, it appears to complement correlation when the latter is present.

Let us now move to case (ii). This case is specific to $GC-DL$ and follows from the peculiar nature of incentive constraints in the dominant strategy environment. Again, it results from the possibility of screening in the presence of correlation. It arises when the principal finds it convenient to distort qualities just enough to saturate incentive and limited liability constraint of the (potentially) mimicking type in some state of nature. This happens in $DL2$ to $DL4$ as well as in $DL6$ to $DL8$. In the former regions, the efficient type receives profits equal to $-l$ in the good state and positive profits in the bad state. In the latter, the inefficient type obtains $-l$ in the bad state and positive profits in the good state. This is so because the principal prefers to decrease the *ex post* payoff as much as it is feasible in the situation that is more likely to materialize, *i.e.* $(\underline{\theta}_1, \underline{\theta}_2)$ and $(\overline{\theta}_1, \overline{\theta}_2)$ respectively, and give up more *ex post* surplus in the less likely state, *i.e.* $(\underline{\theta}_1, \overline{\theta}_2)$ and $(\overline{\theta}_1, \underline{\theta}_2)$ respectively. That is, profits $-l$ are here assigned to decrease the conceded rent and secure surplus more often in an incentive compatible way. Unlike in case (i), in the less likely state, the payoff is initially dictated by incentive compatibility ($\widehat{\pi}_1$ in $DL2$; $\widehat{\pi}_2$ in $DL8$), which also drives expected rents, and then again by *interim* participation requirements ($\widehat{\pi}_1$ in $DL3$ and $DL4$; $\widehat{\pi}_2$ in $DL7$ and $DL8$) once rents vanish.

Remarkably, *interim* participation prevents that any agent's type ever receive the maximum penalty in both states of nature, whether information is correlated or not. Some comments deserves the case of uncorrelated information. From Proposition 2, one should recall that limited liability imposes no structure on the principal's programme when types are independent. In Bayesian frameworks, agents' profits are undefined. Once break-even is ensured *ex ante*, it is always possible to assign the biggest admissible loss (as any other payoff strictly larger than $-l$) to one or both types of agent in some state of nature. By contrast, this approach is impracticable under dominant strategies. In that environment, *ex post* payoffs are fully determined and, given the impossibility to screen states, symmetrically fixed in good and bad state for each type. Clearly, under these circumstances, profits never equal $-l$. *Interim* participation is secured only if they are set nil.

6.5 Liability and correlation

Limited liability does not undermine the possibility of implementing the full information outcome as long as countervailing incentives are at work. Nevertheless, the presence of wealth constraints is not innocuous when private information is correlated. It weakens the principal's capability to take advantage of correlation across individual pieces of information, whatever the way correlation is exploited in the various settings. Most of the benefits from correlation tail off as agents' pockets become less deep.

We have previously mentioned that, given the degree of correlation, abatements in expected rents shrink as l lowers. Additionally, in Bayesian frameworks, (1) the principal implements the full information outcome less often; (2) expected qualities in $BL2$ and $BL4$ diverge from the efficient level and tend to approach expected qualities in $IT2$ and $IT4$ respectively; (3) significant quality distortions are induced and surplus given up for a larger set of values of Δc[24]. On the other hand, under dominant strategies, (1) quality $\overline{q}$ in $DL3$ and $\underline{q}$ in $DL7$ both diverge from the efficient level and tend to approach the quality level in $IT2$ and $IT4$ respectively; (2) quality $\overline{q}$ and $\underline{q}$ are distorted at maximum for a wider set of values of Δc[25]; (3) the set over which all qualities but one are efficiently fixed gets smaller[26].

In the extreme case that agents cannot be deprived of more than the surplus created in the relationship with the principal $(l = 0)$, the possibility persists of screening types and adjusting qualities accordingly, but all other advantages from correlation vanish. In particular, as aforementioned, $GC - BL$ induces the full information outcome exactly when both $GC - IT$ and $GC - DL$ do[27]. This also reflects the circumstance that, as l approaches zero, optimal contracts become increasingly more similar across environments. Indeed, the impossibility to freely design lotteries inhibits the principal from differentiating contracts according to the power of incentives she wishes to provide. The divergence between Bayesian and dominant strategy environments is thus mitigated, and hence so is that between correlated and uncorrelated settings[28].

