Bidder Asymmetry in Takeover Contests: The Role of Deal Protection Devices

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Abstract

We analyze how a takeover contest should optimally be designed. Our key assumption is that not all bidders are equally well informed about a target's value. We present a three-stage sequential procedure which is optimal in such a setting. In this procedure, the target first offers an exclusive deal to a better informed bidder, without considering a less well informed bidder. If rejected, the target may offer an exclusive deal to the less well informed bidder and ignore the better informed bidder; or it may encourage every bidder to participate in a modified first-price auction. If the sequential procedure is used, increased bidder asymmetry is beneficial for target shareholders. We also find that target shareholders benefit if bidders are trade buyers and not financial buyers.

JEL codes: G34, D44

Key Words: Takeovers, asymmetric information, lock-ups, termination fees, poison pills, bidder exclusivity.

1 Introduction

Takeover contests can be complex, with several rounds of negotiating and bidding, in which some bidders may be excluded if their bids seem comparably low. Often, however, a single bidder seems to be negotiating with a target's board. A deal may be concluded quickly, and the target's board may seal it by agreeing to lock-ups, termination fees, no-shopping clauses, or to the selective lifting of poison pills.[1] These deal protection devices make the target less attractive to other potential bidders, making it less likely that they present higher offers for the target. Not surprisingly, the use of these deal protection devices has been challenged repeatedly in court by target shareholders, who claim that they constitute breaches of fiduciary duty by the board of directors. These court decisions give mixed recommendations. In a recent decision,[2] the Delaware Supreme Court ruled that an "absolute lock-up" was a breach of fiduciary duty. Earlier decisions tended to favor the use of lock-ups and similar devices.

In this paper we analyze how a target's board should arrange the sale of the company, if it is free to use selling procedure. We find that a three-stage sequential procedure is optimal, i.e. no other procedure can extract a higher expected transaction price. The first stage of this procedure includes only the target and a better informed bidder. If this bidder's willingness to pay seems sufficiently high, the board should conclude the sale right away, and if another bidder shows interest, the target should ignore that. If the willingness to pay seems low, the situation is reversed: now the target should exclude the better informed bidder from the process, and it should conclude an exclusive deal with a less well informed bidder. Only if the better informed bidder's willingness to pay is in an intermediate range, there should be no exclusive deals: instead, the target should encourage all bidders to compete in a modified first-price auction, in which the winner pays what she bid.

[1] In stock lock-ups, the favored bidder is given the option to purchase a certain number of shares, either from certain (typically large) shareholders, or out of treasury stock. This makes it harder for other bidders to take over a target, or more expensive. Termination fees are payable to the favored bidder if a takeover is not consummated. With no-shopping clauses, target boards commit not to actively encourage additional bids.

[2] Omnicare, Inc. v. NCS Healthcare, Inc. et al. and Miles et al. v. Outcalt et al. (2003 Del. LEXIS 195). Interestingly, the court was split in this decision.

This sequential procedure can extract the highest expected transaction price from the bidders by treating better and less well informed bidders differently. This allows it to play off the bidders better than standard auctions (for example, open auctions), which treat bidders symmetrically. High bids from the better informed bidder are encouraged by promising exclusivity; low bids are discouraged by threatening to offer exclusivity to the less well informed bidder. The procedure thus distorts the allocation, since compared with a standard auction, the better informed bidder is more likely to win with a high valuation and less likely to win with a low valuation. The cost of doing so is that if the sale must be concluded with the less well informed bidder, the transaction price may be lower; however, the value that can be extracted from the better informed bidder more than compensates for this loss.

The optimal three-stage procedure has realistic features, since in practice we observe both exclusive deals with one bidder and bidding contests that resemble auctions. An important feature is that excluded bidders may want to circumvent the outcome of the sequential procedure (in which they lost), by offering to pay more for the target than the price that the winning bidder is supposed to pay. Target boards may be tempted to accept such offers if shareholders can exert sufficient pressure. As we show, doing so would defeat the purpose of the sequential procedure, since if bidders anticipate that their bids are not "final", they will tend to bid less in the first place and instead wait for a bidding war to break out after the sequential procedure has officially ended. Such open competition is sub-optimal, however, which is why boards should refrain from accepting bids after a winner has been declared.

Lock-ups, termination fees, no-shopping clauses, or the selective lifting of poison pills are deal protection devices that can provide the needed commitment to the sequential procedure. While ex post it is in the interest of target shareholders to contest the legality of those devices, they are beneficial from an ex-ante perspective, since they support the sequential procedure and its ability to extract the highest possible transaction price. We thus conclude that while these deal protection devices seem inefficient from an ex-post perspective, it would be wrong to use that argument to declare them illegal.

The model provides numerous empirical implications. We show that a further weakening of the weak bidder reduces the likelihood of a bidding contest between the bidders, i.e. it increases the likelihood of an exclusive deal between the target and one bidder. Thus, we expect that if targets are more likely to face weak bidders, they are more likely to employ deal protection devices like lock-up options. However, this does not imply that these targets are worse off. In fact, by using the three-stage mechanism, the expected transaction price increases if the weak bidder is further weakened. This remarkable results is due to a lower cost of imposing a bias as the weak bidder weakens. Later in the paper, we discuss these and other predictions, and the related empirical literature supporting them.

We are not the first to study takeovers as bidding contests. Fishman (1988) rationalized high initial-bid premia by modeling takeovers as a potential contest between two bidders. Daniel and Hirshleifer (1992), Bhattacharyya (1992), Burkart (1995), Singh (1998), Bulow et al. (1999) and Ravid and Spiegel (1999) also model takeover contest in an applied auction setting. However, all these papers take the target firm as largely passive. In our paper, the target firm is affecting the behavior of the bidders by actively choosing the sale mechanism. We also abstract from search costs and toeholds, which are the focus of the earlier mentioned papers.

Preferential treatment of a particular bidder may also be a manifestation of agency problems, e.g. managerial entrenchment: the target firm's management might choose to favor a particular bidder, for example a white knight, because that bidder promises to retain the current management team and not to interfere in its running of the target. In our paper, we study the value maximizing behavior of target management. This allows us to develop implications that are dependent on the degree of bidder asymmetry, and on the level of private synergies bidders bring to the table, and not dependent on the existence of a cozy relationship (or lack thereof) between the target management and the successful bidder. We hope future empirical work will distinguish between the relative importance of these two explanations.

Two earlier studies analyze why a target board should treat different bidders asymmetrically, or why it may be optimal to exclude certain bidders from a takeover contest. In Shleifer and Vishny (1986), a target's board has private information about possible synergies with a particular bidder, while bidders have to incur costs to research what synergies they can realize. Shleifer and Vishny (1986) restrict the target firm to either pay or not pay greenmail and show that it may then be beneficial to pay off a weak bidder who submits an early bid, to encourage the remaining stronger bidders to incur search costs and compete aggressively. In Berkovitch and Khanna (1990), the target can only use defensive tactics that reduce bidders' valuations of the target, but in different amounts for different bidders. Threatening a larger value reduction to an initial bidder makes it more attractive for a second bidder to enter the contest. In a setup where the first bidder can preempt competition by submitting a sufficiently high first bid, this leads to an increase in that preempting bid.

We go beyond Shleifer and Vishny (1986) and Berkovitch and Khanna (1990), by not restricting the target firm's strategy space in any way and showing that a selling procedure with sequential bids is indeed optimal amongst all selling mechanisms. For example, our analysis would allow for a target firm to ignore a preemptive bid: if a target accepts a seemingly preemptive bid, this is because it chooses to accept it, and not because of restrictions imposed on the strategy space. Similarly, our analysis allows the target to specify the order in which it will accept bids.

We also focus on a different problem. Shleifer and Vishny (1986) and Berkovitch and Khanna (1990) are concerned with a bidder's decision to enter a takeover contest. The key assumption in their analysis is how expensive it is to submit a bid: bidders have to incur costs to discover their expected valuation of the target. In contrast, we analyze a problem in which the information acquisition costs are relatively small, compared to the potential gains from a takeover, and we explain why targets choose to accept bids sequentially, or even to conclude exclusive deals with one bidder even if other bidders are interested in acquiring the firm.

