Procurement and Accidents: Bidding for Judgment Proofness, and the Limited Liability Curse.

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Abstract

In this paper we analyze a procurement setting in which the sponsor intends to allocate a project that involves some risk of external harm. The winning firm may exert care to reduce the probability of accident. There is an ex-post regulatory regime, such as Tort Law, that provides incentives to the winning firm to invest in care. The effectiveness of these incentives is undermined by the limited liability of the winning firm/injurer: the potential liability / monetary sanction cannot exceed its current wealth. Potential bidders differ both in their cost of undertaking the project and in their initial wealth. The paper shows that the "judgment proof" problem leads to the less solvent firms to bid more aggressively in the auction and the competitive mechanism adversely selects undercapitalized firms. The paper also shows that tougher ex post regulations (such as increases in the liability standard) lead to worse allocations.

Keywords: Procurement, limited liability, bankruptcy, Accidents, Liability Standards.

JEL classification numbers: L51, H57, H24, D44, K13, K23, L51.

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1 Introduction

There are many public projects and procurement contracts concerning activities involving relevant risk of harm that are allocated competitively between potential contractors. Examples of such projects include hospitals, airports, large public works, prisons, mineral and oil concessions, security in public spaces and property, defense activities and programs, and so on. In all these cases, once the project is awarded, the contractor enters a stage in which the standard legal liability framework applies. On this, we have a large literature devoted to study the incentives of the injurer (in our case the project winning firm) to take care and reduce the probability of accident to third parties. The increasing popularity of PPP schemes[1] to execute and operate public services, where operational risk is transferred to the contractor, seems to increase the real-world relevance of such settings.

However, as far as we know, there are no previous papers analyzing the interaction between the procurement process and the liability problem that the awarded contractor has to face. We believe this is an important issue, since the procurement process will determine the features of the potential injurer, and these features in turn will affect the outcome of the liability stage. In particular, we know that the probability of accident will be linked to the level of assets of the contractor (winning firm) due to the "Judgment Proof" problem. Less capitalized firms pay lower damages in case of accident and thus exert lower care. For this reason, they obtain larger net profits from the activity, which in turn influences the procurement stage and the selection of the contractor.

In a standard procurement process participating firms are likely to differ both in their costs of undertaking the project and in their level of assets. The selection procedure will determine the winning firm, and consequently the final assets of the potential injurer. Competitive auction mechanisms allocate the project to the firms with the larger willingness to pay (willingness to

[1] See, Burger and Hawkesworth (2011).

accept a lower price in case of procurement). This leads to select the most efficient firm in standard settings. However, in the case of risky projects, the undercapitalized firms have a competitive advantage due to the "Judgment Proof", obstacle to paying damages or monetary sanctions. Then, liability rules will affect not only the incentives of the winning firm to exert care in undertaking the project but also the incentives of firms to bid, and through this channel, liability rules affect the outcome of the procurement process.

In this paper we analyze a procurement setting, in which a project involving risk of external harm has to be allocated among firms that differ in their cost and in their asset level. The winning firm is protected by limited liability and its incentives to exert care depend on the liability rule and on its assets. In this framework, we obtain three fundamental results: i) Competitive mechanisms adversely select undercapitalized firms for undertaking risky projects. ii) Tougher liability standards lead to worse allocations: the winning firm is likely to be both less solvent and less efficient. iii) Minimum asset requirements as pre-qualification checks in the procurement process, and liability rules governing the activity of the contractor are complements in procurement settings (work in progress).

This implies that selection processes to undertake projects (public works and public services among them) and the substantive rules regulating the performance of the project, are more closely intertwined than is commonly perceived. Both instruments need to be considered jointly if one desires to select the more efficient firms to carry out the project, and also to provide incentives for adequately investing in avoidance of external costs (or obtaining quality) in the execution of the project. When one looks at the best practices and guidance in the area of public procurement that organizations such as the World Bank, the WTO and the OECD promote and champion, one observes little trace of such a broader perception of this type of challenge in making correct decisions in the area of public procurement.

This paper is related to two different branches of the literature. There is a rich literature studying procurement settings with cost uncertainty and limited liability [Waehrer (1995), Zheng

(2001), Calveras et al (2004), Engel and Wambach (2006), Board (2007) Chillemi and Mezzetti (2010), Burguet et al (2012)]. The main results from these contributions may be briefly summarized as follows: i) In the presence of cost uncertainty, limited liability introduces the possibility of default in procurement. ii) Limited liability cuts off the potential downside losses of the winning bidder making bidders bid more aggressively. iii) This effect is stronger for financially weaker bidders, and thus they are selected with higher probability by competitive mechanisms. In this paper we obtain a similar result in a tort-procurement setting that adds to the adverse selection problem a moral hazard dimension plus ex-post risk regulation.

