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Summary

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Keywords: Public Procurement, Fixed-Price Contracts, Cost Uncertainty, Time Overruns, Liquidated Damages, Real Options

JEL Classification: C61, D44, D86, K12

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Procurement with unenforceable contract time and the law of liquidated damages

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April, 2012

Abstract

Time overruns are common in public works and are not confined to inherently complex tasks. One explanation advanced in this paper is that bidders can undergo unpredictable changes in production costs which generate an option value of waiting. By exploiting the real-option approach, we examine how the inability to force sellers to meet the contract time influences their bidding behaviour, and how this can ultimately affect the parties' expected payoffs. Further, we examine the outcome of the bidding process when legal rules prevent the promisee from contracting for damage measures which would grant more than her lost expectation. We show that when the pre-agreed compensatory payments prove insufficient to discourage delayed orders, setting a liquidated damages clause would not lead to a Pareto superior outcome with respect to the no-damage-for delay condition. While such a clause would increase the seller's expected payoff, the buyer's expected payoff is lower than when the contract does not provide for any compensation for late-delivery.

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1 Introduction

On-time delivery is one of the most relevant dimensions of the procurement relationship. Yet, buyers often find it difficult to avoid delayed orders, particularly when compliance with the contract time[1] is not sustained by implicit incentives, such as the threat of losing reputation and future business.

Practices like taking past performance into account, using negotiations instead of competitive tendering, or establishing long-term supply chain relationships, can motivate the seller to maintain her promises. However, in exchanges between government and business, these relational-reputational forces tend to play a more limited role, because of the rigidity of public procurement regulations caused by accountability rules (Kelman 1990 and 2002)[2]. Thus, once the contract is in place, the parties' terms of trade will be primarily governed by contractual provisions (Hart and Moore, 1988).

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[1] Following Herbsman *et al.* (1995), we define the "contract time" as the maximum time allowed in the contract for completion of all work as specified in the contract documents.

[2] This is particularly true in Europe where, to minimize discrimination against foreign suppliers and to foster European market integration, a series of EC Directives have forced Member States to move towards the generalised use of rigid and open competitive procedures (Calzolari and Spagnolo, 2009).

Knowing this, buyers usually include in their contracts damage measures which specify in advance the amount of compensation for late completion, in the hopes that they will preclude the need for litigation and will stimulate the seller to meet her obligations. Even these contractual remedies, however, may prove insufficient to discourage project delays.

Indeed, the empirical literature on public procurement suggests that, despite such provisions are routinely included in contract documents, delays are common and are not confined to inherently complex tasks, such as large infrastructure or military projects, where time overruns are often associated with important changes in the initial design (Ganuza, 2007). For example, using a sample including 894 projects, belonging to seventeen infrastructure sectors, completed in India during 1992-2009, Singh (2009) points out that more than 82 per cent experienced time overruns. Another survey carried out in Italy on 45,730 small public works (contracts of a value between 150 and 15,000 kEuro) procured by local authorities in the period 2000-2006, showed that about 78 per cent did not meet the contract time (D'Alpaos *et al.,* 2009). Parallel investigation on the compliance with contractual obligations showed that out of 800 inspections commissioned by the Italian Public Procurement Agency (CONSIP) in the period September 2006-April 2007, a total of 437 infringements were ascertained, but penalties were enforced only in 16 cases (3.66%) (Albano *et al.*, 2008).

The inefficacy of so called "penalty" clauses in stimulating compliance with contractual obligations might be generated by several circumstances.

Firstly, these provisions rest on the assumption of a well-functioning system of enforcement, namely on the courts' ability to resolve disputes cheaply and predictably. In the real world, however, parties must often afford substantial enforcement costs, which can pathologically increase because of the poor quality (*e.g.* the time-inefficiency) of the judicial system. As pointed out by Guash *et al.* (2006), the lower the quality of the system, the lower the probability of contract enforcement.

Secondly, buyers can find it technically difficult to predetermine a damage measure such that the sellers would always decide to meet their obligations. Since the potential suppliers may have different, privately known, opportunity costs of compliance with delivery schedules, the common practice in public procurements to set, at the pre-selection stage, fixed late-delivery penalties can turn out to be insufficient to discourage project delays. Moreover, in some countries, public procurement regulations cap the level of the enforceable amount of compensation for late completion. In Italy, for example, the value of penalties cannot exceed 10 per cent of the contract value (Albano *et al.*, 2006).

Finally, even if buyers were able to set a level of compensation such that it would be potentially convenient for the contractor to comply with the contract time, in case of a dispute the stipulated compensation could not be enforced, because the court might judge it inconsistent with legal standards.

Even if in the economic literature on procurement the term "penalty" is often indistinctly used to describe contractual provisions which are intended to protect the owner from the harm she could suffer from breach, and clauses used for the purpose of pressuring the contractor into performance, the distinction may have relevant legal implications, particularly in Common Law jurisdictions where courts will generally refuse to award compensation if it amounts to a penalty, i.e. if it is found that it was intended to be a punishment or a deterrent against the breach of a contract. Only liquidated damages are enforceable, as long as they appear to be a reasonable estimate of potential damages that are difficult (costly) to prove once incurred.

The common law of liquidated damages has generated an extensive body of legal literature. Though the voidance of penalty clauses has been traditionally justified on public policy and fairness grounds (Di Matteo, 2001), various authors have also argued that it is indeed an efficient rule of the common law of contract. According to the so called "efficient breach theory", by inflating the price of breach, the enforcement of punitive damages would estinguish the economic incentive to pursue an otherwise more profitable venture, by so doing preventing the net social gain that would result from nonperformance (Goetz and Scott, 1977). Shavell (1980) formally proved that limiting a promisee's recovery to her lost expectation is generally efficient respecting breach, because it induces the parties to perform when performance would maximize their joint gains. Rea (1984) inferred from this result that the parties are unlikely to agree to damage measures that exceed the expected loss. Schwartz (1990) extended Rea's inference by arguing that such measures could prove undesirable for the promisees themselves, because they would have to pay for supracompensatory remedies.

In Civil Code countries the attitude is quite different, since the Napoleonic Code, upon which most civil codes are based, allowed for penalties to stimulate performance. However, in recent years, there has been a tendency toward making a more clear-cut distinction between clauses whose main purpose is to induce the promisor to fulfill her obligations and a genuine pre-assessment of damages, and narrowing the scope of penalties (McKenna, 2008). In so doing, some civil codes seem to have followed the precedent of the Council of Europe's Resolution on Penalty Clauses.[3] According to the Resolution, penal clauses are not invalid per se, but courts are allowed to reduce the amount of the penalty if they find it "manifestly excessive".

Thus, depending on the context at hand, the costs incurred in going to courts, the lack of information about the sellers' opportunity cost of compliance, regulations capping the enforceable amount of compensation for late-delivery, or legal rules which prevent the promisee from contracting for damage measures which would grant more than her lost expectation, can ultimately undermine the effectiveness of these contractual provisions. When alternative remedies, such as the threat of disqualification for future tenders, are not available, this can involve the emergency of (a degree of) unenforceability of the contract time.

The scope of this paper is to analyse the consequences arising from such unenforceability. Specifically, we ask two questions. First, who gains and who loses when, for whatever reasons, the buyer is unable to induce a timely performance? And, second, how the parties' terms of trade will be affected by a contractual damage measure which is intended to protect the owner from the harm she could reasonably expect to suffer from late completion?

We address these questions by focussing on the case where a "simple project"[4] is procured by competitive tendering, bidders have private information about some components of the project cost, and the latter cannot be fully predicted because of on-going changes in market conditions, which, without altering the essential nature of the performance, can non-negligibly affect the actual production cost. Therefore, our analysis will be restricted to situations where the uncertainties involved in contract performance are neither of a nature which does not permit to use a fixed-price contract, nor of a nature which could warrant excusing performance (Anderlini, Felli and Postlewaite, 2007).[5]

The proposed framework integrates two bodies of economic literature. The first is that on the real-option approach, which has been applied in several areas, but has not been extensively used to address procurement topics. The available works mostly focus on the evaluation, from a contractor's perspective, of a project embedding some elements of managerial flexibility (see, for example, Ford *et al.*, 2002; Ho and Liu, 2002; Garvin and Cheah, 2004), without addressing the effects of flexibility on agents' bidding behaviour. One of the few exceptions is the paper by You and Tam (2006) who, however, do not employ a game-theoretic framework to analyse how managerial discretion influences

[3] Resolution 78(3) adopted by the Committee of Ministers on January 20, 1978.

[4] Following Bajari and Tadelis (2006), the term "simple" is used here to denote a project which is "easy to design with little uncertainty about what needs to be produced" (p.124).

[5] For example, in the United States, the Uniform Commercial Code provides that "delay in delivery or non-delivery in whole or in part by a seller [...] is not a breach of his duty under a contract for sale if performance as agreed has been made impracticable by the occurrence of a contingency the non-occurrence of which was a basic assumption on which the contract was made" (UCC § 2-615). Comment 4 to UCC § 2-615 specifies that "increased cost alone does not excuse performance unless the rise in cost is due to some unforseen contingency which alters the essential nature of the performance. Neither is a rise or a collapse in the market is in itself a justification, for what is exactly the type of business risk which business contracts made at fixed prices are intended to cover".

bidding behaviour in a competitive environment.