The paper is also related to the literature in optimal auction design. Myerson (1981) was perhaps the first to use mechanism design to analyze optimal auctions. In an example, Myerson (1981) also shows that bidder asymmetry can lead to a biased mechanism, but he does not analyze what impact this has on the expected transaction price, a bidder's chances of winning, etc. The focus in Maskin and Riley (2000) is on the relative performance of standard auctions, e.g. whether the expected transaction price is higher under an open auction or a first-price auction. In their model, bidders have pure private values, but the probability distributions for bidders' private values are different. Maskin and Riley (2000) show why different standard auctions cannot be optimal in the presence of bidder asymmetry, but they do not analyze the optimal selling procedure itself, and how it depends on the bidding environment (how asymmetric the bidders are, how the optimal selling procedure and the outcome change in a common value setup, etc.). Cantillon (2000) extends their analysis, by showing that an increase in bidder asymmetry hurts the seller if she uses standard auctions, since it decreases expected revenue. However, Fibich et al. (2003) argue that while standard auctions can be shown to perform differently with bidder asymmetry, numerical simulations suggest that the differences are of limited practical importance.[3]

The rest of the paper proceeds as follows. Section 2 introduces the auction model, which allows for both private value and common value components. In Section 3 we describe some key properties of the optimal selling procedure. We present the sequential three-stage procedure (which is optimal) in Section 4. In Section 5 we develop empirical implications and discuss findings in the empirical literature that relate to these predictions. Section 6 concludes. Some of the proofs are in the Appendix.

2 The Model

A target firm is for sale, and two bidders, $i, j \in \{1, 2\}$, are interested in buying it. These bidders are imperfectly informed about the target's value. We assume that the full information value of the target firm to the bidders comprises of two independent components, t_1 and t_2, and that each bidder has some information about one of these components.

Bidder i values the firm at $\alpha t_i + (1 - \alpha)t_j$, a weighted average of two independent com-

[3]In Cantillon (2000) and Fibich et al. (2003), like Maskin and Riley (2000), the analysis is carried out in a pure private values setting.

ponents t_i and t_j, with $\alpha \in \left[\frac{1}{2}, 1\right]$. If $\alpha = 1$, we have pure private values; if $\alpha = \frac{1}{2}$, this is a model with pure common values; if $\alpha \in \left(\frac{1}{2}, 1\right)$, both private and common value components are present.[4] The valuation components t_1 and t_2 are independently and identically distributed on the support $\left[\underline{t}, \overline{t}\right]$, with density f and c.d.f. F. Denote the hazard rate by $H(t_i) = f(t_i)/(1 - F(t_i))$. For tractability reasons, we assume that the hazard rate H is increasing in t_i for both bidders. Also for tractability, we assume that the target's shareholders value the target at zero, and that $\underline{t}$ is sufficiently high: $\underline{t}H(\underline{t}) \geq 1$.[5]

Bidders in our setting are imperfectly informed. Bidder i privately observes an imperfect signal s_i on component t_i:

$$s_i = \begin{cases} t_i & \text{with prob } \varphi_i \\ \tau_i & \text{with prob } 1 - \varphi_i, \end{cases}$$

where τ_1 and τ_2 are i.i.d. random variables that have the same distributions as t_1 and t_2. Thus, with probability φ_i the signal s_i is informative, and with probability $1 - \varphi_i$ it is pure noise. If the bidders could observe *both* signals they would use Bayes' law to update their priors, and the conditional expected value would be given by,

$$v_i(s_i, s_j) = E[t] + \varphi_i \alpha (s_i - E[t]) + \varphi_j (1 - \alpha)(s_j - E[t]) \tag{1}$$

(where $E[t]$ is the unconditional expected value of t_i and of the signals s_i). Notice that variations in φ_1 or φ_2 do not affect bidder i's unconditional expected value of the target.

We assume (without loss of generality) that bidder 1 is at least weakly better informed, i.e. $\varphi_1 \geq \varphi_2$. This asymmetry assumption captures a variety of situations in which different bidders have different expertise in evaluating a target. For example, bidders may specialize on different sides of a firm, e.g. its operations, its optimal capital structure, its growth poten-

[4] This valuation model is familiar from the auction literature, see e.g. Myerson (1981) or Bulow and Klemperer (2002). Bulow et al. (1999) use it to analyze takeover contests, assuming pure common values (the case $\alpha = \frac{1}{2}$ in our model). All other analyses of takeover contests are restricted to pure private value models (the case $\alpha = 1$ in our model); see e.g. Fishman (1988), Bhattacharyya (1992), Daniel and Hirshleifer (1992), Burkart (1995), Singh (1998), and Ravid and Spiegel (1999). The alternative model with "affiliated signals" is used in e.g. Back and Zender (1993).

[5] These assumptions simplify the exposition: they are sufficient to ensure that imposing a reserve price for both bidders is sub-optimal.

tial, its cash-generation potential, etc., and their ideas about how to value other dimensions may be very vague. Alternatively, some bidders may have superior information because of their special relationship with the target. Such bidders may be competitors, suppliers or customers, who know more than third parties about the target's strengths and weaknesses. Similarly, a management team offering a buy-out can be expected to have superior information. The effect of asymmetry between bidders on the target firm's ability to extract value is the focus of this paper.

By varying the parameter α, our model captures a second dimension in which bidding environments may differ. A target may attract trade buyers, e.g. competitors, suppliers, customers, etc., who may hope to realize individual synergies if they take over the target. If each bidder can realize synergies that are not available to others, a model with private values is appropriate. We can capture this situation by assuming that α is large. In other situations, bidders may be better described as financial buyers. For example, private equity funds may be attracted to a takeover contest if there are possibilities to add value that are not specific to certain bidders, for example firing current management, selling off non-core assets, cutting costs, changing financial leverage, etc. Nevertheless, some bidders may have superior information about the potential for cost-cutting, etc. These situations are better modeled as common value environments, i.e. α should be small.

In order to focus on how informational asymmetry affects bidding and the optimal selling scheme, we abstract from issues that have been analyzed elsewhere. We assume that bids are cash bids and financed internally, the target firm is an all-equity firm, and we assume that bidders do not own any shares in the target firm.[6] Furthermore, the seller (the target's shareholders) and the bidders maximize their expected profits. Finally, all players are risk-neutral, and all reservation payoffs are zero.

[6] See Rhodes-Kropf and Viswanathan (2000) and (2002) for a discussion of how non-cash bids or debt-financed bids affect bidding. Israel (1991) examines the bids for a target firm, in situations in which some of the increase in value of the target firm is captured by debt. For an analysis of toeholds see Burkart (1995), Singh (1998) and Bulow et al. (1999).

3 Properties of an Optimal Mechanism

We employ the methodology outlined in Bulow and Roberts (1989) and Bulow and Klemperer (1996) to derive the optimal mechanism. They use the revelation principle and show that the optimal mechanism must ensure incentive compatibility and allocate the object to the bidder with the highest "marginal revenue." The methodology has the advantage that it separates the allocation decision from the choice of transfer payments when analyzing the optimal mechanism: optimality follows if the allocation rule satisfies certain conditions; and incentive compatibility then determines the transfers that the bidders make.[7]

Using the methodology of Bulow and Klemperer (1996) requires that we define a bidder's "price", "quantity" and "revenue". For bidder i, the "price" is her valuation $v_i(s_1, s_2)$, and her quantity $q_i(s_i)$ is the probability that the valuation is not smaller than $v_i(s_1, s_2)$. Multiplying the two yields her "revenue",

$$v_i(s_1, s_2) \cdot q_i(s_i) \equiv v_i(s_1, s_2) \cdot (1 - F(s_i)).$$

"Marginal revenue" is then

$$\frac{\partial}{\partial q(s_i)} [v_i(s_1, s_2) \cdot q(s_i)] = \frac{\frac{\partial}{\partial s_i} [v_i(s_1, s_2)(1 - F(s_i))]}{\frac{\partial}{\partial s_i}(1 - F(s_i))} = v_i(s_1, s_2) - \frac{\varphi_i \alpha}{H(s_i)}. \tag{2}$$

For expositional ease, define

$$\Psi(s_i) \equiv \frac{2\alpha - 1}{\alpha}(s_i - E[t]) - \frac{1}{H(s_i)}. \tag{3}$$

Since Ψ is monotonically increasing in s_i, it has an inverse, which we denote by Ψ^{-1}. Combining (1), (2) and (3), we obtain that bidder 1's marginal revenue is higher than bidder 2's if and only if $\Psi(s_1) > \Psi(s_2)$. This defines a threshold signal $z_1(s_2)$ for bidder 1, such that

[7] An alternative method to derive the optimal mechanism is to follow the approach used in Myerson (1981). This leads to exactly the same results; details are available in an earlier version of this paper.

bidder 1's marginal revenue is higher if and only if $s_1 \geq z_1(s_2)$, where

$$z_1(s_2) \equiv \Psi^{-1}\left(\frac{\varphi_2}{\varphi_1}\Psi(s_2)\right). \tag{4}$$

It is easily verified that $z_1(s_2) \in (\underline{t}, \bar{t}]$ for all s_2, so z_1 is well-defined.