The paper also related to the literature on how judgement proofness affects the functioning of liability rules for activities that may produce external harm: Summers (1983); Shavell (1986); Dari-Mattiacci and De Geest (2002); Micelli and Segerson (2003); Ganuza and Gomez (2008, 2011); Wickelgren (2011). These papers, among others, have pointed out that: i) When injurers are insolvent, first-best behavior in terms of accident prevention cannot generally be attained through liability rules. ii) Negligence-like rules are superior to strict liability, at least when one does not consider settlement, and even with settlement, when the level of insolvency is large. iii) Tougher liability standards may worsen the problem, specially when levels of assets are endogenous for firms. iv) Standards and other policy instruments, such as minimum asset requirements, are complements. We add an adverse selection dimension to this moral hazard problem with ex post regulation. Thus, we extend the previous literature to a richer setting in which the potential injurer is selected through a competitive process that, in turn, is affected by the outcome of the accident and liability element of the problem.

The paper is organized as follows: Section 2 presents the basic features of the model. Section 3 characterizes the equilibrium in both the liability and the bidding stages. Section 4 shows the effect of increasing liability standards on the outcome of the procurement process. Section 5 briefly concludes and discusses the extensions we are presently considering.

2 Model

We analyze a procurement setting in which a risk neutral sponsor procures an indivisible project or contract for which he is willing to pay V. We assume V large enough so as to make the possibility of not contracting unattractive for the sponsor. N firms compete for the indivisible contract. Firms differ both in their cost for undertaking the project and in their initial financial status. Let $c_i \geq 0$ and $l_i \geq 0$ denote, respectively, the cost of undertaking the project and the value of the assets of potential contractor $i = 1, 2, ..., N$. Both c_i and l_i are contractor i's private information. Each l_i is an independent realization of a random variable with support $\left[\underline{l}, \bar{l}\right]$, with $\underline{l} \geq 0$, density function $f(\cdot)$, and distribution $F(\cdot)$. Each c_i is an independent realization of a random variable with support $[\underline{c}, \overline{c}]$, with $\underline{c} \geq 0$, density function $g(\cdot)$, and distribution $G(\cdot)$. The contract is awarded using a second price auction.

The contract with the sponsor requires the winning firm to undertake an activity that involves the risk of causing an accident affecting third parties (users of the services provided by the project, the environment, etc.). The contractor may make an effort (that for simplicity we assume to be non monetary) for reducing the likelihood of the accident. Let x be the contractor's monetary equivalent of the precautionary effort and $p(x)$ be the probability of an accident resulting in external harm, D, where $p(x)$ is decreasing and convex in x.

In case of accident, liability of the winning firm is determined by a legal rule taking the form of negligence which specifies that if an accident materializes the contractor (injurer) is liable and has to pay a monetary sum to the victim if her precautionary effort is lower than a pre-specified and legally required level $\overline{x}$. We assume that this standard is weakly lower than the first best care level, $\overline{x} \leq x^* = \arg\min\{(1 - p(x))D + x\}$.[2] Contractors have limited liability, i.e. the losses to contractor i from payments to victims cannot be larger than the firm's total wealth, which at

[2]It is clear from the analysis that it cannot be optimal for the sponsor to set a standard larger than the socially efficient level of care. We make this assumption to simplify the presentation and to avoid deal may with uninteresting cases that would remain out of the equilibrium path.

that point is $P - c_i + l_i$. Therefore, if awarded the project, the contractor i will close down and discontinue the project if there is an accident, she is liable and the net profits from undertaking the project, the sum $(P - c_i)$ and its wealth l_i, are lower than the social harm D. We assume that in case of contractor's bankruptcy, the sponsor has to pay a fraction $\beta \in [0, 1]$ of the unpaid liabilities.

We now summarize the timing of the model:

1. Nature chooses the cost c_i and the financial value l_i of each firm.

2. The sponsor announces the procurement process (that we assume takes the form of a second price auction). Firms submit their bids.