The second strand of literature is that analyzing the consequences associated with the absence of contract enforcement.[6] The papers most related to our work are Spulber (1990) and Lewis and Sappington (1991). The former illustrates how the ability of buyers and sellers to make credible commitments determines their behaviour, and shows that the less-qualified firms, that intend to perform only under the most favorable cost conditions, can force the most qualified bidders to bid low, to the point at which they can breach the contract if a cost overrun occurs. Lewis and Sappington (1991) illustrate the impact, upon the parties' terms of trading, arising when the quality of the procured product can be observed perfectly by the buyer and the contractor, but may not be verifiable by a third party, and present a set of conditions under which the equilibrium welfare of both parties is higher when quality is verifiable than when it is unverifiable. However, these, as well most of the studies dealing with the consequences that arise when certain relevant quality dimensions are difficult to enforce, do not focus on our main concern. Although delivery guarantees are often mentioned as one of such relevant dimensions, the theoretical literature has paid relatively limited attention to the specific consequences arising from bidders anticipating the unenforceability of the contract time.

Our paper offers two contributions. First, by using the real-option approach, we examine the outcome of the bidding process when the buyer cannot affect the probability of performance through her choice of a contract damage measure. We show that the seller's expected payoff is lower when the contract time is unenforceable than when is enforceable, while the buyer's expected payoff can be either higher or lower, depending on the relative importance attached to on-time delivery. Second, we contribute to the literature on the law of liquidated damages, by analysing the outcome of the process when the stipulated amount of compensation for late-delivery is intended to protect the owner from the expected costs of time overruns. Our model suggests that, when the pre-agreed compensatory payments fail to discourage delayed orders, setting a liquidated damages clause would not make both parties better off. Specifically, while such a clause would increase the seller's expected payoff, the buyer's expected payoff is lower than when the contract does not provide for any compensation for late-delivery.

The rest of the paper proceeds as follows. Section 2 introduces the basic assumptions of the model. In Section 3 we analyse the effects of unenforceability of contract time on the parties' expected payoffs. Section 4 is devoted to the effects of awarding a contract containing liquidated damages provisions. Section 5 concludes, and the Appendix contains the proofs omitted in the text.

2 The model

Consider a buyer who wants to procure a simple and indivisible project (good or service) whose specifications can be easily monitored and verified by any third party.

By assuming that there is no uncertainty about what needs to be produced, and that the project's quality standards, as specified in contract documents, can be easily verified, we abstract away from situations where time overruns are related to incomplete project design as well as from situations where performance standards, other than the completion time, are unverifiable.

[6] The literature addressing the problems arising when some unverifiable quality dimensions are present in economic exchange, can be broadly divided into two groups. First, there is a large literature looking at the mechanisms by which the outcome of the procurement process could be improved, namely by taking factors other than price into account in the award process. The literature on scoring auctions starting with Che (1993) fits within this group. Second, we have a literature describing the consequences arising from the absence of contract enforcement, by taking as fixed the institutional framework (*e.g.* procurement regulations forcing public sector beaurocrats to award fixed-price contracts by competitive tendering), or particular award rules used in practice (*e.g.* price-only auctions). Our paper fits into the second group.

There are n ($n > 1$) agents capable of performing the task, which will be assigned through a sealed-bid auction, with the fixed-price contract going to the lowest bidder, who will receive the winning bid (p) on the delivery date (τ).[7]

The buyer values the project B, provided that it will be completed within the date established at the contract award. To economize on notation, without loss of generality, we shall set the contract time at zero.

Should the contractor not to comply with the contract time, B would fall by $D(\tau)$, which reflects the cost of delays to the owner, with $D(0) = 0$ and $D'(\tau) > 0$.[8]

A central feature of our model is that it allows for on-going unpredictable exogenous variations in production costs (*e.g.* changes in the price of materials, equipment rental rates, labour costs) which, without requiring a new project design -i.e., for both parties to adapt- could non-negligibly affect the actual cost of completing all work as specified in the contract documents. Thus, sellers can potentially save on project cost, by adjusting delivery plans on the ground of the information arriving after contract award.

Specifically, we make the following assumptions about the production costs.

Assumption 1 Given that agent i is selected, the instantaneous[9] *ex-post* project cost K_t^i has two components:

$$K_t^i = \theta^i + C_t \tag{1}$$

where θ^i reflects the ith agent's innate capabilities, and $\{C_t, t \geq 0\}$, is a random variable representing unpredictable changes that arise in the course of the project.

Assumption 2 The value of θ is private knowledge. Agent i only knows that θ^j, $j \neq i$ is drawn from a common prior cumulative distribution $F(\theta)$ with continuously differentiable density $f(\theta)$ defined on a positive support $\Theta = [\theta^l, \theta^u] \subseteq R_+$

Assumption 3 The unpredictable cost component evolves over time according to a geometric Brownian motion which is common knowledge:

$$dC_t = \alpha C_t dt + \sigma C_t dZ_t \qquad \text{with } \alpha > 0, \sigma > 0 \text{ and } C_{t=0} = C > 0 \tag{2}$$

where dZ_t are identically and independently distributed according to a normal distribution with mean zero and variance dt, and both the drift parameter α and the volatility parameter σ are constant.[10] Also C is a publicly observed information.

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[7] It is assumed that the buyer cannot write state-contingent contracts. This may be due to transaction costs or the inability to observe the realized value of project cost (Spulber, 1990) or, in the case of public works, to regulations forcing civil servants to use fixed-price contracts when awarding "simple" projects.

[8] The costs for late completion may vary depending on the buyer and the nature of the project. For example, in public works, such as the rehabilitation of existing transport facilities, the cost of delays will include direct costs, such as those related to providing alternative temporary facilities, as well as indirect (social) costs, such as those related to increased traffic congestion or losses for the business community (Herbsman *et al.*, 1995; Arditi *et al.* 1997).

[9] The assumption that the task can be instantly accomplished can be relaxed without affecting the qualitative results of our model. For example, suppose that it takes "time-to-build" the project but there is a maximum rate k at which the contractor can invest in every period. Therefore, if the total expenditure is K, it takes $T = K/k$ periods to complete the project. Assuming that the expenditures are made continuously over T, their present value is:

$$\hat{K} = \int_0^{K_t/k} k e^{-rs} ds = (1 - e^{-rK_t/k})\frac{k}{r}$$

Since $e^{-rK_t/k} \simeq 1 - r\frac{K}{k} + ...$, we get $\hat{K} \simeq K$ and the analysis can proceed pretty much as in the text.

[10] Assuming that the state variable follows a lognormal random walk is standard in real-option models. However, alternative processes, such as mean-reverting, can be used. This would complicate the analysis, without changing the results significantly.

Assumption 4 θ is independent of $\{C_t, t \geq 0\}$ and is exponentially distributed on R_+, i.e. $F(\theta) = 1 - e^{-\lambda\theta}$, with density $f(\theta) = \lambda e^{-\lambda\theta}$ for some $\lambda > 0$.

Assuming that bidders have symmetric rational expectations about the cost component C_t and asymmetric private information on θ allows us to set the auction format into the independent private value framework.[11] Moreover, the exponential distribution is an useful simplification in order to study the case where the buyer cannot enforce a timely performance. By assuming that bidders' information rents and the cost savings derived by not complying with the contract time are independent on θ, we rule out situations where, even though allocatively efficient, the award process fails to assign the task to the agent who supplies first.

Finally, we exclude ex-post renegotiation as well as the introduction by the buyer of a maximum bid.

3 Enforceable versus unenforceable contract time

3.1 Enforceable contract time

As a useful benchmark, let us first suppose that the buyer is able to induce a timely performance. Implicitly, we allow sufficiently large penalties to be (costlessly) enforced, so that the seller will always find it convenient to comply with the contract time.

Thus, given that bidder i is selected, the *ex-post* value of the contract is:

$$NPV(p^i, C) = p^i - \theta^i - C \tag{3}$$

where p^i is the bid.

Each agent will then choose the bid so as to maximize

$$\Pi^{enf}(p^i) = NPV(p^i, C) \Pr\left(p^i < \max_{j \neq i} p^j\right) \tag{4}$$

where $\Pr\left(p^i < \max_{j \neq i} p^j\right)$ is the probability of reporting the lowest bid.

The symmetric Bayesian-Nash equilibrium of this bidding game is well known (McAfee and McMillan, 1987; Krishna, 2002), and is characterized by a strictly increasing bid function $p(\theta)$, such that, if all bidders other than i bid $p^j = p(\theta^j)$, then agent i bids $p^i = p(\theta^i)$.

The optimal equilibrium strategy is recorded in the following Proposition.

Proposition 1 *When the contract time is enforceable, the unique equilibrium in symmetric strictly monotone increasing strategies is characterized by:*

(i) the bid function:

$$p^{enf}(\theta^i) = \theta^i + C + \frac{1}{\lambda(n-1)} \quad \forall i. \tag{5}$$

(ii) the expected payoff:

$$\Pi^{enf}(\theta^i) = \frac{1}{\lambda(n-1)} e^{-\lambda(n-1)\theta^i} \quad \forall i. \tag{6}$$

with $\Pi^{enf}(\theta^u \to \infty) = 0$.