We denote an allocation rule by $p_i(s_1, s_2)$. It specifies the probability that bidder i wins the target, given signals s_1 and s_2.

Lemma 1 *The optimal allocation rule is*

$$p_1(s_1, s_2) = 1 - p_2(s_1, s_2) = \begin{cases} 1 & \text{if} \quad s_1 \geq z_1(s_2), \\ 0 & \text{otherwise.} \end{cases} \tag{5}$$

The expected payoff for the seller is

$$R = \sum_{i=1,2}\left\{\int_{\underline{t}}^{\bar{t}}\int_{\underline{t}}^{\bar{t}}\left[v_i(s_1, s_2) - \frac{\varphi_i \alpha}{H(s_i)}\right]p_i(s_1, s_2)f(s_1)ds_1 f(s_2)ds_2\right\}. \tag{6}$$

Proof. Our assumption $\underline{t}H(\underline{t}) \geq 1$ ensures that the bidders' marginal revenue is never negative. The rest of the proof follows directly from Bulow and Klemperer (1996) and is therefore omitted. ■

To study the properties of the optimal allocation rule it will be convenient to work with bidder 1's cut-off signal, $z_1(s_2)$, as defined in (4). It is optimal for the target firm to choose to be sold to bidder 1 if and only if her signal is at least weakly higher than $z_1(s_2)$. Analyzing the properties of z_1, thus, allows us to predict under what circumstances the target firm will choose to sell to a better informed bidder.

Lemma 2 *The function z_1 is monotonically increasing. In $s_2 = \underline{t}$ it attains a value $z_1(\underline{t}) > \underline{t}$. In $s_2 = \bar{t}$ it attains a value $z_1(\bar{t}) \leq \bar{t}$. If $\alpha > \frac{1}{2}$ then the last inequality is strict, and the function z_1 crosses the 45-degrees line exactly once. If $\alpha = \frac{1}{2}$ (pure common values) then $z_1(\bar{t}) = \bar{t}$, i.e. z_1 is never below the 45-degree line.*

Proof. See the Appendix. ■

Lemma 2 implies that bidder 1's probability of winning is non-decreasing in s_1 and non-increasing in s_2, which are plausible properties of an optimal mechanism. The optimal allocation rule can be summarized as follows: if bidder 1 announces a signal $s_1 \geq z_1(\bar{t})$, she wins with certainty; if $s_1 < z_1(\underline{t})$, bidder 2 wins with certainty; if $s_1 \in \left[z_1(\underline{t}), z_1(\bar{t})\right)$, bidder 1 wins if and only if $s_1 \geq z_1(s_2)$, and bidder 2 otherwise. Notice that with pure common values, i.e. if $\alpha = \frac{1}{2}$, the threshold $z_1(\bar{t})$ collapses in $\bar{t}$, i.e. the function $z_1(s_2)$ is above the 45-degrees line for every $s_2 < \bar{t}$, and there is no signal s_1 which guarantees that bidder 1 wins the target. (But there always exist signals s_1 which guarantee that bidder 1 does *not* win, since $z_1(\underline{t}) > \underline{t}$.)

4 A Three-Stage Selling Procedure That Is Optimal

We now describe sequential selling procedure, which is optimal (it uses the optimal allocation rule and maximizes the expected transaction price) and has realistic features. The target first offers an exclusive deal to the better informed bidder, without accepting any bids from the less well informed bidder; if a sale is not concluded immediately, the target may encourage all bidders to submit bids; or it may exclude the better informed bidder from the sale and allow a takeover by the less well informed bidder at a pre-specified price.

Stage I: After explaining the details of the sequential procedure to bidder 1, ask her whether she is willing to purchase the target at a price of $\bar{b}_1$. If so, conclude the sale at that price; if not, proceed to Stage II.

Stage II: Ask bidder 1 whether she is willing to compete with bidder 2 in the modified first-price auction described in Stage III, with a minimum bid of $\underline{b}_1$. If so, proceed to Stage III; if not, exclude bidder 1 and offer the target to bidder 2 at a price $\underline{b}_2$.

Stage III: Ask bidders 1 and 2 to submit sealed bids b_1 and b_2. Bidder 1 wins if and only if $b_1 > \widehat{z}_1(b_2)$; bidder 2 wins otherwise. The winner pays her bid, the loser pays nothing.

Just like a standard first-price auction, Stage III requires the winning bidder to pay her own bid, and the loser nothing. However, we call it a modified first-price auction, since the winning bidder did not necessarily submit the highest bid. (Also, bidder 1 is not allowed to bid below $\underline{b}_1$.)

Lemma 3 *The following describes a Bayesian Nash Equilibrium in the sequential procedure.* Bidder 1's strategy*: Accept offer to pay $\bar{b}_1$ in Stage I if $s_1 \geq z_1(\bar{t})$; agree to participate in Stage III only if $s_1 \geq z_1(\underline{t})$; and in Stage III bid*

$$b_1(s_1) = E_{s_2 \in [\underline{t}, z_2(s_1)]}\left[v_1(s_1, s_2)\right] - \varphi_1 \alpha \int_{z_1(\underline{t})}^{s_1} \frac{F(z_2(s))}{F(z_2(s_1))} ds. \tag{7}$$

Bidder 2's strategy*: Accept offer to pay $\underline{b}_2$ in Stage II; and in Stage III bid*

$$b_2(s_2) = E_{s_1 \in [z_1(\underline{t}), z_1(s_2)]}\left[v_2(s_1, s_2)\right] - \varphi_2 \alpha \int_{\underline{t}}^{s_2} \frac{F(z_1(s)) - F(z_1(\underline{t}))}{F(z_1(s_2)) - F(z_1(\underline{t}))} ds. \tag{8}$$

These are equilibrium strategies if the targets sets

$$\bar{b}_1 = v_1(z_1(\bar{t}), E[t]) - \varphi_1 \alpha \int_{z_1(\underline{t})}^{z_1(\bar{t})} F(z_2(s)) ds, \tag{9}$$

$$\underline{b}_1 = v_1(z_1(\underline{t}), \underline{t}), \tag{10}$$

$$\underline{b}_2 = E_{s_1 \in [\underline{t}, z_1(\underline{t})]}\left[v_2(s_1, \underline{t})\right], \tag{11}$$

$$\widehat{z}_1(b) = b_1(z_1(b_2^{-1}(b))), \tag{12}$$

where b_2^{-1} is the inverse of b_2.

Proof. See the Appendix. ■

The bidding functions b_1 and b_2 are reminiscent of the equilibrium bidding functions in a standard first-price auction. The first term is the expected value conditional on the bidder winning the auction (after having reached Stage III in the sequential procedure); the second term is the level of shading that maximizes the bidder's expected payoff. If we set $z_1(s_2) = s_2$, i.e. with an unbiased allocation rule, the bidding functions b_1 and b_2 are the standard first-price equilibrium bidding functions.

Proposition 1 *The three-stage sequential selling procedure raises the highest possible expected transaction price and is therefore optimal.*

Proof. As in Bulow and Klemperer (1996), a selling procedure is optimal if it uses the optimal allocation rule (described in Lemma 1) and a bidder with the lowest possible signal realization earns her reservation payoff (which we assumed is zero). Both requirements are satisfied by construction: The allocation rules are the same; and the probability of winning and the payment for a bidder with a signal realization of $\underline{t}$ is zero. ■

The key feature of the selling procedure is that it accentuates the incentive for the bidders to reveal a high willingness to pay. The optimal procedure is a stick-and-carrot mechanism — it promises exclusivity to bidder 1 if she reveals a high willingness to pay (the "carrot" side), while bidder 1 has no chance of winning if she is unwilling to bid above a lower threshold (this is the "stick" side of the mechanism). Because bidder 1's signal is more informative than bidder 2's, and the sequential procedure puts more emphasis on extracting high payments from bidder 1. Bidder 2's willingness to pay is only solicited if bidder 1's turned out to be in the intermediate range.