3. The project is awarded to the firm with the lowest bid at a price equal to the second lowest bid. Ties are decided using a lottery. Denote the auction price by P, and the cost and the assets of the winning firm by c and l. The winning firm starts undertaking the project and chooses the level of care, x. The accident takes place or not, according to the probability $p(x)$. If there is an accident and the contractor is liable, *i.e.* $x < \overline{x}$, the contractor goes on and completes the project if $P - c + l - D > 0$. Otherwise, $P - c + l - D \leq 0$, the firm declares bankruptcy and exits, and the sponsor pays (or incurs the cost of) $\beta(D - P + c - l)$, with $\beta \in [0, 1]$.

4. Sponsor and firm receive their payoffs.

The sponsor's objective is to minimize both the procurement price, the expected accident costs, and bankruptcy. In the next subsection we show that a simple auction mechanism, as the standard second price auction, does not optimally balance these goals.

3 Characterization of the Equilibrium

We solve the model by backwards induction. We start with the accident stage.

3.1 Accident Stage

In this stage, the winning bidder, the contractor, faces an effective penalty in case of being found liable of $z = \min\{P - c + l, D\}$. A potentially liable injurer chooses a level of care $x_L(z)$ which minimizes her expected total cost,

$$x_L(z) \in \arg\min p(x)z + x,$$

where z is the effective penalty (assumed to be monetary) faced by the liable injurer whenever the accident occurs. Let $\gamma(z)$ be the expected private cost of being liable,

$$\gamma(z) = p(x_L(z))z + x_L(z).$$

Intuitively, $x_L(z)$ and $\gamma(z)$ are increasing functions.

Under a negligence rule, the judgment-proof injurer compares its private expected cost of being liable $\gamma(z)$ with the cost of satisfying the negligence standard $\overline{x}$. As a result, the equilibrium level of care will be

$$x_E(\overline{x}, l) = \begin{cases} \overline{x} & \text{if } \overline{x} < \gamma(z) \\ x_L(z) & \text{otherwise.} \end{cases}$$

given that the exerted effort (probability of accident) is increasing (decreasing) in l. Therefore, the net expected profits of the contractor are

$$\pi_N(P, c, l, \overline{x}) = P - c - \min\{\overline{x}, \gamma(z)\}$$

Lemma 1 *The net expected profits are increasing in P, and decreasing in c, l and $\overline{x}$.*

3.2 Bidding Stage

Firm i wins the second price auction if and only if $P_i^* = \min\{P_1^*, \ldots, P_i^*, \ldots, P_N^*\}$, and will be paid $P = \min\{P_1^*, \ldots, P_{i-1}^*, P_{i+1}^*, \ldots, P_N^*\}$. Under the second price auction the procurement process is similar to Bertrand competition among heterogeneous firms. Hence, the equilibrium bid of each firm i is the minimum price P_i^* for which firm i is willing to accept the project, defined by:

$$E\{\pi_N(P_i^*, c, l, \overline{x})\} = 0, \tag{1}$$

In other words, the equilibrium bid of i is the price for which her net expected profits are zero, in case firm i wins the project.

If firm satisfies the liability standard (which means she is not liable), the price that makes the net expected profits zero is $P_i^* = c_i + \overline{x}$. Equivalently, if we take the markup between the contract price and the cost as the relevant variable, the equilibrium margin in such case is equal to the standard, $g_{NL}^* = P_i^* - c_i = \overline{x}$. If the firm is liable, the price that makes the net expected profits equal to zero is given by the expression $P_i^* = c_i + \gamma(P_i^* - c_i + l_i)$ or, in terms of the price-cost markup $g_L^*(l_i) = P_i^* - c_i$, $g_L^*(l_i) = \gamma(g_L^*(l_i) + l_i)$. Notice that $g_L^*(l_i)$ is uniquely defined, since $\gamma(g + l_i)$ is increasing and has a slope lower than one. Moreover, $g_L^*(l_i)$ is increasing in l_i and $g_L^*(0) = 0$.

Given that the equilibrium bid is the minimum price for which her net expected profits are zero, the firm chooses the minimum markup between the two. Then, the equilibrium bid is $P_i^* = c_i + g(\overline{x}, l)$, where $g(\overline{x}, l) = \min\{g_{NL}^* = \overline{x}, g_L^*(l_i)\}$. Notice that the decisions to be liable or not (choosing g_{NL}^* or g_L^*) depend on the level of wealth of the firm. There is a cut-off level l^* , such that $g_L^*(l^*) = g_{NL}^* = \overline{x}$, where $l^*(\overline{x})$ is increasing on $\overline{x}$. Thus, the equilibrium bidding markup is

$$g(\overline{x}, l) = \begin{cases} \overline{x} & \text{if } l > l^*(\overline{x}) \\ g_L^*(l_i) & \text{otherwise.} \end{cases}$$

Proposition 1 summarizes the characterization of the bidding equilibrium, provides direct comparative statics and a useful feature of the equilibrium markup function $g(\overline{x}, l)$.