[11] Note that none of the major results depend on this assumption. More generally, what is required is that conditionally on θ, the cost K has a continuous density $g(K/\theta)$ on R_+, that satisfies the strict Monotone Likelihood Ratio Property, or equivalently that $g(K/\theta)$ is log-supermodular, i.e. $\frac{\partial^2 \log(g)}{\partial K \partial \theta} > 0$. As θ and C are independent, $g(K/\theta) = \int_{R_+} n(K - \theta) d\theta$, where $n(.)$ is the density of C, then the log-supermodularity is trivially satisfied as C has a log-normal distribution.

Proof. See Appendix A ■

Given that agent i wins with bid $p^{enf}(\theta^i)$, the buyer will earn the value she places on performance less the price:

$$W^{enf}(\theta^i) = B - p^{enf}(\theta^i) \tag{7}$$

3.2 Unenforceable contract time

Now consider the opposite situation where the buyer cannot affect the probability of performance. Implicitly, we assume that the contract does not provide for any (enforceable) compensation for late completion.

Thus, barring reputation effects from nonperformance, bidders compete for acquiring a project that includes an option-like component. Specifically, since the actual costs are determined by (2), the ability to optimize plans, by choosing the delivery date, is analogous to acquiring a Put Option.

Assuming, for the sake of analytical tractability, that the winning bidder acquires a perpetual option, the *ex post* value of the contract is given by:[12]

$$V^i(p^i, C; \tau^i) = E_0(e^{-r\tau^i})(p^i - \theta^i - C_{\tau^i}) \tag{8}$$

where $(p^i - \theta^i - C_{\tau^i})$ is the NPV resulting from performing the task at the trigger C_{τ^i}, τ^i is the random delivery date, and r is the discount rate.

To make the problem interesting, we introduce an additional assumption, which expresses that unpredictable costs are not negligible compared to the cost component θ, so that agents prefer to choose the delivery date in order to acquire more information about the actual production cost.

Assumption 5 Bidders have an option value of waiting before performing the task, i.e:

$$C_{\tau^i} < C \quad \forall i$$

Our analysis proceeds by backward induction. First, we analyse the optimal exercise rule of a bidder that is awarded the contract. Next, we consider how agents will bid in the auction.

By Assumption 5, (8) can be rewritten as follows:[13]

$$V^i(p^i, C; \tau^i) = \left(\frac{C}{C_{\tau^i}}\right)^{\beta} (p^i - \theta^i - C_{\tau^i}) \tag{9}$$

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[12] This assumption, which allows us to find closed-form solutions, implies that the contractor is allowed to keep the right to perform the assigned task forever. Admittedly this is quite unrealistic, since owners are generally entitled to terminate the contract when delays become "unacceptably large". However, none of the qualititative results presented in this section are substantially affected by this assumption.

[13] The solution to $E_0(e^{-r\tau})$ can be obtained by using dynamic programming (see, for example, Dixit *et al.*, 1999). Since (2) is continuous, the expected discount factor is increasing in C and decreasing in C_τ; then it can be defined by a function $\Lambda(C; C_\tau)$. Over the infinitesimal time interval dt, C will change by the small value dC, hence we get the following Bellman equation: $r\Lambda(C; C_\tau)dt = E(d\Lambda(C; C_\tau))$. By applying Itô's Lemma to $d\Lambda$ we obtain the following differential equation:

$$\frac{1}{2}\sigma^2 C^2 \Lambda'' + \alpha C \Lambda' - rD\Lambda = 0\,,$$

which can be solved by imposing the two boundary conditions: $\lim_{C\to 0} \Lambda(C; C_\tau) = 0$ and $\lim_{C\to C_\tau} \Lambda(C; C_\tau)) = 1$. The general solution is $\Lambda(C; C_\tau)) = \left(\frac{C}{C_{\tau^i}}\right)^{\beta}$, where $\beta < 0$ is the negative root of the auxiliary quadratic equation $\Psi(\beta) = \frac{1}{2}\sigma^2\beta(\beta - 1) + \alpha\beta - r = 0$.

where:

$$\beta = (\frac{1}{2} - \frac{\alpha}{\sigma^2}) - \sqrt{(\frac{1}{2} - \frac{\alpha}{\sigma^2})^2 + \frac{2r}{\sigma^2}} < 0$$

Therefore, for any p^i, the contractor will comply with the contract time if and only if $V^i \leqslant NPV^i$. Otherwise, she will be better off by maximizing (9) with respect to C_{τ^i} and determining the optimal stopping time:

$$\tau^i(C_{\tau^i}) = \inf(t \geq 0 \mid p^i = K^i_{\tau^i} + V^i(p^i, C_{\tau^i}; \tau^i)).$$

Following the real-option approach, the optimal exercise rule is that the project's benefits must outweigh its cost, where the latter consists of the strike price $K^i_{\tau^i}$ plus the value of the option exercised by undertaking the project. Thus, by (9), the optimal trigger is:

$$C^*_{\tau^i} = \frac{\beta}{\beta - 1}(p^i - \theta^i) \tag{10}$$

Plugging (10) into (9) yields

$$V(p^i, C) = \Gamma(C)\left(p^i - \theta^i\right)^{1-\beta} \qquad \text{for } C > C^*_{\tau^i} \tag{11}$$

where $\Gamma(C) \equiv \frac{1}{1-\beta}\left(\frac{\beta}{\beta-1}\right)^{-\beta} C^\beta > 0$.

Hence, each agent will look for the optimal bidding strategy p^i that maximizes:

$$\Pi^{put}(p^i) = \Gamma(C)\left(p^i - \theta^i\right)^{1-\beta} \Pr\left(p^i < \max_{j \neq i} p^j\right) \tag{12}$$

The solution for this bidding game is recorded in Proposition 2.

Proposition 2 *If there are no damages for breach of contract, the unique equilibrium in symmetric strictly monotone increasing strategies is characterized by:*

(i) the bid function:

$$p^{put}(\theta^i) = \theta^i + \frac{1-\beta}{\lambda(n-1)} \quad \forall i. \tag{13}$$

(ii) the expected payoff:

$$\Pi^{put}(\theta^i) = \Gamma(C)\frac{1-\beta}{\lambda(n-1)} e^{-\frac{\lambda(n-1)}{1-\beta}\theta^i} \quad \forall i. \tag{14}$$

with $\Pi^{put}(\theta^u \to \infty) = 0$

(iii) the optimal trigger:

$$C^*_{\tau^i} = -\frac{\beta}{\lambda(n-1)} \quad \forall i. \tag{15}$$

Proof. See Appendix B ■

Note that (13) can be written as $p^{put}(\theta^i) - K^i_{\tau^i} = \frac{1}{\lambda(n-1)} + \left[C^*_{\tau^i} - C\right]$. The innovation with respect to (5) is that the bidders' markups reflect the cost savings derived by not complying with the contract time.

Thus, when the contract time is unenforceable, each bidder will maximize the probability of winning the project by identifying two prices contingent to the completion date, and reporting the lowest one: $p^{nf}(\theta^i) = \min\left[p^{put}(\theta^i), p^{enf}(\theta^i)\right]$, where $p^{enf}(\theta^i)$ stands for the price (5) which maximizes NPV^i, and $p^{put}(\theta^i)$ stands for the price (13) which maximizes the Put Option V^i.

The optimal equilibrium strategy is recorded in Proposition 3.

Proposition 3 *If there are no damages for breach of contract, the optimal equilibrium strategy is characterised by:*

$$p^{nf}(\theta^i) = p^{put}(\theta^i) < p^{enf}(\theta^i) \qquad \forall i$$

Proof. See Appendix C ■

The result summarized in Proposition 3 shows that, when bidders have an option value of waiting (i.e., $C^*_{\tau^i} < C$), the buyer's inability to enforce compliance with the contract time will stimulate agents to bid more aggressively.

The intuition is that the possibility of saving on costs, by choosing the delivery date, allows weak agents to lower their bids, thereby forcing the most qualified bidders to exploit the time flexibility to preserve their chances of winning.

The whole competitive process will then drive down the price, by so doing making all bidders potential violators of the contractual agreement.

Therefore, given that agent i wins with bid $p^{nf}(\theta^i)$, the corresponding expected payoff for the buyer is:

$$W^{nf}(\theta^i) = B - E_0(e^{-r\tau^i})p^{nf}(\theta^i) - E_0[D(\tau^i)] \tag{16}$$

where $E_0(e^{-r\tau^i})$ takes into account that the winning bid will be paid on the delivery date, and $E_0[D(\tau^i)]$ represents the expected harm for late completion, with the information available at the time of contract award.

3.3 Comparison

Each party's expected payoff is clearly affected by the unenforceability of the contract time.

By Proposition 3 and direct inspection of (6) and (14), it is apparent that the seller's expected payoff cannot take on a higher value when the contract time is unenforceable than when it is enforceable (see Appendix C):

$$\Pi^{nf}(\theta^i)\ (= \Pi^{put}(\theta^i)) < \Pi^{enf}(\theta^i) \qquad \forall i \tag{17}$$

The reason is that, when the contract time is unenforceable, the potential savings stemming from the possibility of optimally choosing the delivery date are outweighed by the stronger price competition spurred by the option-like nature of the bidded contract.