When designing the selling procedure, the seller must trade off two goals. One goal is to extract as much of the value that bidders realize if they win the target. Biasing the procedure helps, since a threat to sell to the rival bidder makes a bidder willing to pay more. This bias conflicts with a second goal, however: less value is created, since a biased allocation rule makes it more likely that the winning bidder is not the bidder with the highest valuation. It may then pay to reduce the degree of bias in the allocation rule: while this allows the bidders to keep a larger fraction of the value that is being created, the increase in the overall value created (with a less biased allocation rule) may offset the seller's loss from a lower-powered incentive scheme, since she may benefit from obtaining a somewhat smaller fraction of a larger overall value.

Thus, if s_1 is sufficiently high, value creation is more beneficial on the margin than value extraction. Notice that this holds only if there is a private value component, i.e. if $\alpha > \frac{1}{2}$.

With pure common values, i.e. if $\alpha = \frac{1}{2}$, this is not the case: it is then irrelevant which bidder wins, and the seller must worry only about extracting as much value as possible.

We assume that the target commits not to change the rules of the sequential procedure, once it has started. Without such a commitment, the procedure will not be incentive compatible. One particular threat is that after concluding a deal with one bidder, a rejected bidder may put a higher offer on the table. This is a threat, since if the seller might consider such a late offer, this undermines the effectiveness of the selling procedure in extracting a high expected price from the bidder. A bidder would hold back her best bid, if that bid may not be regarded as a final bid by the seller. The optimal sequential procedure may be undermined by possible late bids which are higher than the winner's bid. Late bids are particularly threatening if the sequential procedure ends in Stages I or II, where one bidder enjoys exclusivity and the other bidder is excluded from bidding: in these cases, target shareholders may side with the rejected bidder and try to force the board to accept the unsolicited higher offer, since to an econometrician or a court there seems to have been no real competition for the target.

Proposition 2 *If the sequential procedure ends in Stage I or Stage II, the losing bidder's estimate of the target's value may be higher than the price that the winning bidder is supposed to pay, so the losing bidder can (profitably) offer to pay more.*

Proof. See the Appendix. ∎

It is easy to see how this may happen: in either case, the target is sold to one bidder, and the price does not depend on the exact realization of the signals. For example, in Stage I, the price $\bar{b}_1$ is chosen such that even with the threshold signal $s_1 = z_1(\bar{t})$, bidder 1 is willing to buy the target (if $s_1 > z_1(\bar{t})$, then she values it even more). If the procedure ends in Stage I, then bidder 2 can infer that s_1 was high; if her own signal is high enough, her updated estimate of the target's value can be above $\bar{b}_1$, and it would pay for her to convince the target to ignore the outcome of the sequential procedure and accept a payment which is higher than $\bar{b}_1$. Similarly, suppose the procedure ends in Stage II, and bidder 2 is supposed to pay $\underline{b}_2$, a price low enough such that she is willing to pay it even with the lowest signal,

$\underline{t}$. If bidder 1's signal is close to the threshold $z_1(\underline{t})$, then her valuation may be high enough such that she is willing to offer more than $\underline{b}_2$ for the target after bidder 2 was declared the winner.

Thus, if the selling procedure is to extract the highest possible expected price, the target needs to offer the bidders some form of assurance that the losing bidder will not step in and try to bypass the sequential procedure. If not, the selling procedure is not incentive compatible, and it is not likely to extract the highest possible transaction price from the bidders. After all, if bids are accepted until no bidder is willing to submit a higher bid, the procedure takes on features of a standard English auction: it treats the bidders more symmetrically, i.e. it loses the benefits of the optimal bias described in Lemma 1.

We come back to this commitment problem in Section 5, where we discuss the implications of our results. There we describe deal protection devices that are used in practice to discourage the losing bidder from trying to top the price that the winner is to pay. Lock-up options, no-shopping clauses or termination fees can make the target less attractive to bidders other than the winner, and if the value reduction is large enough, they may be sufficient to keep prevent unsolicited late bids.

4.1 The Effect of Bidder Asymmetry

An important question is how bidder asymmetry affects the selling procedure and the expected price obtained by the target shareholders. We first study how informational asymmetries affect the optimal selling procedure and the takeover outcome by examining the effect of a change in φ_2 on the allocation rule. After that, we discuss how changes of bidder asymmetry affect the expected proceeds.

Proposition 3 *A decrease in φ_2, i.e. an increase in bidder asymmetry, has the following effects:*

1. If $\alpha > \frac{1}{2}$, it increases the likelihood of a Stage I sale (to bidder 1).

2. It increases the likelihood of a Stage II sale (to bidder 2).

3. It decreases the likelihood of a Stage III sale, i.e. a bidding contest.

Proof. See the Appendix. ■

A decrease in φ_2 tilts the playing field, since the weak bidder becomes weaker. This is bad for the target, since this reduces the competition between the bidders. However, it is not in the target's interest to undo this weakening, by changing the mechanism such that it treats the weak bidder more favorably. Instead, the seller's optimal response is to accentuate the stick-and-carrot policy: she can use a weakening of the weak bidder to her own advantage. The optimal response is to lower $z_1(\bar{t})$, the hurdle for bidder 1 to enjoy exclusivity, while at the same raising $z_1(\underline{t})$, the threshold for exclusivity being offered to bidder 2. The intuition for this is that as bidder 1's signal becomes relatively more informative, distortions of the allocation become more effective, but at the same time such distortions become more costly for high signals s_1. Consequently, the optimal selling procedure makes it easier for bidder 1 to win with a high signal, and it is optimal to make it harder for her to win with a low signal. Unavoidably, the likelihood of enjoying exclusivity increases for both bidders.

The allocation decision is only one of several variables of interest in takeovers. The target's shareholders will care more about the expected transaction price, while bidders will care about both the allocation rule and the price they will expect to pay. Our model quickly becomes intractable when we try to analyze the equilibrium values of these variables. However, assuming that f is uniform is sufficient to make this analysis possible. Specifically, we assume that f is uniform with support $[1, 2]$. This simplifies the integrals, and we can derive closed form solutions for all variables of interest.

Proposition 4 *If f is uniform with support $[1, 2]$, then a decrease in φ_2, i.e. an increase in bidder asymmetry, results in:*

(a) an increased expected transaction price;

(b) an increased price paid by the winner ($\bar{b}_1$, $\underline{b}_2$, $b_1(s_1)$ and $b_2(s_2)$ increase);

(c) a reduced likelihood of bidder 1 winning; and

(d) a reduction in the total value created in the sale.

Proof. See the Appendix. ■

The first result is remarkable: the competitive position of the weaker bidder is additionally weakened by the decrease in φ_2, and yet the optimal selling procedure's ability to play the bidders off against each other is improved, since it can extract a higher expected transaction price. A weakening of the weak bidder reduces the degree of competition between the bidders, which should harm the target's shareholders. However, the target can adapt the optimal selling procedure in response to a reduction in φ_2. Proposition 3 shows that if bidders are more asymmetrically informed, the target's optimal response is to design a more biased selling procedure. A weaker bidder is a more effective tool when it comes to extracting a higher payment from the strong bidder. Additionally, a decrease in φ_2 reduces the informational advantage the weak bidder has over the target firm, and therefore the rents that she can expect to earn. Combined, these two effects increase the target's expected transaction price (and the prices and bids in different stages of the sequential procedure). However, the expected transaction price is increased by biasing the allocation more, which means that the winner is less likely to be the bidder with the higher valuation (recall that marginal revenue determines the winner). This explains the last result in Proposition 4, that total value creation is reduced if φ_2 decreases.

4.2 Synergies Between Target and Bidders

Our model is general enough to capture both private value and common value environments, as well as setups with elements of both. A private value component makes it costly to bias the selling procedure against bidder 1, whose signal more strongly affects her expected valuation, while having a smaller effect on that of bidder 2. Consequently, more value is destroyed by letting bidder 2 win even if bidder 1's signal is high. If $\alpha = \frac{1}{2}$, no such value destruction occurs, since for given signals s_1 and s_2, both bidders value the target equally. This explains why in the $\alpha = \frac{1}{2}$ case there is no need for a "carrot", i.e. no threshold $z_1(\bar{t})$ such that if $s_1 \geq z_1(\bar{t})$, 1 wins with certainty. We now analyze how the optimal selling procedure depends on α.