Proposition 1 *The equilibrium bid is $P_i^* = c_i + g(\overline{x}, l_i)$, which is increasing in $c_i, \overline{x}$, and l_i and $g(\overline{x}, l_i)$ is supermodular(and consequently P_i^* is supermodular in $(\overline{x}, l_i)$).*

The intuition of the proposition is as follows: the equilibrium bid is such that the expected profits of the bidder are equal to zero. Then, the price (bid) has to compensate the private cost of undertaking the project, c_i and the liability cost, $g(\overline{x}, l_i)$. The liability costs are larger, the larger is the standard and the larger is the asset level of the bidder. We can also illustrate Proposition 1 with the following algebraic example.

3.3 Example

Consider that $p(x) = 1 - \sqrt{x}$, $l \in [0, 1]$ and $D = 1$.

The contractor chooses a level of care $x_L(z)$ which minimizes her expected total cost given the expected penalty z,

$$x_L^*(z) \in \arg\min(1 - \sqrt{x})z + x. \rightarrow x_L^*(z) = \frac{z^2}{4}$$

Given $x_L(z)$, the expected total cost of being liable is

$$\gamma(z) = p(x_L(z))z + x_L(z) = z - \frac{z^2}{4}.$$

The equilibrium markup, in case of being liable is given by $g_L^*(l_i) = \gamma(g_L^*(l_i) + l_i)$. Then

$$\begin{aligned} g_L^*(l_i) &= \gamma(g_L^*(l_i) + l_i) = g_L^*(l_i) + l_i - \frac{(g_L^*(l_i) + l_i)^2}{4} \\ g_L^*(l_i) &= -l + \sqrt{4l} \end{aligned}$$

Where $g_L^*(l_i)$ is increasing, $\frac{\partial g_L^*}{\partial l} = -1 + \frac{1}{\sqrt{l}} \geq 0$.

The equilibrium bid is $P_i^* = c_i + g(\overline{x}, l_i)$, where $g(\overline{x}, l) = \min\{\overline{x}, -l + \sqrt{4l}\}$. Finally,

$$\overline{x} = g(\overline{x}, l^*) \Longrightarrow \overline{x} = \sqrt{4l^*} - l^* \Rightarrow l^* = (1 - \sqrt{1 - \overline{x}})^2$$

Then

$$P^* = \begin{cases} c_i + \overline{x} & \text{if } l \geq l^* = (1 - \sqrt{1 - \overline{x}})^2 \\ c_i - l + \sqrt{4l} & \text{otherwise.} \end{cases}$$

[FIGURE 1 AROUND HERE]

Let $i = (c_i^*, l_i^*)$ be the winner of the auction, such that $P_i^* = \min\{P_1^*, \ldots, P_i^*, \ldots, P_N^*\}$.

3.4 The Adverse Selection Effect

Therefore, for a given level of private cost in delivering the project, the lower is l, the larger is the probability of winning. This leads to the following corollary, which is the main implication from Proposition 1

Corollary 1 *The second price auction mechanism adversely selects undercapitalized firms for undertaking the project.*

It is very likely that this result does not change with alternative competitive procurement mechanisms. Burguet et al (2012) use a mechanism design approach for analyzing a procurement setting with cost uncertainty and where, like in the present paper, firms have private information regarding their wealth and are protected by limited liability. They show that, in this setting, financially weaker contractors are selected with higher probability in any incentive compatible mechanism. In our setting, the opportunity cost of undertaking the project is decreasing in the wealth of the injurer and then, we conjecture that any "monotone" auction (including first price, all pay, etc..) would adversely select undercapitalized contractors. Finally, it is easy to see that increasing competition in the procurement process does not improve matters. Consider the case in which the cost of undertaking the project is constant. Then, the winner, l_i^*, will be the firm with the lowest level of assets, $l_i^* = \min\{l_1, \ldots, l_i, \ldots, l_N\}$. Increasing the number of bidders will lead to an even lower l_i^*.

4 The Liability Curse

The previous analysis has an important implication for the design of optimal liability rules (or expost regulation in undertaking the project) for firms in procurement settings. We have to take into account that the liability system influences the probability of accidents in two ways: i) by shaping the incentives of the winning firm to exert care; and ii) by affecting the incentives of firms to bid and, in this way, determining the outcome of the procurement process.