In the auction literature, a similar result may be found in DeMarzo et al. (2005), who compare the expected payoffs of bidders in auctions where the value of the auctioned asset is not contingent on future events (in our framework, this occurs when the contract time is forceable), with those where the bids are securities whose values are derived from the future cash flows. They show that all security-bid auctions yield lower bidders' payoffs than a cash auction, and call options yield the lowest possible payoff of any security-bid auction.[14]

For the buyer, by (7) and (16), we get:

$$W^{nf}(\theta^i) - W^{enf}(\theta^i) = [p^{enf}(\theta^i) - E_0(e^{-r\tau^i})p^{nf}(\theta^i)] - \ E_0(D((\tau^i)) \qquad \forall i \tag{18}$$

Since, by Proposition 3, the first term on the r.h.s. is positive, the sign of $W^{nf} - W^{enf}$ will depend on the relative magnitude of the cost of delays to the owner. If the expected costs from late delivery come to exceed the expected benefits resulting from price reductions and late payments, the buyer

[14] In the literature on concessions, a similar result can be found in Dosi and Moretto (2011).

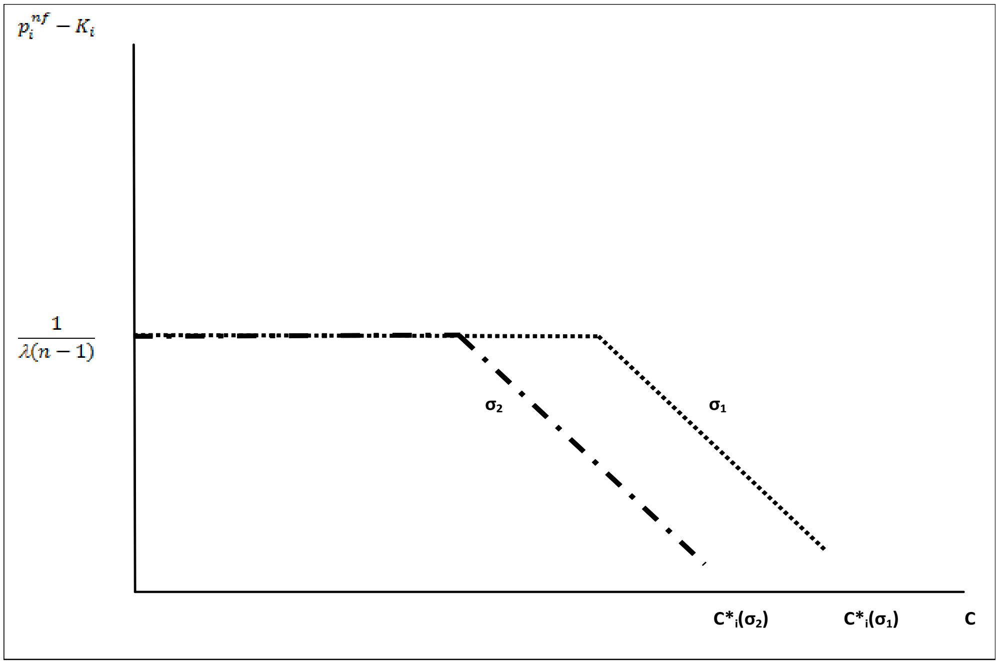

Figure 1: Cost uncertainty and the ex post value of the contract under unenforceable contract time ($\sigma_2 > \sigma_1$)

prefers the contract time to be enforceable. The opposite occurs when the expected financial savings outweight the harm that the buyer could expect to suffer from breach.

The outcome of the bidding process is also affected by the number of bidders. As shown by (15), the optimal trigger declines as n increases, i.e. project delays are more likely to occur if there are many competing agents, which is consistent with previous studies pointing out that, while squeezing agents' rents, open competition can entail a strong quality distortion (see, for example, Manelli and Vincent, 1995; Calzolari and Spagnolo, 2009). Therefore, when the buyer is unable to induce compliance with the contract time, a strong competition should be favoured only if the harm the buyer expected from late completion is comparatively low with respect to the expected benefits arising from bid reductions.

As for the effect of cost uncertainty, since $\mid \frac{\partial \beta}{\partial \sigma} \mid > 0$, taking the derivative of (14) with respect to σ, we find that:

$$\frac{d\Pi^{nf}(\theta^i)}{d\sigma} < 0$$

i.e., the higher is the volatility parameter, the lower the seller's expected payoff in the absence of contract enforcement.

For the buyer, as in the case of n, the impact of cost uncertainty is not univocal, insofar an increase in σ entails both a price reduction and an increased probability of time overruns (see Figure 1):

$$\frac{dp^{nf}(\theta^i)}{d\sigma} < \mathbf{0} \quad \text{and} \quad \frac{dC^*_{\tau^i}}{d\sigma} < \mathbf{0}$$

Thus, once again, the positive impact of a price reduction must be assessed against the importance attached to on-time completion. *Coeteris paribus*, when the latter is very important for the buyer, the higher is σ, the higher is the potential loss arising from the inability to stimulate compliance with the contract time.

4 Liquidated damages

The preceding analysis shows that, when unpredictable production costs are non-negligible, the seller's expected payoff is strictly lower when the contract time is unenforceable than when is forceable.

The same applies to the buyer if the expected costs from late-delivery outweigh the potential benefits arising from price reductions and late payments, in which case the buyer would wish for damages for breach to be set sufficiently high that the contract time would always be obeyed. [15]

Courts, however, may refuse to enforce compensation if the amount established at the time of contract award appears that it is was intended to pressurize the contractor into performance.

In particular, as already noted, in Common Law jurisdictions it is generally agreed that, to be enforceable, a liquidation of damages must be a reasonable estimate, with the information available at the time of contract award, of the harm a party could expect to suffer from breach. If, regardless of what the actual loss turns out to be, the stipulated amount of compensation exceeds the probable loss, it is a penalty.[16]

The scope of this section is to analyze the effects of introducing a liquidated damages clause upon the parties' expected payoffs.

We will do it by assuming that, to avoid litigation, the contract provides that, if a breach will occur ($\tau > 0$), the owner will be entitled to charge $L(\tau)$ for late completion, with $L'(\tau) > 0$.

Thus, if the pre-agreed amount of compensatory payment is enforceable, the ith agent's *ex post* value of the project becomes:

$$V^i(p^i, C; \tau^i) = E_0(e^{-r\tau^i}) \left[p^i - \theta^i - C_{\tau^i}\right] - E_0[L(\tau^i)] \tag{19}$$

Since liquidated damages are commonly calculated on a cost per unit of time basis (*e.g.* per day basis) and are generally deducted in one lump-sum when making payment for the delayed delivery, to reflect real-world practices we shall set:[17]

$$E_0[L(\tau^i)] = E_0(e^{-r\tau^i})E_0(\tau^i)h \tag{20}$$

where $E_0(\tau^i)$ is the expected time overrun, and h is taken to represent a widely recognized reasonable estimate of the average unit time cost, such that:

$$E_0[L(\tau)] \equiv E_0[D(\tau)] \tag{21}$$

which rules out the risk that liquidated damages could be challenged as a penalty.

---

[15] We have assumed that the buyer is forced to use fixed-price contracts, which, barring reputation effects from nonperformance, "creates a role for legal remedies for breach of contract" (Spulber, 1990, p.328). However, if the buyer were able to write state-contingent contracts, compliance with the contract time could be sustained by designing an appropriate cost-reimbursement scheme. For instance, suppose that the buyer is able to observe the realized value of costs and can make a binding committment to pay on delivery $P = p + C_\tau$, where p is the winning bid. By simply substituting P into(9), we get that the agent maximizes V_t^i by choosing $C_{\tau^i} = C_t$.

[16] While the common law does not enforce predetermined damages that were unreasonably large at the time of contract award, damages that were reasonable ex ante, but exceed the actual loss, may or may not be enforced depending on the jurisdiction (see Rea, 1984). For example, in the United States, federal courts have enforced liquidated damages, inserted in public contracts, regardless of the actual damages (see, for example, *Southern Engineering Co. v. United States* 341 F.2d 998 (8th Cir. 1965), cert. denied, 382 U.S. 819 (1965)). In some states, however, courts have adopted a different approach, by not enforcing damage clauses when the actual loss appeared to be lower than the predetermined damages (see, for example, *Norwalk Door Closer Co. v. Eagle Lock and Screw Co.*, 153 Conn. 681, 221 A.2d 263 (1966)).

[17] Since, for increasing delays, $e^{-r\tau^i}$ and τ^i covariate to zero, without loss of generality we can write: $E_0(e^{-r\tau^i}\tau^i)h = E_0(e^{-r\tau^i})E_0(\tau^i)h$

To cap the level of compensation, we approximate the expected amount of liquidated damages by expanding $E_0(\tau^i)$ by Taylor's theorem around the initial value C:[18] [19]

$$E_0(\tau^i)h \simeq \left(1 - \frac{C_{\tau^i}}{C}\right) H \tag{22}$$

where $H = (\frac{1}{2}\sigma^2 - \alpha)^{-1}h$ indicates the maximum potential compensation payable for breach.