By now it should be clear that a principal who faces strongly wealth-constrained agents will not be able to significantly benefit from yardstick competition. From Proposition 2 recall however that, if it is possible to create countervailing incentives for agents, then the

[24] $BL1$ and $BL5$ become wider, $BL2$ and $BL4$ move closer.

[25] $DL2$ and $DL8$ get larger.

[26] $DL4$ and $DL6$ shrink, $DL3$ and $DL7$ move closer.

[27] From Demougin and Garvie [9] we know that, absent countervailing incentives, under the requirement of *ex post* individual rationality, the principal could not implement the first-best solution even in correlated Bayesian frameworks.

[28] Recall that Bayesian and dominant strategy mechanisms are analogous in uncorrelated frameworks.

principal can obtain full efficiency and extract surplus even without correlation. Hence, the gains from countervailing incentives may compensate for the diminished benefits from yardstick competition in situations where agents have correlated information but not deep pockets.

7 Concluding remarks

We have studied the design of the optimal centralized mechanism in situations where the principal deals with multiple agents, each of whom is protected by limited liability and may have countervailing incentives to misrepresent private information on technology. Adopting a simple two-agent two-type model, we have shed light on the principal's strategies and achievements in these settings, characterizing the optimal mechanism under both Bayesian and dominant strategies. We have further assessed how the principal takes advantage of correlation across individual pieces of information by inducing yardstick competition between agents. We have been able to provide a partial ranking by comparing the contractual performance across frameworks.

Despite the simplicity of the stylization we have chosen, our analysis does deliver various predictions.

To begin with, whether agents have independent or correlated information and whether they are induced to play Bayesian or dominant strategies, the principal implements the full information outcome when agents are turned between the desire to overstate and that to understate private information. When any such desire prevails, the principal is forced to introduce allocative distortions and concede information rents. Specifically, as efficient agents' outside opportunities become increasingly more attractive, distortions move from the bottom to the top of the type distribution and expected rents from the top to the bottom. Importantly, this path is exclusively shaped by the structure of agents' incentives, which explains why the core features of the optimal incentive mechanism have been found to be similar in the various considered settings.

Albeit countervailing incentives represent a substitute for correlation (while not so does a deep pocket) in the absence of informational externalities, correlation still appears to be useful to the principal. Present correlation, the latter plays one agent against the other and improves the contractual performance, as compared to independent information settings. In particular, the full information outcome is implemented more often in the Bayesian framework. By contrast, this benefit does not result under dominant strategies because self-selection is harder to solicit in that framework. Yet, in either case, yardstick competition helps contain distortions and rents whenever first best is beyond reach, albeit more surplus is retained when agents follow Bayesian strategies.

First best is not always at hand in correlated environments because agents are protected by limited liability. By allowing the principal to screen states of nature, correlation makes agents' liability relevant, while it is not with independent information. Wealth constraints impede that too small *ex post* payoffs be assigned in those states where this would be optimal, which correlation helps pin down. For this reason, limited liability weakens the principal's capability to take advantage of the correlation across individual pieces of information and imposes structure on the optimal contract. The benefits it conveys tail off as agents' pockets become less deep. Most of them eventually vanish, while the welfare-enhancing effect of countervailing incentives persists. This signals that liability complements correlation and that, in turn, correlation complements countervailing incentives. Noticeably, in any setting, correlation would be a substitute for countervailing incentives only if it were perfect. In fact, while the presence of countervailing incentives helps decentralize the full information outcome only for some values of cost uncertainty, perfect correlation would yield that outcome without any restriction and would thus be a more powerful tool. Analogous outcome would emerge with imperfect correlation and unlimited liability.

The results of our study allows us to identify further occasions, besides those enucleated in the literature, in which the principal may benefit from creating countervailing incentives for her agents.