The effects of liability rules on the outcome of the procurement process are counterintuitive, as shown in the following proposition.

Proposition 2 *Let $(\bar{l}, \overline{c})$ be the type of the winner under the standard $\overline{x}$. Under a higher liability standard $\overline{x}'$ the winner $(\bar{l}', \overline{c}')$ will be both less solvent and less efficient than under a less exacting legal rule, i.e, $\bar{l}' \leq \bar{l}$ and $\overline{c}' \geq \overline{c}$.*

The next figure shows the bidding equilibrium for a given c when when the negligence standard increases from $\overline{x}$ to $\overline{x}'$ and which, may help to understand the intuition of Proposition 2

[FIGURE 2 AROUND HERE]

If we increase the standard from $\overline{x}$ to $\overline{x}'$, then the firms with levels of assets in the interval $[l^*, l^{*'}]$ that would have met the standard $\overline{x}$, would not meet the higher standard $\overline{x}'$. Therefore, these firms would bid more aggressively than firms with assets larger than $l^{*'}$, which in turn would increase the probability of winning of these firms that are now more aggressive bidders. If the winning firm under standard $\overline{x}$, is a firm with assets lower than $l^{*'}$, this latter firm would remain the winner under $\overline{x}'$. This informal argument shows that the winning firm would have lower assets than when the legal standard is weaker. The second part of the proposition is less intuitive at first blush: the winning firm is not only less solvent but is also less efficient (has larger costs) in undertaking the project. This is because if one firm wins the contest under $\overline{x}'$ but loses under $\overline{x}$, this necessarily means that it has higher costs than the winner under the lower standard $\overline{x}$. In sum, a higher liability standard has the effect of inducing the selection of both a less solvent and a less efficient winner. We may call this effect the liability curse in procurement.

Proposition 2 possesses interesting implications for legal and regulatory policy, since it strongly suggests that there are additional cost of increasing liability standards. This result is very much in line with the main insight of Ganuza and Gomez (2008), showing that in a standard accident setting higher $\overline{x}$ does not lead to higher care (lower probability of accidents). In fact, we may reproduce the result of Ganuza and Gomez (2008) in our present procurement setting.

Corollary 2 *Care exerted by the winning bidder may be lower under a higher standard.*

This corollary is a combination of Ganuza and Gomez (2008), that shows that for a fixed l care may be decreasing in the standard, and Proposition 2, that shows that l would decrease with the standard.

We can illustrate Corollary 2 (and also Proposition 2) with the following example in which the equilibrium exerted care decreases when the sponsor increases the standard. In particular, consider the parametric example of section 3.3, $p(x) = 1 - \sqrt{x}$, $D = 1$, and two bidders with types (l, c) equal to $(1, 0)_1$ and $(0, \frac{1}{9} + \varepsilon)_2$. If the standard $\overline{x}$ is $\frac{1}{9}$, the bids are $b_1 = \frac{1}{9}$ and $b_2 = \frac{1}{9} + \varepsilon$, the winner will be bidder 1 and the exerted care equal to the standard $\frac{1}{9}$. If the standard $\overline{x}'$ increases to $\frac{1}{9} + 2\varepsilon$, the bids would be $b_1 = \frac{1}{9} + 2\varepsilon$ and $b_2 = \frac{1}{9} + \varepsilon$, the winner will be bidder 2, and the exerted care would be $x_L^*(z) = \frac{z^2}{4}$ in our case, $z = P - c = \varepsilon$, then $x_L^*(P - c) = \frac{\varepsilon^2}{4}$. As this simple example shows increasing the standard may lead to a worse allocation, leading to the selection of a winning firm with higher costs and lower assets, and to a lower exerted care in equilibrium.

5 Conclusions and Additional Research

The previous analysis explains why competitive mechanisms are likely to select undercapitalized firms for undertaking risky projects. On top of that, enhanced competition in the process does not help, and tougher regulation (more stringent negligence standards) directed to contractors will be counterproductive, since they lead to worse allocations.

These results we believe have important policy implications. In particular, it is very likely that in procurement environments in which the social cost of harm by contractors is large, non purely competitive mechanisms (contests, fixed price, negotiated procedures, competitive dialogues...) may outperform competitive ones.

When one looks at initiatives in the area of public procurement by organizations such as the World Bank, the WTO, who often emphasize international competitive bidding (ICB), one may wonder if the proposals advocated are always desirable, since they may lead to the unattractive results described above, specially if competitive bidding is combined with tough legal or regulatory standards in the execution of the project, and inadequate or insufficient pre-screening of potential bidders. It is true that such initiatives also refer to pre-qualification controls, but the combined role of such ex-ante check, competitive bidding, and substantive standards in executing projects does not seem to be properly understood by the sponsoring institutions of legal change in this area.