Substituting (22) into (19) yields:

$$V^i(p^i, C; \tau^i) = \left(\frac{C}{C_{\tau^i}}\right)^{\beta} \left[p^i - \theta^i - C_{\tau^i} - \left(1 - \frac{C_{\tau^i}}{C}\right) H\right] \tag{23}$$

i.e., introducing a liquidated damages clause makes the project-value a path-dependent option, since the payoff depends both on C and the trigger C_{τ^i}.

Therefore, for any given C, the strategy for valuing $V^i(.)$ is to start from the exercise date, when the option value is known (equal to the payoff), and working backwards till the time of contract award.

Thus, maximizing (23) gives the optimal exercise boundary under liquidated damages:

$$C^{**}_{\tau^i} = \frac{\beta}{\beta - 1}(1 - \frac{H}{C})^{-1}(p^i - \theta^i - H) \tag{24}$$

that separates an early exercise region where $C \leq C^{**}_{\tau^i}(C)$, from an hold region where $C > C^{**}_{\tau^i}(C)$.

Plugging the optimal trigger (24) into (23) yields:

$$V(p^i, C) = \hat{\Gamma}(C)\left(p^i - \theta^i - H\right)^{1-\beta} \qquad \text{for } C > C^{**}_{\tau^i} \tag{25}$$

where $\hat{\Gamma}(C) \equiv \Gamma(C)(1 - \frac{H}{C})^{\beta} > 0$.

Hence, each agent will look for the optimal bidding strategy p^i that maximizes:

$$\Pi^{ld}(p^i) = \hat{\Gamma}(C)\left(p^i - \theta^i - H\right)^{1-\beta} \Pr\left(p^i < \max_{j \neq i} p^j\right) \tag{26}$$

The solution for this bidding game is recorded in Proposition 4.

Proposition 4 *By Assumption 5, under liquidated damages the unique equilibrium in symmetric strictly monotone increasing strategies is characterized by:*

(i) The bid function:

$$p^{ld}(\theta^i) = \theta^i + H + \frac{1-\beta}{\lambda(n-1)} \quad \forall i. \tag{27}$$

(ii) The expected payoff:

$$\Pi^{ld}(\theta^i) = \hat{\Gamma}(C)\frac{1-\beta}{\lambda(n-1)}e^{-\frac{\lambda(n-1)}{1-\beta}\theta^i} \quad \forall i. \tag{28}$$

[18] Note that, for the sake of analytical tractability, we have assumed that the bidder that is awarded the contract is allowed to keep the right to perform the task forever (see Section 3.2). This, however, could bring us to the unrealistic case of a potentially explosive value of compensation for time overruns. Therefore, the approximation (22) allows us to maintain analytical tractability, while capping the amount of compensation for breach (i.e., when $C_{\tau^i} = 0$).

[19] $E_0(\tau)$ is the mean time that the process C takes to reach the trigger level C_τ for the first time. If the trigger exists, i.e. $\frac{1}{2}\sigma^2 - \alpha > 0$, the mean time is given by: $E_0(\tau) = (\frac{1}{2}\sigma^2 - \alpha)^{-1} \log\left(\frac{C}{C_\tau}\right)$ (see Cox and Miller, 1965,p.221-222). Thus, by the Taylor's theorem:

$$E_0(\tau) \simeq (\frac{1}{2}\sigma^2 - \alpha)^{-1}\left(\frac{C - C_\tau}{C}\right)$$

with $\Pi^{ld}(\theta^u \to \infty) = 0$,
(iii) The optimal trigger:

$$C^{**}_{\tau^i} = -(1 - \frac{H}{C})^{-1} \frac{\beta}{\lambda(n-1)} \quad \forall i. \tag{29}$$

Proof. See Appendix D ■

The central finding in Proposition 4 is property *(i)*, which states that, by exploiting the time flexibility, bidders can add the maximum potential compensation payable for breach into the bid.

The intuition is the following. Since agents bid knowing that they can choose the delivery date, by compensating the owner for late completion, competition will force the weakest bidder to revise delivery plans to preserve the non-negative payoff condition when paying H. This allows the other bidders to increase the price by H, without altering the monotonicity property of $p^{ld}(\theta^i)$, and then to make more profits, by getting the difference $H - E_0(\tau^i)h$.

Thus, by following the same reasoning as in Section 3.2, each bidder will maximize the probability of winning the project by reporting $\min\left[p^{ld}(\theta^i), p^{enf}(\theta^i)\right]$, where $p^{ld}(\theta^i)$ stands for the price (27), and $p^{enf}(\theta^i)$ stands for the price (5) which maximizes the project value when complying with the contract time (NPV^i).

The optimal equilibrium strategy is recorded in Proposition 5.

Proposition 5 *Under liquidated damages, bidders will bid lower than when the buyer is able to induce full compliance with the contract time, and higher than when the contract does not provide for any compensation for breach:*

$$p^{nf}(\theta^i) < p^{ld}(\theta^i) < p^{enf}(\theta^i) \qquad \forall i$$

Proof. Straightforward from Appendix C ■

Proposition 5 rests on Assumption 5, which, by (29), requires that $C > H - \frac{\beta}{\lambda(n-1)} = H + C^{*}_{\tau^i}$, in which case, by exploiting the time flexibility, bidders will report $p^{ld}(\theta^i) < p^{enf}(\theta^i)$. However, if the liquidated damages clause happens to discourage project delays ($C < H + C^{*}_{\tau^i}$), bidders will report $p^{enf}(\theta^i)$ (see Figure 2).

The foregoing discussion can thus be summarised by the following Proposition.

Proposition 6 *If* $C < H + C^{*}_{\tau^i}$ *then:*

$$(i)\ \ \Pi^{ld}(\theta^i) = \Pi^{enf}(\theta^i) \quad \text{and} \quad (ii)\ W^{ld}(\theta^i) = W^{enf}(\theta^i), \qquad \forall i.$$

On the other hand, if $C > H + C^{*}_{\tau^i}$*, then:*

$$(iii)\ \ C^{**}_{\tau^i} > C^{*}_{\tau^i},\ (iv)\ \ \Pi^{ld}(\theta^i) > \Pi^{nf}(\theta^i) \quad \text{and} \quad (v)\ W^{ld}(\theta^i) < W^{nf}(\theta^i), \qquad \forall i.$$

Proof. Straightforward from Propositions 2 and 3. ■

Comparisons *(iv)* and *(v)* are of particular interest for evaluating the potential effects of a liquidated damages clause on the parties' terms of trading.

The former follows from direct inspection of (14) and (28), from which it is apparent that the seller's expected payoff is higher under the expectation damage measure than when the contract does not provide for any compensation for late-delivery.

Comparison *(v)* follows from the condition $E_0[L(\tau)] \equiv E_0[D(\tau)]$, which implies that, under compensatory payments, the buyer's expected payoff is simply given by:

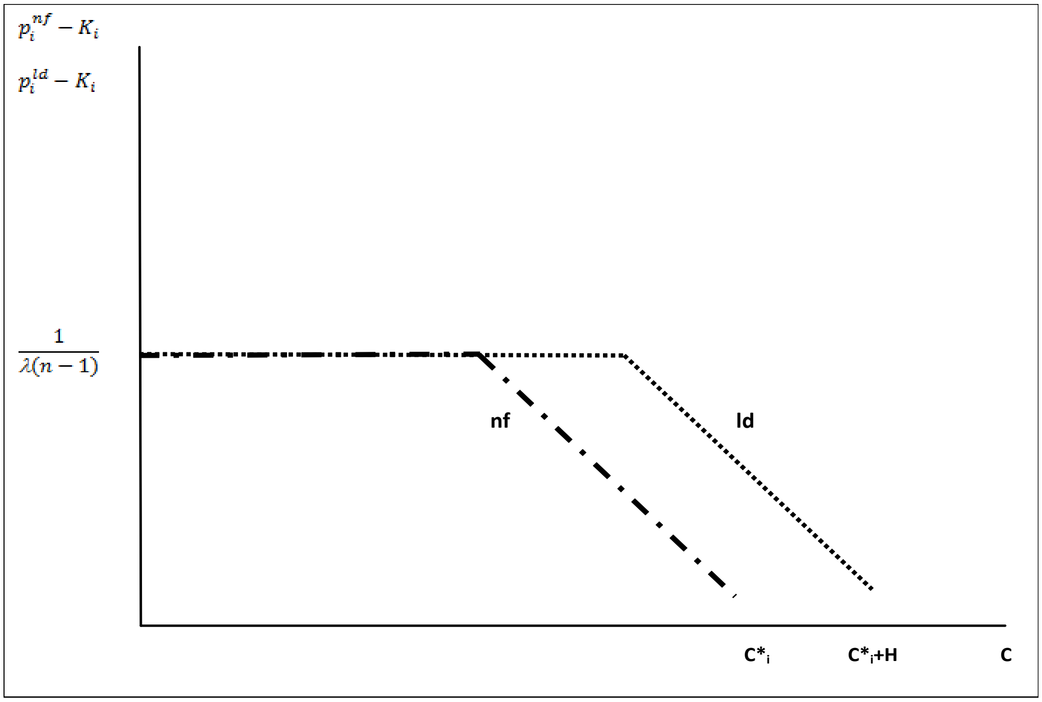

Figure 2: The ex post value of the contract under unenforceable contract time (nf) and liquidated damages (ld)

$$W^{ld}(\theta^i) = B - E_0^{ld}(e^{-r\tau^i})p^{ld}(\theta^i)$$

whereas the corresponding payoff, when the contract does not provide for any compensation for late-delivery, is given by:

$$W^{nf}(\theta^i) = B - E_0^{nf}(e^{-r\tau^i})p^{nf}(\theta^i) - E_0^{nf}(e^{-r\tau^i})E_0^{nf}(\tau^i)h$$