Proposition 5 *An increase in α increases the likelihood of a Stage I sale and reduces the likelihood of a Stage II sale. Bidder 1's chances of winning improve.*

Proof. See the Appendix. ■

If α increases, the target optimally makes it easier for the strong bidder to win, for any signal s_2 that the weak bidder receives. A larger private value component α implies that bidders put more weight on their own signal. The target must trade off allocative efficiency and rent extraction: more value is *created* if the target is sold to the bidder with the higher valuation; more value can be *extracted* by biasing the selling procedure. If bidder 1's signal becomes more informative, then with a high signal s_1, more value is created if she buys the target. With low signals s_2, the weak bidder 2 trusts her signal more if α increases, and this reduces her willingness to pay for the target. This increases the cost of threatening the strong bidder that the target will be sold to the weak bidder, since doing so yields less. Consequently, the cut-off $z_1(s_2)$ decreases for all s_2 if α increases.

As a consequence, it becomes more likely that bidder 1 wins. It also becomes more likely that the sequential procedure ends in Stage I, since the strong bidder's signal is more likely to be above the threshold $z_1(\bar{t})$. It is also less likely that the sequential procedure ends in Stage II (where the target is sold to the weak bidder at a pre-specified price), since the strong bidder's signal is less likely to be below the threshold $z_1(\underline{t})$. In other words, it becomes more likely that the target will deal with bidder 1 exclusively, and less likely that bidder 1 is excluded from the bidding.

Proposition 6 *If f is uniform with support $[1, 2]$, then an increase in α leads to a higher expected transaction price and to increased value creation.*

Proof. See the Appendix. ■

As before (see Proposition 4), assuming that f is uniform allows us to analyze the equilibrium outcome in more detail. An increase in α benefits the shareholders, since the expected transaction price increases. However, this is not achieved by biasing the selling procedure more, since total value creation increases, too. Instead, an increase in α strengthens competition between the bidders: the relevance of their signals for their valuation increases, and that makes both bidders better informed. Reducing the bias in the selling procedure is optimal: competition between the bidders is fiercer, so it is easier to extract value; and reduced bias generates more value which can then be extracted by the target.

5 Empirical Implications

Our model has a number of empirical implications. Several of them are consistent with existing work, while others are novel and untested. We now collect these empirical implications and provide related evidence. However, before we discuss our empirical implications in detail we suggest some measures that can be employed to proxy for the existence of bias in the selling procedure, proxy for the degree of bidder asymmetry, and differentiate between trade versus financial buyers.

5.1 Proxies and Measures

In Proposition 2 we show that the target may want to resort to deal protection devices which make it unlikely that additional bids are tabled after a winner has been declared. If a bidder can never trust that a final bid is truly final, she will submit lower bids than she would under the optimal selling procedure. Typically, these deal protection devices prevent unwanted late bids by bidders who did not win, by reducing the expected value of the target to those bidders, without affecting the value to the bidder that was declared the winner of the takeover contest.

In some cases, mere animosity towards unsolicited bids may keep unwanted bidders from speaking up (for example, the unsolicited bid may be termed “hostile”, or the target may initiate antitrust proceedings). In other cases, boards will have to use deal protection devices to cement their commitment to one bidder. Termination fees create commitment by making it explicitly costly for the target to pull out of a deal. Lock-up clauses give a certain bidder the right to buy shares or assets at a low price. No-shopping clauses can make it harder for third parties to prepare a bid, since the target’s board may restrict access to relevant information (however, they cannot prevent the target from *considering* unsolicited bids). Finally, a target may have poison pills in place that it promises to lift after concluding a sale to the preferred bidder, but not otherwise.

These deal protection devices are widely used in practice.[8] This is useful for our purposes, since if their use is observable they may be a good proxy for the degree of bias in a selling procedure. We would expect that targets agree to no-shopping clauses, termination fees and lock-up options if bidder asymmetry is an important consideration.

Some of our results distinguish strong and weak bidders. In some cases, this may be easy to do. Management buy-outs are a case in point: a target's management team should be expected to have superior information, compared with any other party. The same holds for investors with large financial stakes in the target. Alternatively, a firm's direct competitors should have better information available than bidders who do not operate in the target's industry.

Measuring the severity of information problems is less straightforward, but an indirect measure may be useful. There is more scope for bidder asymmetry to be a serious concern if investors find it hard to value a target, for example because its R&D performance is kept secret, because its operations are complex or its financial and ownership structure is not transparent. Such firms are more opaque than others, but they may be less opaque to their managers, competitors, and other related parties, than to outside investors. On the other hand, if most of the information that is needed to value a target is readily available, there is little scope for bidder asymmetry to be a major concern. Thus, we suggest the use of measures of firm opaqueness as proxies for the severity of bidder asymmetries. Our argument is not that opaque firms are necessarily going to face asymmetric bidders. Instead, the idea is that in the case of opaque firms there is more scope for bidder asymmetry to have a measurable effect on the selling procedure or its outcome. Hence, one is more likely

[8] Coates and Subramanian (2000) find that 37.3% of the firms in their samples sign termination fees, and 12.7% grant lock-up options. Bates and Lemmon (2003) find that 37% of the firms in their sample agree to target termination fees, and 17% grant lock-up options. They find that the use of termination fees has increased from 2% in 1989 to 60% in 1998. Officer (2003) finds that more than 40% of the firms in his sample include target termination fees.

to econometrically see evidence of bidder asymmetry for opaque firms.

Finally, distinguishing trade buyers and financial buyers may be possible by looking at the justifications that bidders give for their bids, or for their interest in the target: competitors, suppliers or customers of the target may hope to realize cost savings through more complete product lines, streamlined supply chains and better communication; and companies operating in similar but not directly related business lines may hope to add value through cross-selling, for example insurance firms and banks. Key to all these is that the synergies are more important to one bidder than to another. Financial buyers, on the other hand, are interested in more general types of value creation, which are not specific. Private equity funds specialized on buyouts are an example for such bidders.

5.2 Implications for the Use of Deal Protection Devices

Empirical studies have shown that the use of deal protection devices that favor one bidder does not necessarily harm target shareholders, which is consistent with our results.[9] An important question is how likely or severe biases should be when target firms decide which bid to accept. Proposition 3 implies that the wider the asymmetry in bidders' information, the more biased the selling procedure should be.

Prediction 1 *The incidence of termination fees, lock-up options and no-shopping clauses is higher for targets that are R&D intensive, operate in new or complex industries, have few tangible assets, are larger, have larger growth opportunities, or are diversified conglomerates.*

This prediction is confirmed by existing empirical studies. Coff (2003) finds that the incidence of lock-up options is higher for R&D intensive firms. Similarly, Bates and Lemmon (2003) find that termination fees are more common in technology and pharmaceutical industries. These are also industries that are newer and more complex, have less tangible assets and have larger growth opportunities (see also Officer (2003)). Bates and Lemmon

[9]See e.g. Jennings and Mazeo (1993), Comment and Schwert (1995), Bates and Lemmon (2003), Officer (2003), or Peck (2002). Kaplan (1989) finds significant premia even in MBOs and argues that management cannot use informational advantages to purchase the target at a lower price (see also Lee (1992)).

(2003) also use size as a proxy for complexity and find that with increasing size, termination fees become more likely. Using a target's market-to-book ratio as a proxy for the presence of growth opportunities, they also confirm that larger growth opportunities make termination fees more likely.

5.3 Implications for Target Shareholder Gains

A key question in the empirical literature on takeovers is how much target shareholders benefit. Researchers measure either announcement effects, arguing that in efficient capital markets, investors should immediately anticipate what benefits shareholders will eventually realize; or researchers measure bid premia, i.e. how much higher an initial or final bid was, compared with the last closing price before bidding started. Our model predicts that target shareholders should benefit from bidder asymmetry (cf. Proposition 4), and if the private value component in bidders' valuations is higher (cf. Proposition 6):

Prediction 2 *Average bid premia and target announcement effects are higher if targets are R&D intensive, operate in new or complex industries, have few tangible assets, are larger, have larger growth opportunities, or are diversified conglomerates. They are also higher if the competing bidders are trade buyers than if they are financial buyers.*

The expected transaction price is higher if the weak bidder is less well informed and if the private value component is larger (i.e. bidders are trade buyers). If investors understand and anticipate this, it should be reflected in the announcement effect. This is interesting for conglomerates in particular: a high premium may be a consequence of bidder asymmetry, and not necessarily evidence of agency problems within conglomerates that are resolved through a takeover (even though managerial entrenchment may be highly correlated with opaqueness, the suggested proxy for bidder asymmetry).