This paper is work in progress, and we are currently analyzing several extensions of the present model. In particular, we want to formally show the previous statement concerning the potential advantage of non competitive selection. We also want to study the role of minimum asset requirements in this setting (excluding firms with lower assets than a given $\bar{l}$ from participating in the procurement process). We conjecture that if c_i and l_i are independent, it should not affect the expected efficiency, and it would improve the solvency of the winning firm, but will also lead to an additional cost (from certifying and/or freezing some financial resources), $\rho(\bar{l})$, and to a higher price (lower competition and higher l). Finally, we would like to analyze whether minimum asset requirement and liability standards are complements or substitutes. We conjecture, that they are likely to be complements: with, $\overline{x}' > \overline{x}$, and $\bar{l}' > \bar{l}$,

$$\Pi_S(\overline{x}', \bar{l}') - \Pi_S(\overline{x}, \bar{l}') \geq \Pi_S(\overline{x}', \bar{l}) - \Pi_S(\overline{x}, \bar{l})$$

This is likely to be difficult to prove formally, since the minimum requirement also affect the expected price and this in turn affects the probability of default. We believe these extensions will make the basic results and insights from the paper more comprehensive, in terms of the analyzed dimensions, and also more robust.

Finally, we want to emphasize that the key element of our model is the moral hazard problem between the sponsor and the winning firm. Others settings in which a similar moral hazard dimension is in place are likely to deliver similar results. In particular, we could completely reinterpret our model in terms of contracting for quality in the output of the project. Consider that the procurement contract can be performed with different levels of quality and that the sponsor has to ex-ante specify a minimum quality level for the project, $\overline{q}$. Producing quality is costly and quality is not perfectly observable expost. If the winning firm satisfies $\overline{q}$, there is no additional cost for the firm. If the firm produces a lower level $q < \overline{q}$, with some probability (that it is natural to assume that it is decreasing in quality) the firm has to compensate the sponsor and has to pay some kind of monetary penalty. This expost payments are constrained by the wealth of the winning firm. Then the firm has to choose between undertaking the prespecified quality $\overline{q}$ or to minimize expected cost, $p(q)\min\{z, \overline{q} - q + P\} - q$. This model will generate the same results and implications as the ones presented in the paper.

A Appendix

Proof of Lemma 1:

Differentiating the net profit function with respect to P , we obtain:

$$\frac{\partial \pi_N}{\partial P} = \begin{cases} 1 & \text{if } \overline{x} < \gamma(z) \\ 1 - p(x_L(z)) & \text{otherwise.} \end{cases}$$

Notice that due to the envelope theorem, we can disregard the effect of P over x_L. By the same token

$$\frac{\partial \pi_N}{\partial c} = \begin{cases} -1 & \text{if } \overline{x} < \gamma(z) \\ -1 + p(x_L(z)) & \text{otherwise.} \end{cases}$$

$$\frac{\partial \pi_N}{\partial l} = \begin{cases} 0 & \text{if } \overline{x} < \gamma(z) \\ -p(x_L(z)) & \text{otherwise.} \end{cases}$$

$$\frac{\partial \pi_N}{\partial \overline{x}} = \begin{cases} -1 & \text{if } \overline{x} < \gamma(z) \\ 0 & \text{otherwise.} \end{cases}$$

■

Proof of Proposition 1.

Immediate from the arguments in the main text. We have only to show that $g(\overline{x}, l)$ is a supermodular function, i.e, if $\overline{x}' > \overline{x}$ then $g(\overline{x}, l) - g(\overline{x}', l)$ is weakly increasing in l.Consider $\overline{x}' > \overline{x}$,

$$g(\overline{x}', l) - g(\overline{x}, l) = \begin{cases} \overline{x}' - \overline{x} & \text{if } l \geq l^*(\overline{x}'). \\ g_L(l) - \overline{x} & \text{if } l^*(\overline{x}') \geq l \geq l^*(\overline{x}) \\ 0 & \text{if } l < l^*(\overline{x}) \end{cases}$$

Notice that as $g_L(l)$ is increasing in l, and $g_L(l^*(\overline{x}')) = \overline{x}'$, then $g(\overline{x}', l) - g(\overline{x}, l)$ is increasing in l. This implies that $g(\overline{x}, l)$ is a supermodular function. ■