Therefore:

$$W^{ld}(\theta^i) - W^{nf}(\theta^i) = p^{nf}(\theta^i)\left[E_0^{nf}(e^{-r\tau^i}) - E_0^{ld}(e^{-r\tau^i})\right] + E_0^{nf}(e^{-r\tau^i})E_0^{nf}(\tau^i)h - E_0^{ld}(e^{-r\tau^i})H \qquad \forall i \tag{30}$$

Since both terms on the r.h.s. are negative, we get property *(v)* which states that, when damage provisions prove insufficient in stimulating full compliance with the contract time, the buyer's expected payoff will be lower under liquidated damages than when the contract does not provide for any compensation for delay. This is because, while shortening the expected time of delivery (see comparison *(iii)*), the benefit the promisee will receive from protecting herself against the potential loss arising from late completion is outweighed by the increase in the equilibrium bid.

5 Final remarks

This paper rests on two empirical premises. First, time overruns are common in public works and are not confined to inherently complex tasks, as even relatively simple projects, with little uncertainty about what needs to be done, are not immune from late completion. And second, this occurs despite damage measures, setting in advance compensation for late-delivery, are routinely included in contract documents.

One explanation advanced in this paper is that sellers, who have been awarded with fixed-price contracts, can undergo unpredictable changes in input costs which may generate an option value of waiting. Therefore, the higher is the volatility of costs, the higher should be the "penalty" required to force the promisor to give up the potential benefits derived by adjusting delivery plans after contract award.

In reality, as suggested by empirical evidence, damage measures are often not sufficiently stringent to prevent sellers from exploiting such flexibility. This may be due to several factors, including enforcement costs, which could draw promisees away from going to courts, or regulatory provisions and legal rules which put constraints upon the enforceable amount of compensation for late-delivery.

Whatever the source is, the inability to force sellers to meet their contractual obligations determines their bidding behaviour. Conversely, bidding behaviour alters the incentive to meet the contract time. In particular, by placing more aggressive bids, all bidders may become potential violators of the contractual agreement. The more the bidders and/or the higher the expected cost volatility, the higher the probability of breach.

The main question addressed in this paper was how this would ultimately affect the parties' expected payoffs. Barring reputation effects for nonperformance, we showed that, when the buyer cannot affect the probability of performance through her choice of an appropriate damage measure, the welfare of both parties will be lower than when the contract time is enforceable, unless the benefits to the buyer, resulting from bid reduction, outweigh the expected costs from late-delivery. Thus, when on-time delivery is very important for the buyer, she may wish for damages for failure to be set sufficiently high that the contractual obligations would always be fulfilled.

This, however, may be impeded by legal rules which prevent the promisee from contracting for damage measures which would grant more than her lost expectation, in which case, unless the expectation damage measure happens to discourage time overruns, setting a liquidated damages clause would not lead to a Pareto superior outcome with respect to the no-damage-for-delay condition. While increasing the seller's expected payoff, this clause would be detrimental for the buyer because she would have to over pay for protecting herself against the potential loss arising from late completion, and so would gain nothing by pursuing it.

Taken together, these results cast doubt on the efficiency rationale of the common law penalty doctrine. As long as buyers are bound to award fixed-price contracts through competitive tendering and bidders face non-negligible unpredictable changes of production costs, both parties may wish for damages for late-delivery which provide an effective incentive against delayed orders.

A Proof of proposition 1

The proof is quite standard in the auction literature (see, for example, McAfee and McMillan, 1987; Krishna 2002), and we include it for the convenience of the reader. Consider a common prior cumulative distribution $F(\theta)$, with continuously differentiable density $f(\theta)$ defined on a positive support $\Theta = [\theta^l, \theta^u] \subseteq R_+$, where the lowest value θ^l, possibly zero, is such that $\theta^l = \inf[\theta : f(\theta) > 0]$, and the highest value, possibly infinite, is $\theta^u = \sup[\theta : f(\theta) > 0]$.

First, consider the ith agent's bidding behaviour. Assuming that all other bidders use a strictly monotone increasing bid function $p^{enf}(\theta^i) : [\theta^l, \theta^u] \to [p^{enf}(\theta^l), p^{enf}(\theta^u)]\ \forall i$, the expected payoff from bidding p^i is:

$$\Pi^{enf}(p^i) \equiv \left[p^i - \theta^i - C\right] \Pr\left(p^i < \max_{j \neq i} p^j\right)$$

Since $p^{enf}(\theta^i)$ is monotone in $[\theta^l, \theta^u]$, the probability of winning when bidding p^i against rivals who play the strategy is $\Pr(p^i < p^{enf}(\theta^j) \mid \forall j \neq i) = \Pr(\theta^j > p^{-1}(p^{enf}(\theta^i)) \mid \forall j \neq i) = \left[1 - F(p^{-1}(p^{enf}(\theta^i)))\right]^{n-1} \equiv \left[1 - F(\theta^i)\right]^{n-1}$.

Thus, we can then write the ith agent's expected payoff as:

$$\Pi^{enf}(\theta^i) \equiv \left[p^{enf}(\theta^i) - \theta^i - C\right] \left[1 - F(\theta^i)\right]^{n-1} \tag{31}$$

from which we find that $NPV(\theta^i) \equiv \left[p^{enf}(\theta^i) - \theta^i - C\right]$ must be non-negative to guarantee a positive expected payoff (otherwise winning the auction would be unprofitable). Let's suppose that the firm i submits a bid $p^{enf}(\tilde{\theta}^i)$ when its true cost is θ^i. Maximizing (31) with respect to $\tilde{\theta}^i$ and imposing the truth-telling condition $\tilde{\theta}^i = \theta^i$ yields the necessary condition:

$$\begin{aligned} 0 &= \frac{\partial \Pi^{enf}(\tilde{\theta}^i, \theta^i)}{\partial \tilde{\theta}^i} \Big|_{\tilde{\theta}^i = \theta^i} \\ &= \frac{dp^{enf}(\theta^i)}{d\theta^i} \left[1 - F(\theta^i)\right]^{n-1} - (n-1)\left[p^{enf}(\theta^i) - \theta^i - C\right]\left[1 - F(\theta^i)\right]^{n-2} f(\theta^i). \end{aligned} \tag{32}$$

Rearranging, we get $d[p^{enf}(\theta^i)\left[1 - F(\theta^i)\right]^{n-1}] = K^i d\left[1 - F(\theta^i)\right]^{n-1}$. Since $F(\theta^u) = 1$, integration yields:

$$\begin{aligned} p^{enf}(\theta^i)\left[1 - F(\theta^i)\right]^{n-1} &= \int_{\theta^u}^{\theta^i} (x + C) d\left[1 - F(x)\right]^{n-1} \\ &= C\left[1 - F(\theta^i)\right]^{n-1} + \theta^i\left[1 - F(\theta^i)\right]^{n-1} - \int_{\theta^u}^{\theta^i} \left[1 - F(x)\right]^{n-1} dx \end{aligned}$$

and, then

$$p^{enf}(\theta^i) = K^i + \int_{\theta^i}^{\theta^u} \frac{\left[1 - F(x)\right]^{n-1}}{\left[1 - F(\theta^i)\right]^{n-1}} dx \quad \text{for any } \theta^i < \theta^u \tag{33}$$

Differentiating (33) with respect to θ^i confirms the assumed monotonicity of the optimal strategy $p^{enf}(\theta^i)$:

$$\frac{d}{d\theta^i} p^{enf}(\theta^i) = (n-1)\frac{f(\theta^i)}{1 - F(\theta^i)} \int_{\theta^i}^{\theta^u} \frac{\left[1 - F(x)\right]^{n-1}}{\left[1 - F(\theta^i)\right]^{n-1}} dx \ > 0 \text{ for all } \theta^i \in [\theta^l, \theta^u) \tag{34}$$

and by continuity for $\theta^i = \theta^u$ as well. Further, the monotonicity of $NPV(\theta^i)$ and the fact that the first order condition (32) has a unique solution assure that (33) is a global maximum. Finally, substituting $F(\theta^i) = 1 - e^{-\lambda\theta^i}$, with $\lambda > 0$ and $\theta^i \in [0, \infty)$, it is easy to show that:

$$\int_{\theta^i}^{\infty} \frac{[1 - F(x)]^{n-1}}{\left[1 - F(\theta^i)\right]^{n-1}} dx = \frac{1}{\lambda(n-1)} \tag{35}$$

and

$$\Pi^{enf}(\theta^i) = \int_{\theta^i}^{\infty} [1 - F(x)]^{n-1} dx = \frac{1}{\lambda(n-1)} e^{-\lambda(n-1)\theta^i}$$

with $\Pi^{enf}(\infty) = 0$.This concludes the proof.