Bidder asymmetry is particularly likely to be a concern if one of the bidders is the current (or recent) management team. Outside bidders may then be particularly wary of the information that is available about the firm, i.e. their information may seem much less reliable when compared with the information that management has available. We find that this should not harm target shareholders:

Prediction 3 *Takeover premia are higher in successful MBOs or takeovers by competitors if targets are R&D intensive, operate in new or complex industries, have few tangible assets, are larger, have larger growth opportunities, or are diversified conglomerates.*

This prediction allows us to make a sharp distinction between the implications of our model and implications that may follow from a model based on agency problems between managers and shareholders. If agency problems were indeed the reason for the use of deal protection devices, we should find them most damaging in the case of MBOs, where the agency view would predict that managers are trying to expropriate shareholders in collusion with the board. Thus, MBOs with deal protection should be associated with lower premia. On the other hand, if deal protection devices are used by target boards that try to maximize shareholder value, then we should observe the opposite, cf. Prediction 3. This is ultimately an empirical question, which deserves further investigation.

5.4 Implications for Bidder Success

Propositions 4 and 5 show that the strong bidder's chances of winning are higher if the bidder asymmetry is smaller or if the private value component is larger.

Prediction 4 *MBO offers or takeover bids by competitors have lower success rates if targets are R&D intensive, operate in new or complex industries, have few tangible assets, are larger, have larger growth opportunities, or are diversified conglomerates. They have higher success rates if other bidders are trade buyers and lower success rates if other bidders are financial buyers.*

These are novel predictions, that have not been addressed in the literature before. It is worth examining the chances of success of better informed bidders, since their informational advantage may give them a head start in a takeover contest. And this should be more pronounced the more asymmetric the bidders are. However, our model predicts the opposite: in the presence of bidder asymmetry, a value-maximizing board should optimally design a procedure that makes it harder for better informed bidders to win, since this allows the target to extract a higher expected transaction price from the bidders. So in takeover contests in which bidder asymmetry is a major concern, bidders that probably have access to superior information should be *less* likely to win, not *more* likely.

5.5 Implications for Post-takeover Performance

Another topic of interest in the empirical literature is how efficient or profitable firms are after a takeover is concluded. Our model allows for predictions on this. The optimal procedure is biased and may lead to a distorted allocation: the target is sold to the bidder with the highest *marginal revenue*, not necessarily the bidder with the highest *valuation*. A bidder's valuation may be lower because less synergies can be realized, or because a bidder is less experienced at running the target. We should thus expect that if the winning bidder did not have the highest valuation, the target's post-takeover productivity and profitability are below their true potential. Furthermore, the more biased the allocation rule, the wider the gap between realized and potential productivity and profitability.

Prediction 5 *Target post-takeover productivity and profitability is lower after takeover contests in which management or competitors participated, if targets are R&D intensive, operate in new or complex industries, have few tangible assets, are larger, have larger growth opportunities, or are diversified conglomerates. It is higher if management or competitors won against trade buyers and not financial buyers.*

Propositions 4 and 6 show that the target benefits if φ_2 or α increase: when trading off value extraction (through a more biased allocation rule) and value creation (through a less biased allocation rule), value creation becomes more relevant to the target. Consequently, the allocation rule should be less biased, i.e. it is more likely that the bidder with the higher valuation actually wins the target. In other words, the bidder who can produce cash flows with a higher present value is more likely to win the takeover contest.

The empirical evidence on long-term performance after takeovers seems inconclusive, cf. Andrade et al. (2001); our results suggest possible new tests which may clarify under what circumstances we can expect more or less value creation, or even destruction, when comparing post-takeover performance to industry averages.

6 Conclusion

We have analyzed how a takeover contest should optimally be designed in the presence of asymmetrically informed bidders. We have analyzed the properties of optimal selling procedures in general, and the details of a three-stage sequential procedure that is optimal. This sequential procedure encourages bidders to compete, but it may also offer exclusive deals to one bidder and reject bids from another bidder.

The key assumption in our model is that one bidder is better informed than another bidder. At first sight, this seems to be a disadvantage for the target, since a weak bidder is a weak competitor to the better informed bidder. However, the asymmetry allows the target to better play off the bidders against each other. Specifically, the possibility of an exclusive deal encourages the better informed bidder to reveal a high willingness to pay (and then pay a high price), and the threat of an exclusive deal with the other bidder discourages the revelation of a low willingness to pay. The more asymmetric bidders are, the more likely an exclusive deal with one of the bidders becomes. We find that bidder asymmetry is actually beneficial for the target: if the less well informed bidder becomes even less well informed, the expected transaction price increases. We also find that the target benefits if bidders' valuations include a significant private value component; for practical purposes, this means that targets should prefer takeover contests between trade buyers and not financial buyers.

Our results shed light on an issue that regularly appears before courts of justice: whether target boards may treat bidders asymmetrically, or even seal exclusive deals with one bidder even if other potential buyers show interest in the target. The court decisions have in the past been mixed, which indicates the need for a more thorough analysis of these issues. Existing theoretical work offers little support for decision-making. Earlier contributions have shown that an asymmetric treatment of different bidders may be optimal; but this typically follows from constraints that are exogenously imposed on what selling procedures a target can choose, for example that bids must be accepted in a certain order, or that only certain types of deal protection device are available. We impose no such restrictions, and as we show, it is generally optimal to treat asymmetric bidders in an asymmetric fashion. In particular, it may be optimal to offer exclusive deals to certain bidders, and courts should protect the sanctity of a deal, even if the target wants to close a deal with a specific bidder and a second bidder submits a higher but unsolicited bid.

Appendix: Proofs

A.1 Proof of Lemma 2

Since Ψ is continuous and strictly increasing, z_1 is continuous and strictly increasing, too. If $\alpha > \frac{1}{2}$, the function Ψ as defined in (3) attains a negative value for $s_2 = \underline{t}$ and a positive value for $s_2 = \bar{t}$. So there must be a signal $\sigma \in (\underline{t}, \bar{t})$ such that $\Psi(\sigma) = 0$. This implies that $z_1(\sigma) = \sigma$, i.e. z_1 has a fixed point in $(s_1, s_2) = (\sigma, \sigma)$. This fixed point is defined implicitly by

$$\Psi(\sigma) = 0 \iff \sigma = E[t] + \frac{\alpha}{2\alpha - 1} \frac{1}{H(\sigma)}.$$

This implies that $\sigma > E[t]$. Since $\frac{\varphi_2}{\varphi_1}\Psi(\underline{t}) < 0$, $\varphi_2 \le \varphi_1$, and Ψ is increasing, it follows that $z_1(\underline{t}) \in (\underline{t}, \sigma)$. Similarly, since $\frac{\varphi_2}{\varphi_1}\Psi(\bar{t}) > 0$, it follows that $z_1(\bar{t}) \in (\sigma, \bar{t})$. If $\alpha = \frac{1}{2}$, the only change in our arguments is that the first term in the definition of Ψ vanishes (cf. (3)), and we have $\Psi(\sigma) = 0 \iff \sigma = \bar{t}$, i.e. $\sigma = z_1(\bar{t}) = \bar{t}$. ■