Proof of Proposition 2:

Firstly, consider contrary to the Proposition that the winner under $\overline{x}'$ is more solvent than the winner under $\overline{x}$, $\bar{l}' > \bar{l}$. Given that P^* is increasing in c and increasing in $l, \bar{l}' > \bar{l}$ and $P(\bar{l}', \overline{c}', \overline{x}') < P(\bar{l}, c, \overline{x}')$, implies that $\overline{c}' < \overline{c}$. Given that $(\bar{l}', \overline{c}')$ is the winning bid under $\overline{x}'$, and $(\bar{l}, c)$ under $\overline{x}$. Then, the next two conditions have to be satisfied.

$$\begin{aligned} P(\bar{l}', \overline{c}', \overline{x}') &= \overline{c}' + g(\bar{l}', \overline{x}') \leq \overline{c} + g(\bar{l}, \overline{x}') = P(\bar{l}, \overline{c}, \overline{x}') \\ P(\bar{l}', \overline{c}', \overline{x}) &= \overline{c}' + g(\bar{l}', \overline{x}) > \overline{c} + g(\bar{l}, \overline{x}) = P(\bar{l}, \overline{c}, \overline{x}) \end{aligned}$$

This is equivalent to

$$\begin{aligned} g(\bar{l}', \overline{x}') - g(\bar{l}, \overline{x}') &\leq \overline{c} - \overline{c}' \\ g(\bar{l}', \overline{x}) - g(\bar{l}, \overline{x}) &> \overline{c} - \overline{c}' \end{aligned}$$

These two conditions imply that

$$g(\bar{l}', \overline{x}) - g(\bar{l}, \overline{x}) > g(\bar{l}', \overline{x}') - g(\bar{l}, \overline{x}')$$

or equivalently

$$g(\bar{l}, \overline{x}') - g(\bar{l}, \overline{x}) > g(\bar{l}', \overline{x}') - g(\bar{l}', \overline{x})$$

and this leads to a contradiction with Lemma 1, since $g(l, \overline{x})$ is supermodular, which implies that

$$g(\bar{l}, \overline{x}') - g(\bar{l}, \overline{x}) \leq g(\bar{l}', \overline{x}') - g(\bar{l}', \overline{x}).$$

Finally, consider contrary to the Proposition that the winner under $\overline{x}'$ is more efficient than the winner under $\overline{x}$, $\overline{c}' < \overline{c}$. The case in which the winner under $\overline{x}'$ is also more solvent, is discussed above. But, if the winner under $\overline{x}'$ is more efficient and less solvent, she should have won also under $\overline{x}$, since her bid is lower than the bid of $(\bar{l}, \overline{c})$ for any legal standards. ■

PROOF OF COROLLARY 2: See the explanation of the Corollary in the main text. ■

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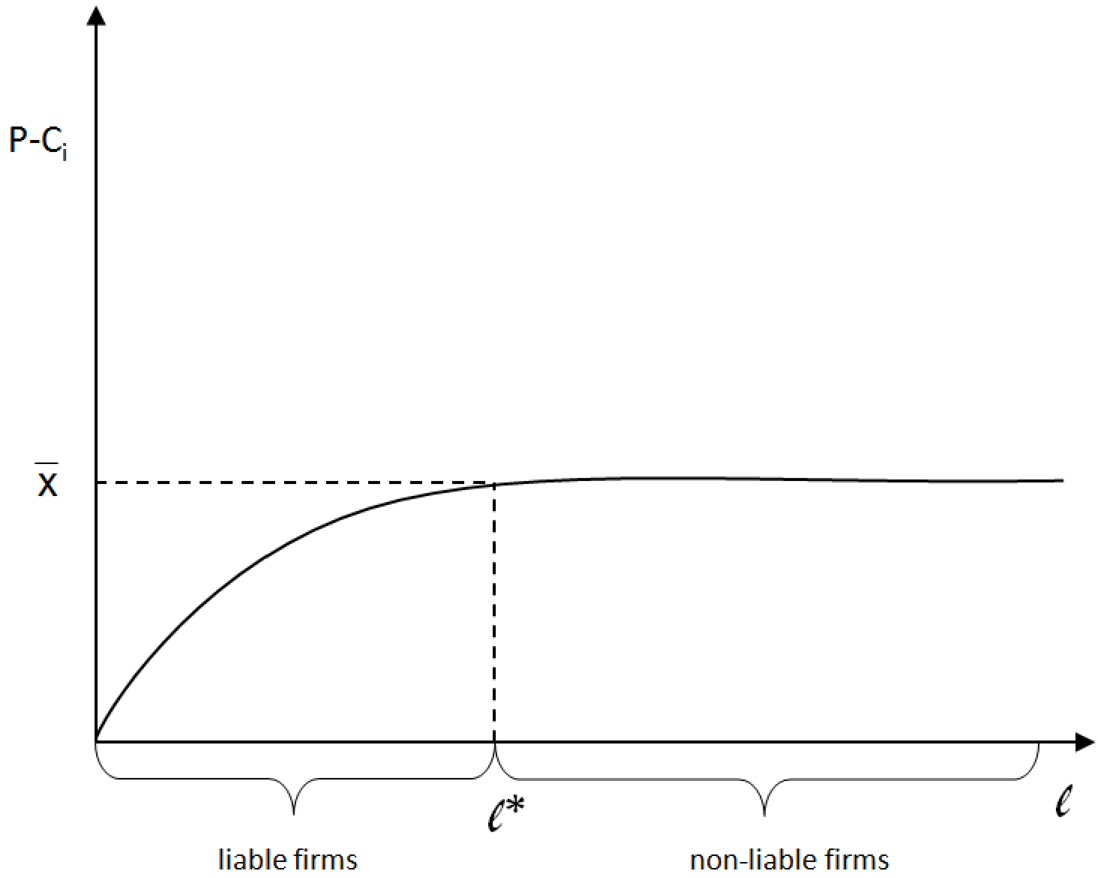