B Proof of proposition 2

Consider the ith agent's bidding decision, by assuming that all other bidders use a strictly monotone increasing bid function $p^{put}(\theta^i) : [\theta^l, \theta^u] \to [p^{put}(\theta^l), p^{put}(\theta^u)]\ \forall i$. The agent's expected payoff from bidding p^i is:

$$\Pi^{put}(p^i) \equiv \Gamma \left(p^i - \theta^i\right)^{1-\beta} \Pr\left(p^i < \max_{j \neq i} p^j\right)$$

where $\Gamma \left(p^i - \theta^i\right)^{1-\beta}$ is the winning bidder's Put Option. Again, since $\Pr(p^i < p^{put}(\theta^j) \mid \forall j \neq i) = \left[1 - F(\theta^i)\right]^{n-1}$, we can write the ith agent's expected payoff as:

$$\Pi^{put}(\theta^i) \equiv \Gamma \left(p^i - \theta^i\right)^{1-\beta} \left[1 - F(\theta^i)\right]^{n-1} \tag{36}$$

Let's now suppose that agent i submits a bid $p^{put}(\tilde{\theta}^i)$ when the nature reveals her expected cost θ^i. Maximizing (36) with respect to $\tilde{\theta}^i$ and imposing the truth-telling condition $\tilde{\theta}^i = \theta^i$ yields the necessary condition:

$$\begin{aligned} 0 &= \frac{\partial \Pi^{put}(\tilde{\theta}^i, \theta^i)}{\partial \tilde{\theta}^i} |_{\tilde{\theta}^i = \theta^i} \qquad (37) \\ &= \frac{dp^{put}(\theta^i)}{d\theta^i}(1-\beta)\Gamma \left(p^i - \theta^i\right)^{1-\beta-1} \left[1 - F(\theta^i)\right]^{n-1} - (n-1)\Gamma \left(p^i - \theta^i\right)^{1-\beta} \left[1 - F(\theta^i)\right]^{n-2} f(\theta^i). \end{aligned}$$

By (37), the maximization problem can be reduced to the following first-order linear differential equation:

$$\frac{dp^{put}(\theta^i)}{d\theta^i} + S(\theta^i) p^{put}(\theta^i) = Q(\theta^i) \tag{38}$$

where $S(\theta^i) \equiv \frac{n-1}{\beta-1} \frac{f(\theta^i)}{1-F(\theta^i)}$ and $Q(\theta^i) \equiv \theta^i S(\theta^i)$. The (38) is a first-order linear differential equation with variable coefficient and variable term. The general solution of (38) can be obtained from:

$$p^{put}(\theta^i) = A(\theta^i) e^{-\int_{\theta^l}^{\theta^i} S(x)dx} = A(\theta^i) \left[1 - F(\theta^i)\right]^{\frac{n-1}{\beta-1}} \tag{39}$$

where $A(\theta^i)$ is a function to be determined. Differentiating the above expression and substituting into ((38) we get:

$$\frac{dA(\theta^i)}{d\theta^i} = \theta^i \frac{n-1}{\beta-1} \frac{f(\theta^i)}{1-F(\theta^i)} \left[1 - F(\theta^i)\right]^{\frac{n-1}{1-\beta}} \equiv \theta^i \frac{d\left[1 - F(\theta^i)\right]^{\frac{n-1}{1-\beta}}}{d\theta^i}$$

Integrating, we obtain:

$$\int_{\theta^l}^{\theta^i} dA = \int_{\theta^l}^{\theta^i} x d\left[1 - F(x)\right]^{\frac{n-1}{1-\beta}}$$

which yields

$$A^i - A^l = \theta^i \left[1 - F(\theta^i)\right]^{\frac{n-1}{1-\beta}} - \theta^l - \int_{\theta^l}^{\theta^i} \left[1 - F(x)\right]^{\frac{n-1}{1-\beta}} dx \tag{40}$$

Substituting (40) in (39) we get the general solution of the ith agent's bid function, where A^l is a constant that can be determined by setting an appropriate initial condition. Thus by (36) we get

$$\Pi^{put}(\theta^i) \equiv \Gamma \left(A^l - \theta^l - \int_{\theta^l}^{\theta^i} \left[1 - F(x)\right]^{\frac{n-1}{1-\beta}} dx \right)^{1-\beta} \tag{41}$$

But (36) also implies that

$$\Pi^{put}(\theta^u) = 0 \tag{42}$$

thus, from (41) we get:

$$A^l = \theta^l + \int_{\theta^l}^{\theta^u} \left[1 - F(x)\right]^{\frac{n-1}{1-\beta}} dx$$

Rearranging (39) and (41), we get the final expression reported in the proposition:

$$p^{put}(\theta^i) = \theta^i + \int_{\theta^i}^{\theta^u} \frac{\left[1 - F(x)\right]^{\frac{n-1}{1-\beta}}}{\left[1 - F(\theta^i)\right]^{\frac{n-1}{1-\beta}}} dx \tag{43}$$

and for the ex-ante payoff:

$$\begin{aligned} \Pi^{put}(\theta^i) &\equiv \Gamma \left(A^l - \theta^l - \int_{\theta^l}^{\theta^i} \left[1 - F(x)\right]^{\frac{n-1}{1-\beta}} dx \right)^{1-\beta} \\ &= \Gamma \left(\int_{\theta^i}^{\theta^u} \left[1 - F(x)\right]^{\frac{n-1}{1-\beta}} dx \right)^{1-\beta} \end{aligned} \tag{44}$$

Finally, differentiating (43) with respect to θ^i confirms the assumed monotonicity of the optimal strategy $p^{put}(\theta^i)$:

$$\frac{d}{d\theta^i} p^{put}(\theta^i) = \frac{n-1}{1-\beta} \frac{f(\theta^i)}{1 - F(\theta^i)} \int_{\theta^i}^{\theta^u} \frac{\left[1 - F(x)\right]^{\frac{n-1}{1-\beta}}}{\left[1 - F(\theta^i)\right]^{\frac{n-1}{1-\beta}}} dx \; > 0 \text{ for all } \theta^i \in [\theta^l, \theta^u)$$

and by continuity for $\theta^i = \theta^u$ as well.

It remains to show that (44), provides the unique local maximum to (36). As usual, the uniqueness follow from (38) with the boundary condition (42). For the maximum, consider a firm with private cost θ^i that reports a bid $p^i = p^{put}(\tilde{\theta}^i)$ with $\tilde{\theta}^i \neq \theta^i$. From (36) and (43), we can write:

$$\Pi^{put}(\tilde{\theta}^i, \theta^i) \equiv \Gamma \left(\tilde{\theta}^i + \int_{\tilde{\theta}^i}^{\theta^u} \frac{\left[1 - F(x)\right]^{\frac{n-1}{1-\beta}}}{\left[1 - F(\tilde{\theta}^i)\right]^{\frac{n-1}{1-\beta}}} dx - \theta^i \right)^{1-\beta} \left[1 - F(\tilde{\theta}^i)\right]^{n-1} \tag{45}$$

Differentiating (45) with respect to $\tilde{\theta}^i$ yields:

$$\frac{\partial \Pi^{put}(\tilde{\theta}^i,\theta^i)}{\partial \tilde{\theta}^i} = (1-\beta)\Gamma\left(\tilde{\theta}^i + \int_{\tilde{\theta}^i}^{\theta^u} \frac{[1-F(x)]^{\frac{n-1}{1-\beta}}}{\left[1-F(\tilde{\theta}^i)\right]^{\frac{n-1}{1-\beta}}}dx - \theta^i\right)^{1-\beta-1} \times$$

$$\left(\frac{n-1}{1-\beta}\frac{f(\tilde{\theta}^i)}{1-F(\tilde{\theta}^i)}\int_{\theta^i}^{\theta^u} \frac{[1-F(x)]^{\frac{n-1}{1-\beta}}}{\left[1-F(\tilde{\theta}^i)\right]^{\frac{n-1}{1-\beta}}}dx\right)\left[1-F(\tilde{\theta}^i)\right]^{n-1}$$

$$-(n-1)\frac{f(\tilde{\theta}^i)}{1-F(\tilde{\theta}^i)}\Gamma\left(\tilde{\theta}^i + \int_{\tilde{\theta}^i}^{\theta^u} \frac{[1-F(x)]^{\frac{n-1}{1-\beta}}}{\left[1-F(\tilde{\theta}^i)\right]^{\frac{n-1}{1-\beta}}}dx - \theta^i\right)^{1-\beta}\left[1-F(\tilde{\theta}^i)\right]^{n-1}$$

and rearranging:

$$\frac{\partial \Pi^{put}(\tilde{\theta}^i,\theta^i)}{\partial \tilde{\theta}^i} = \Gamma\left(\tilde{\theta}^i + \int_{\tilde{\theta}^i}^{\theta^u} \frac{[1-F(x)]^{\frac{n-1}{1-\beta}}}{\left[1-F(\tilde{\theta}^i)\right]^{\frac{n-1}{1-\beta}}}dx - \theta^i\right)^{1-\beta-1}\left[1-F(\tilde{\theta}^i)\right]^{n-1} \times$$