A.2 Proof of Lemma 3

Define

$$\widehat{b}_1(s_1) \equiv \begin{cases} \bar{b}_1 & \text{in Stage I} \\ b_1(s_1) & \text{in Stage III} \end{cases}$$

$$\widehat{b}_2(s_2) \equiv \begin{cases} \underline{b}_2 & \text{in Stage II} \\ b_2(s_2) & \text{in Stage III} \end{cases}$$

and abusing notation slightly,

$$V_i(s_i) \equiv \int_{\underline{t}}^{\bar{t}} (v_i(s_i, s_j) - \widehat{b}_i(s_i)) p_i(s_i, s_j) f(s_j) ds_j,$$

$$U_i(s_i, \widehat{s}_i) \equiv \int_{\underline{t}}^{\bar{t}} (v_i(s_i, s_j) - \widehat{b}_i(\widehat{s}_i)) p_i(\widehat{s}_i, s_j) f(s_j) ds_j,$$

$$Q_i(s_i) \equiv \int_{\underline{t}}^{\bar{t}} p_i(s_i, s_j) f(s_j) ds_j.$$

Combine to obtain

$$\begin{aligned} U_i(s_i, \widehat{s}_i) =& \int_{\underline{t}}^{\bar{t}} (v_i(\widehat{s}_i, s_j) - \widehat{b}_i(\widehat{s}_i)) p_i(\widehat{s}_i, s_j) f(s_j) ds_j \\ &+ \int_{\underline{t}}^{\bar{t}} (v_i(s_i, s_j) - v_i(\widehat{s}_i, s_j)) p_i(\widehat{s}_i, s_j) f(s_j) ds_j \\ =& V_i(\widehat{s}_i) + \varphi_i \alpha (s_i - \widehat{s}_i) Q_i(\widehat{s}_i). \end{aligned} \quad \text{(A1)}$$

We first show that if $\frac{\partial V_i(s_i)}{\partial s_i} = \varphi_i \alpha Q_i(s_i)$ and $Q_i'(s_i) \geq 0$ then a bidder with signal s_i will not deviate to a bid that would be the equilibrium bid with signal $\widehat{s}_i$, i.e., $V_i(s_i) \geq U_i(s_i, \widehat{s}_i)\ \forall s_i, \widehat{s}_i$. From $\frac{\partial V_i(s_i)}{\partial s_i} = \varphi_i \alpha Q_i(s_i)$ we get

$$V_i(s_i) = V_i(\widehat{s}_i) + \int_{\widehat{s}_i}^{s_i} \frac{\partial V_i(s)}{\partial s} ds = V_i(\widehat{s}_i) + \int_{\widehat{s}_i}^{s_i} \varphi_i \alpha Q_i(s) ds. \quad \text{(A2)}$$

Substituting for $V_i(\widehat{s}_i)$ from (A1) in (A2),

$$V_i(s_i) = U_i(s_i, \widehat{s}_i) - \varphi_i \alpha (s_i - \widehat{s}_i) Q_i(\widehat{s}_i) + \int_{\widehat{s}_i}^{s_i} \varphi_i \alpha Q_i(s) ds. \quad \text{(A3)}$$

If $s_i > \widehat{s}_i$ then since Q is weakly increasing, we can substitute for the lower bound on $Q_i(s_i)$ to obtain the following inequality:

$$\begin{aligned} V_i(s_i) &\geq U_i(s_i, \widehat{s}_i) - \varphi_i \alpha (s_i - \widehat{s}_i) Q_i(\widehat{s}_i) + \int_{\widehat{s}_i}^{s_i} \varphi_i \alpha Q_i(\widehat{s}_i) ds \\ &= U_i(s, \widehat{s}_i) - \varphi_i \alpha (s_i - \widehat{s}_i) Q_i(\widehat{s}_i) + \varphi_i \alpha Q_i(\widehat{s}_i)(s_i - \widehat{s}_i) \\ &= U_i(s_i, \widehat{s}_i). \end{aligned}$$

The argument for $s_i \leq \widehat{s}_i$ is similar.

Now we show that the strategies (7)-(11) imply $\frac{\partial V_i(s_i)}{\partial s_i} = \varphi_i \alpha Q_i(s_i)$ and $Q_i'(s_i) \geq 0$. Define the inverse to z_1,

$$z_2(s_1) = \begin{cases} \bar{t} & \text{if} \quad s_1 > z_1(\bar{t}) \\ \Psi^{-1}(\frac{\varphi_1}{\varphi_2}\Psi(s_1)) & \text{if} \quad z_1(\underline{t}) < s_1 \leq z_1(\bar{t}) \\ \underline{t} & \text{if} \quad s_1 \leq z_1(\underline{t}) \end{cases}$$

The functions b_1 and b_2 are increasing, so by construction of $\widehat{z}_1$ we have

$$p_1(s_1, s_2) = 1 - p_2(s_1, s_2) = \begin{cases} 1 & \text{if} \quad s_1 > z_1(\bar{t}) \\ 1 & \text{if} \quad z_1(\underline{t}) < s_1 \leq z_1(\bar{t}), \ s_2 < z_2(s_1) \\ 0 & \text{if} \quad z_1(\underline{t}) < s_1 \leq z_1(\bar{t}), \ s_2 \geq z_2(s_1) \\ 0 & \text{if} \quad s_1 \leq z_1(\underline{t}) \end{cases}$$

and

$$Q_1(s_1) = \begin{cases} 1 & \text{if} \quad s_1 > z_1(\bar{t}) \\ F(z_2(s_1)) & \text{if} \quad z_1(\underline{t}) < s_1 \leq z_1(\bar{t}) \\ 0 & \text{if} \quad s_1 \leq z_1(\underline{t}) \end{cases}$$

$$Q_2(s_2) = F(z_1(s_2)).$$

Notice that $Q_i'(s_i) \geq 0$. If $s_1 > z_1(\bar{t})$, then $V_1(s_1) = \int_{\underline{t}}^{\bar{t}} v_1(s_1, s_2) f(s_2) ds_2 - \bar{b}_1$ and

$$V_1'(s_1) = \int_{\underline{t}}^{\bar{t}} \frac{\partial}{\partial s_1} v_1(s_1, s_2) f(s_2) ds_2 = \alpha\varphi_1 = \alpha\varphi_1 Q_1(s_1).$$

If $z_1(\bar{t}) < s_1 \leq z_1(\bar{t})$, then $V_1(s_1) = \int_{\underline{t}}^{z_2(s_1)} \left[v_1(s_1, s_2) - b_1(s_1) \right] f(s_2) ds_2$ and

$$\begin{aligned} V_1'(s_1) = & \int_{\underline{t}}^{z_2(s_1)} \left[\frac{\partial}{\partial s_1} v_1(s_1, s_2) - \frac{\partial}{\partial s_1} b_1(s_1) \right] f(s_2) ds_2 \\ & + z_2'(s_1) \left[v_1(s_1, z_2(s_1)) - b_1(s_1) \right] f(z_2(s_1)) \\ = & \left[\alpha\varphi_1 - \frac{\partial}{\partial s_1} b_1(s_1) \right] F(z_2(s_1)) + z_2'(s_1) \left[v_1(s_1, z_2(s_1)) - b_1(s_1) \right] f(z_2(s_1)). \end{aligned}$$

Since

$$\frac{\partial}{\partial s_1} b_1(s_1) = [v_1(s_1, z_2(s_1)) - b_1(s_1)] \frac{f(z_2(s_1)) z_2'(s_1)}{F(z_2(s_1))}$$

we have $V_1'(s_1) = \alpha\varphi_1 F(z_2(s_1)) = \alpha\varphi_1 Q_1(s_1)$. If $s_1 \leq z_1(\underline{t})$, then bidder 1 cannot win, and therefore $V_1'(s_1) = 0 = \alpha\varphi_1 Q_1(s_1)$. Similarly, for bidder 2,

$$\begin{aligned} V_2'(s_2) =& \alpha\varphi_2 F(z_1(\underline{t})) + \int_{z_1(\underline{t})}^{z_1(s_2)} \left[\alpha\varphi_2 - \frac{\partial}{\partial s_2} b_2(s_2)\right] f(s_1) ds_1 \\ &+ z_1'(s_2) \left[v_2(z_1(s_2), s_2) - b_2(s_2)\right] f(z_1(s_2)), \end{aligned}$$

and since

$$\frac{\partial}{\partial s_2} b_2(s_2) = [v_2(z_1(s_2), s_2) - b_2(s_2)] \frac{f(z_1(s_2)) z_1'(s_2)}{[F(z_1(s_2)) - F(z_1(\underline{t}))]}$$

we have $V_2'(s_2) = \alpha\varphi_2 F(z_1(s_2)) = \alpha\varphi_2 Q_2(s_2)$. We have, thus, shown $Q_i'(s_i) > 0$ and $V_i'(s_i) = \alpha\varphi_i Q_i(s_i)\ \forall s_i$. Therefore, bidder i has no incentive to deviate from $\widehat{b}_i(s_i)$ to $\widehat{b}_i(\widehat{s}_i) \in \left[\widehat{b}_i(\underline{t}), \widehat{b}_i(\overline{t})\right]$. For either bidder, there is clearly no benefit to deviating to bids $\widehat{b}_i' < \widehat{b}_i(\underline{t})$ or $\widehat{b}_i'' > \widehat{b}_i(\overline{t})$, since $\widehat{b}_i'$ is equivalent to $b_i(\underline{t})$ (the bidder loses for sure) and $\widehat{b}_i''$ cannot increase the chances of winning above 1, while possibly leading to higher payments. Thus, the bidders will not deviate from the strategies (7)-(11). ■