Figure 1

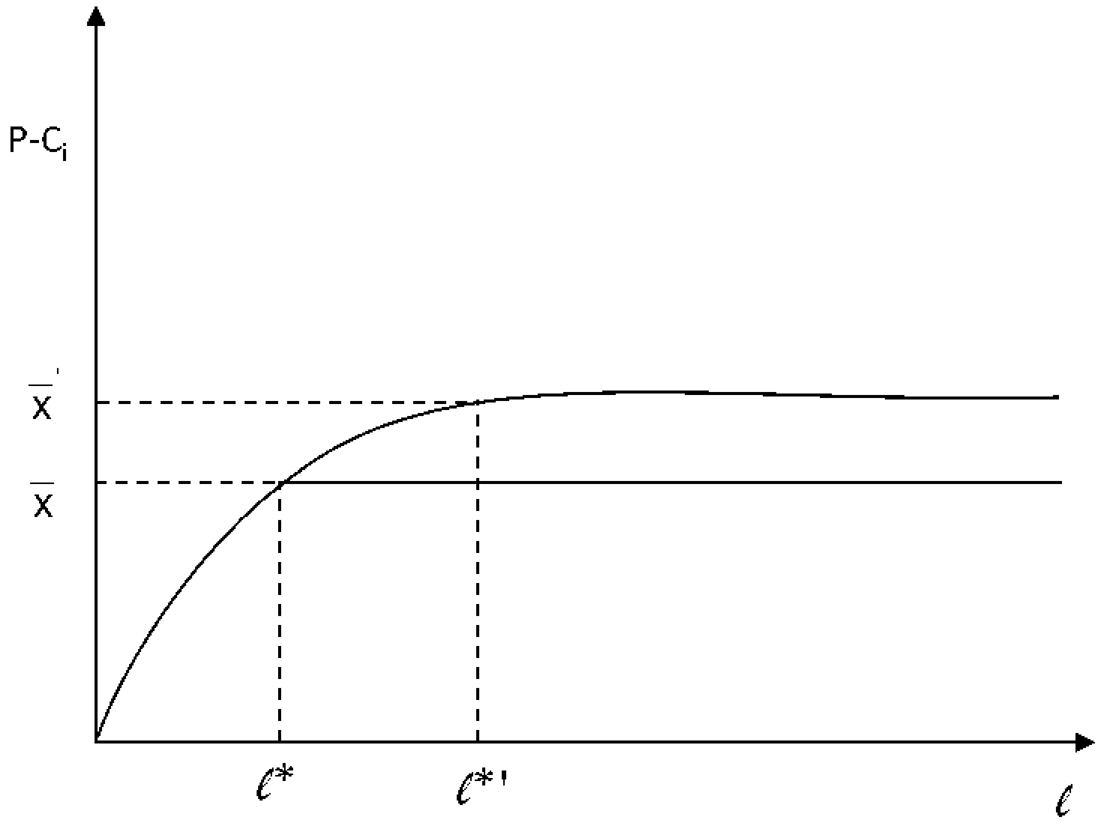

Figure 2