$$\left[(1-\beta)\left(\frac{n-1}{1-\beta}\frac{f(\tilde{\theta}^i)}{1-F(\tilde{\theta}^i)}\int_{\theta^i}^{\theta^u} \frac{[1-F(x)]^{\frac{n-1}{1-\beta}}}{\left[1-F(\tilde{\theta}^i)\right]^{\frac{n-1}{1-\beta}}}dx\right) - (n-1)\frac{f(\tilde{\theta}^i)}{1-F(\tilde{\theta}^i)}\left(\tilde{\theta}^i + \int_{\tilde{\theta}^i}^{\theta^u} \frac{[1-F(x)]^{\frac{n-1}{1-\beta}}}{\left[1-F(\tilde{\theta}^i)\right]^{\frac{n-1}{1-\beta}}}dx - \theta^i\right)\right]$$

$$\begin{aligned}
\frac{\partial \Pi^{put}(\tilde{\theta}^i,\theta^i)}{\partial \tilde{\theta}^i} &= \Gamma\left(\tilde{\theta}^i + \int_{\tilde{\theta}^i}^{\theta^u} \frac{[1-F(x)]^{\frac{n-1}{1-\beta}}}{\left[1-F(\tilde{\theta}^i)\right]^{\frac{n-1}{1-\beta}}}dx - \theta^i\right)^{1-\beta-1}\left[1-F(\tilde{\theta}^i)\right]^{n-1}(n-1)\frac{f(\theta^i)}{1-F(\theta^i)}\left(\theta^i - \tilde{\theta}^i\right) \\
&= \Pi^{put}(\tilde{\theta}^i,\theta^i)\left(\tilde{\theta}^i + \int_{\tilde{\theta}^i}^{\theta^u} \frac{[1-F(x)]^{\frac{n-1}{1-\beta}}}{\left[1-F(\tilde{\theta}^i)\right]^{\frac{n-1}{1-\beta}}}dx - \theta^i\right)^{-1}(n-1)\frac{f(\tilde{\theta}^i)}{1-F(\tilde{\theta}^i)}\left(\theta^i - \tilde{\theta}^i\right)
\end{aligned}$$

which goes to zero only if $\theta^i - \tilde{\theta}^i = 0$. The second derivative of (45) evaluated at $\theta^i = \tilde{\theta}^i$ yields:

$$\frac{\partial^2 \Pi^{put}(\tilde{\theta}^i,\theta^i)}{\partial (\tilde{\theta}^i)^2} = -\Pi^{put}(\theta^i)\left(\int_{\tilde{\theta}^i}^{\theta^u} \frac{[1-F(x)]^{\frac{n-1}{1-\beta}}}{\left[1-F(\theta^i)\right]^{\frac{n-1}{1-\beta}}}dx\right)^{-1}(n-1)\frac{f(\theta^i)}{1-F(\theta^i)} < 0$$

which guarantees that a strict local maximum exists. By continuity and the fact that the first order condition has unique solution we get a global maximum. Again, by substituting $F(\theta^i) = 1 - e^{-\lambda\theta^i}$, with $\lambda > 0$ and $\theta^i \in [0,\infty)$, we obtain:

$$\int_{\theta^i}^{\infty} \frac{[1-F(x)]^{\frac{n-1}{1-\beta}}}{\left[1-F(\theta^i)\right]^{\frac{n-1}{1-\beta}}}dx = \frac{1-\beta}{\lambda(n-1)}$$

and

$$\Pi^{enf}(\theta^i) = \int_{\theta^i}^{\infty}[1-F(x)]^{\frac{n-1}{1-\beta}}dx = .\frac{1-\beta}{\lambda(n-1)}e^{-\frac{\lambda(n-1)}{1-\beta}\theta^i}$$

with $\Pi^{enf}(\infty) = 0$.This concludes the proof.

C Proof of proposition 3

Defining $\Phi(x,\theta^i) \equiv \frac{[1-F(x)]^{n-1}}{\left[1-F(\theta^i)\right]^{n-1}} < 1$ and recalling that $\beta < 0$, from (33) and (43) it is easy to show that:

$$p^{enf}(\theta^i) - p^{put}(\theta^i) = C + \int_{\theta^i}^{\theta^u} [\Phi(x,\theta^i) - \Phi(x,\theta^i)^{\frac{1}{1-\beta}}]dx$$

which is increasing in C. Therefore there exists a value $\hat{C}^i \equiv \int_{\theta^i}^{\theta^u} [\Phi(x,\theta^i)^{\frac{1}{1-\beta}} - \Phi(x,\theta^i)]dx > 0$ such that:

$$p^{enf}(\theta^i) - p^{put}(\theta^i) = \begin{cases} \geq 0 & \text{if } C \geq \hat{C}^i \\ \\ < 0 & \text{if } C < \hat{C}^i \end{cases} \tag{46}$$

Next, substituting $\int_{\theta^i}^{\infty} \Phi(x,\theta^i)dx = \frac{1}{\lambda(n-1)}$ and $\int_{\theta^i}^{\infty} \Phi(x,\theta^i)^{\frac{1}{1-\beta}}] = \frac{1-\beta}{\lambda(n-1)}$, we get that $\hat{C}^i = C^{i*} = \frac{-\beta}{\lambda(n-1)}$ and, by Assumption 5, the optimal bid is $p^{nf}(\theta^i) = p^{put}(\theta^i)$. From (36) and (10), the ex-ante payoff $\Pi^{nf}(\theta^i) = \Pi^{put}(\theta^i)$ can be written as:

$$\begin{aligned} \frac{\Pi^{nf}(\theta^i)}{\left[1-F(\theta^i)\right]^{n-1}} &= \frac{1}{1-\beta}\left(\frac{\beta}{\beta-1}\right)^{-\beta} C^{\beta} \left(\int_{\theta^i}^{\infty} \Phi(x,\theta^i)^{\frac{1}{1-\beta}}]\right)^{1-\beta} \\ &= \frac{1}{1-\beta}\left(\frac{\beta}{\beta-1}\right)^{-\beta} C^{\beta} \left(\frac{1-\beta}{\lambda(n-1)}\right)^{1-\beta} \end{aligned}$$

Therefore, the difference between the expected payoff when the contract time is unenforceable and when is enforceable is:

$$\begin{aligned} \frac{\Pi^{nf}(\theta^i) - \Pi^{enf}(\theta^i)}{\left[1-F(\theta^i)\right]^{n-1}} &= \frac{1}{\lambda(n-1)}\left[\left(\frac{-\beta}{\lambda(n-1)}\right)^{-\beta} C^{\beta} - 1\right] \\ &= \frac{1}{\lambda(n-1)}\left[\left(\frac{C}{C^{i*}}\right)^{\beta} - 1\right] < 0 \end{aligned}$$

D Proof of proposition 4

The proof follows the one of Proposition 2. The agent i 's expected payoff with the liquidated damages is:

$$\Pi^{ld}(\theta^i) \equiv \hat{\Gamma}\left(p^i - \theta^i - H\right)^{1-\beta}\left[1-F(\theta^i)\right]^{n-1} \tag{47}$$

Maximizing (47) with respect to $\tilde{\theta}^i$ and imposing the truth-telling condition $\tilde{\theta}^i = \theta^i$ yields the necessary condition:

$$\begin{aligned} 0 &= \frac{\partial \Pi^{ld}(\tilde{\theta}^i,\theta^i)}{\partial \tilde{\theta}^i}|_{\tilde{\theta}^i=\theta^i} && (48) \\ &= \frac{dp^{ld}(\theta^i)}{d\theta^i}(1-\beta)\hat{\Gamma}\left(p^i-\theta^i-H\right)^{1-\beta-1}\left[1-F(\theta^i)\right]^{n-1} - (n-1)\hat{\Gamma}\left(p^i-\theta^i-H\right)^{1-\beta}\left[1-F(\theta^i)\right]^{n-2} f(\theta^i). \end{aligned}$$

which can be reduced to the following first-order linear differential equation:

$$p^{ld}(\theta^i) - \theta^i = -\frac{\frac{dp^{ld}(\theta^i)}{d\theta^i}}{S(\theta^i)} + H \tag{49}$$

where $S(\theta^i) \equiv \frac{n-1}{\beta-1}\frac{f(\theta^i)}{1-F(\theta^i)}$. Comparing (49) with (38) suggests that, under liquidated damages, the bidder will rise the bid by H. Then applying the general solution (39) to (49) we obtain:

$$p^{ld}(\theta^i) = \theta^i + H + \int_{\theta^i}^{\theta^u} \frac{[1-F(x)]^{\frac{n-1}{1-\beta}}}{\left[1-F(\theta^i)\right]^{\frac{n-1}{1-\beta}}} dx$$

and for the expected payoff:

$$\Pi^{ld}(\theta^i) = \hat{\Gamma}\left(\int_{\theta^i}^{\theta^u} [1-F(x)]^{\frac{n-1}{1-\beta}} dx\right)^{1-\beta}$$

where $\hat{\Gamma} \equiv \Gamma(1-\frac{H}{C})^{\beta} > 0$. Finally, since $\hat{\Gamma} > \Gamma$ we gets:

$$\Pi^{ld}(\theta^i) > \Pi^{nf}(\theta^i) \tag{50}$$

This concludes the proof.

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