On one side, creation of such incentives may help circumvent the impossibility to induce yardstick competition between agents, whether the latter face or not wealth difficulties. This may prove particularly useful in situations where a single authority is in charge of regulating local monopolies whose private information is uncorrelated because, say, the contexts in which they operate are quite heterogeneous. A good example of this situation is provided by electricity distribution networks, for which comparisons seem to be especially problematic (see López and Glachant [18]).

On the other side, creating countervailing incentives may help compensate for the impossibility to fully benefit from yardstick competition in contexts where agents have correlated information but not deep pockets. As an illustration, consider oligopolies where services of general interest are provided. In the latter, inducing firms to adopt a technological mix that generates countervailing incentives (Lewis and Sappington [16]) could be a way for regulators to promote efficiency without leaving rents and simultaneously warrant firms' financial health so as to prevent disruption. Another example can be found in public procurement. Governments could achieve desirable outcomes by promising up-front endowments of production capacity (Lewis and Sappington [17]) when they auction out activities to operators who have correlated private information but cannot be exposed to unbounded losses. This should enhance welfare because bidders would be turned between their desire to understate production costs, so as to be awarded the contract that they can attempt to renegotiate at later stage by claiming overruns, and the desire to overstate such costs so as to decrease the value of the up-front endowment they would receive from the principal in case of win[29].

Our work could be extended along various directions, which identify alleys for further research.

Firstly, we have focused on the case where agents have two possible types and a negative relation is known to tie the two cost components. It would be interesting to further elaborate on the information structure. For instance, we would expect the optimal grand-contract to commend some bunching if agents have more than two (and, possibly, a continuum of) types. In that framework, one could study the impact of limited liability and correlation on the dimension of the set of pooled types[30].

Secondly, we have assumed that the principal deals with all her agents by means of a unique grand-contract. This seems to realistically represent principal/agents hierarchies in public procurement and regulation. Indeed, one may reasonably expect institutions to have sufficiently strong commitment power, at least as far as developed economies are concerned. Different situations could be imagined, in which the principal is unable to bring all her agents to the contracting table and thus stipulates separated bilateral contracts. Dequiedt and Martimort [11] show that, in such situations, preventing the principal from manipulating what she learns from one negotiation while undertaking the other negotiations weakens her ability to take advantage of correlation across pieces of private information. Welfare is reduced by the appearance of a trade-off between efficiency and rent extraction. It would be interesting to assess whether countervailing incentives would restore the possibility of implementing the full information outcome when the principal deals separately with limitedly liable agents under non-manipulability constraints. This would be especially relevant with regard to labour relationships. It is not unusual that employers engage in bilateral contracting with their employees, who typically face outside options and cannot bear unbounded losses.

Thirdly, we have characterized the optimal grand-contract in Bayesian and dominant strategy frameworks. We have assessed that, when information is correlated, the principal strictly prefers the Bayesian contract, as far as expected rents are concerned, while the comparison remain ambiguous in terms of allocations. One could check whether the principal is better off in a mixed situation. As in Demski and Sappington **[10],** this can be a situation in which one agent is induced to play dominant strategies, while his partner the Nash best reply.

Lastly, one could explore a situation in which agents collude, rather than playing non-

[29] The issue of renegotiation for cost overruns in procurement agreements with operators who cannot be exposed to large losses has long concerned both economists and politicians. One may think about military and defense projects, such as the production of weapon systems. See, among others, the classical work of Tirole [30] and the more recent contribution by Chen and Smith [6].

[30] I am grateful to David Martimort for bringing this point to my attention.

cooperatively as here supposed. That incentives to coordinate arise in the setting of our interest seems to be a reasonable presumption, provided the principal is able to retain surplus from all her agents, at least to some extent, even with independent information. Within a context of duopoly regulation under incomplete information, Pouyet [22] studies the impact of correlation on firms' incentives to collude and finds that negative correlation favours the principal because it makes firms' objectives diverge, while positive correlation is beneficial to agents because it helps align their goals. It would be interesting to investigate whether and how this result would change in the presence of countervailing incentives and limited liability. It would also be interesting to learn whether countervailing incentives would suffice to decentralize first best even in the presence of collusion.

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