A.3 Proof of Proposition 2

$$\begin{aligned} \overline{b}_1 &= v_1(z_1(\overline{t}), E[t]) - \varphi_1\alpha \int_{z_1(\underline{t})}^{z_1(\overline{t})} F(z_2(s)) ds \\ &< E[t] + \varphi_1\alpha(z_1(\overline{t}) - E[t]). \end{aligned}$$

If α is sufficiently small, this is smaller than

$$\begin{aligned} &E[t] + \varphi_1(1-\alpha)(E\left[s_1 | s_1 > z_1(\overline{t})\right] - E[t]) + \varphi_2\alpha(\overline{t} - E[t]) \\ &= E_{s_1 \in [z_1(\overline{t}), \overline{t}]}\left[v_2(s_1, \overline{t})\right]. \end{aligned}$$

Similarly,

$$\begin{aligned} v_1(z_1(\underline{t}), E[t]) &= E[t] + \varphi_1 \alpha (z_1(\underline{t}) - E[t]) \\ &\geq E[t] + \varphi_1 (1-\alpha)(z_1(\underline{t}) - E[t]) \\ &> E[t] + \varphi_1 (1-\alpha)(E[s_1 | s_1 < z_1(\underline{t})] - E[t]) + \varphi_2 \alpha (\underline{t} - E[t]), \end{aligned}$$

which equals $\underline{b}_2$ (both inequalities follow from the proof of Lemma 2). ■

A.4 Proof of Proposition 3

From Lemma 2, the function z_1 has a fixed point in σ, which does not depend on φ_1 or φ_2 since they are not arguments of Ψ, cf. (3). Elements of z_1 are characterized by $\varphi_1 \Psi(s_1) = \varphi_2 \Psi(s_2)$. Suppose φ_2 decreases by a small $\varepsilon > 0$. This affects the right-hand side of $\varphi_1 \Psi(s_1) = \varphi_2 \Psi(s_2)$, which becomes less positive (if $s_2 > \sigma$) or less negative (if $s_2 < \sigma$). In order to remain on the z_1 curve, for a given s_2 we must select a signal s_1 such that $\varphi_1 \Psi(s_1) = (\varphi_2 - \varepsilon) \Psi(s_2)$. If $s_2 = \sigma$, no change to s_1 is needed. If $s_2 < \sigma$, then $\Psi(s_2) < 0$ and $\Psi(z_1(s_2)) < 0$, too, requiring an increase in s_1. If $s_2 > \sigma$, then $\Psi(s_2) > 0$ and $\Psi(z_1(s_2)) > 0$, too, requiring a decrease in s_1. ■

A.5 Proof of Proposition 4

We have

$$\begin{aligned} z_1(s_2) &= \frac{\varphi_2}{\varphi_1} s_2 + \frac{\varphi_1 - \varphi_2}{\varphi_1} \frac{10\alpha - 3}{2(3\alpha - 1)}, \\ z_2(s_1) &= \frac{\varphi_1}{\varphi_2} s_1 - \frac{\varphi_1 - \varphi_2}{\varphi_2} \frac{10\alpha - 3}{2(3\alpha - 1)}, \\ \bar{b}_1 &= \frac{3}{2} + \frac{\varphi_1 - \varphi_2}{2(3\alpha - 1)} \alpha^2, \\ \underline{b}_2 &= \frac{3}{2} + \frac{\varphi_1 - \varphi_2}{2(3\alpha - 1)} \alpha^2 - \frac{\varphi_1 + \varphi_2}{4}, \end{aligned}$$

$$b_1(s_1) = \frac{3}{2} + \frac{\varphi_1 - \varphi_2}{2(3\alpha - 1)}\alpha^2 - \frac{\varphi_1 + \varphi_2}{4} - \frac{\varphi_1 - \varphi_2}{4(3\alpha - 1)}\alpha + \frac{1}{2}\varphi_1(s_1 - 1),$$
$$b_2(s_2) = \frac{3}{2} - \frac{\varphi_1 - \varphi_2}{2(3\alpha - 1)}\alpha^2 + \frac{\varphi_1 - \varphi_2}{2(3\alpha - 1)}\alpha - \varphi_2 + \frac{1}{2}\varphi_2 s_2.$$

The expected transaction price is then

$$\int_1^2 \left(\int_1^{z_1(1)} \underline{b}_2 ds_1 + \int_{z_1(1)}^{z_1(s_2)} b_2(s_2) ds_1 + \int_{z_1(s_2)}^{z_1(2)} b_1(s_1) ds_1 + \int_{z_1(2)}^{2} \overline{b}_1 ds_1 \right) ds_2.$$

Part (a) follows by substituting z_1 and taking derivatives (and recalling that $\varphi_2 < \varphi_1$ and $\alpha \geq \frac{1}{2}$). Similarly, part (b) follows by taking derivatives of $\overline{b}_1$, $\underline{b}_2$, $b_1(s_1)$ and $b_2(s_2)$. Bidder 1's probability of winning is

$$\int_{\underline{t}}^{\overline{t}} (1 - F(z_1(s_2))) f(s_2) ds_2 = \frac{(2\alpha - 1)\varphi_1 + \varphi_2 \alpha}{2\varphi_1(3\alpha - 1)}.$$

This is increasing in φ_2, which proves part (c). Finally, the total value created is

$$\int_1^2 \left(\int_1^{z_1(1)} v_2(s_1, s_2) ds_1 + \int_{z_1(1)}^{z_1(s_2)} v_2(s_1, s_2) ds_1 + \int_{z_1(s_2)}^{z_1(2)} v_1(s_1, s_2) ds_1 + \int_{z_1(2)}^{2} v_1(s_1, s_2) ds_1 \right) ds_2. \tag{A4}$$

Substituting z_1 and taking derivatives proves part (d).

A.6 Proof of Proposition 5

First we show that if there exists a pair (s_1, s_2) that is on the z_1 curve for any α, it must be that $s_2 = E[t]$. In order to be on the z_1 curve for both α and $\alpha + \varepsilon$, for a small $\varepsilon > 0$, we must have

$$\Psi_\alpha^{-1}\left(\frac{\varphi_2}{\varphi_1}\Psi_\alpha(s_2)\right) = \Psi_{\alpha+\varepsilon}^{-1}\left(\frac{\varphi_2}{\varphi_1}\Psi_{\alpha+\varepsilon}(s_2)\right),$$

where the subscripts α and $\alpha + \varepsilon$ indicate that the functions Ψ and Ψ^{-1} have α and $\alpha + \varepsilon$ as parameters. This equation is satisfied iff

$$\begin{aligned} \Psi_\alpha(s_2) &= \Psi_{\alpha+\varepsilon}(s_2) \\ \Leftrightarrow \frac{2\alpha - 1}{\alpha}(s_2 - E[t]) &= \left(\frac{2\alpha - 1}{\alpha} + \frac{\varepsilon}{(\alpha + \varepsilon)\alpha}\right)(s_2 - E[t]), \end{aligned}$$

which is only possible if $s_2 = E[t]$. Second, we show that in $s_2 = E[t]$, $z_1(s_2)$ must decrease if α increases. If $s_2 = E[t]$, $\Psi(s_2)$ does not depend on α; for a given s_2, an increase in α requires a change in s_1 in order to remain on the z_1 curve. Since $\sigma > E[t]$, it must be that $s_2 < \sigma$, and $\varphi_1 \Psi(z_1(s_2))$ must be negative. So in order for $\Psi(s_1)$ to be unchanged if α increases, s_1 must decrease. Third, since $z_1(s_2)$ must change for any s_2 if α increases, and since it must decrease if $s_2 = E[t]$, it must decrease for all s_2. ■

A.7 Proof of Proposition 6

Follows immediately from (A4), by taking derivatives. ■

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