Optimal bid disclosure in patent license auctions under alternative modes of competition*

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Abstract

The literature on patent license auctions in oligopoly assumed that the auctioneer reveals the winning bid and stressed that this gives firms an incentive to bid high in order to signal an aggressive output strategy in a downstream Cournot market game, and conversely bid low to signal acquiescent pricing in a Bertrand market game. The present paper examines the information revealed by publishing the winning or the losing or no bid, assuming an oligopoly with differentiated goods. We rank disclosure rules and find that it is not optimal for the innovator to disclose the winning bid, regardless of the mode of competition.

KEYWORDS: Auctions, innovation, licensing.

JEL CLASSIFICATIONS: D21, D43, D44, D45

1 Introduction

An outside innovator auctions the right to use a cost reducing, non-drastic innovation to a firm in an oligopoly with differentiated goods under either Bertrand or Cournot competition. Should he choose an auction rule that discloses some or all bids prior to the oligopoly game? The present paper explores this issue and determines which of the standard auctions is optimal.

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The literature on patent license auctions in oligopoly assumed that the auctioneer reveals the winning bid and stressed that this gives firms an incentive to bid high in order to signal aggressive behavior in a subsequent Cournot market game, and conversely bid low and signal acquiescent pricing in a Bertrand market game. However, the literature never examined whether revealing the winning bid (or any other bid) is actually beneficial for the innovator.

The analysis of license auctions in oligopoly was initiated by Katz and Shapiro (1986), Kamien and Tauman (1986) and others who showed that auctioning a limited number of licenses is more profitable than other selling mechanisms such as royalty licensing (see the survey by Kamien, 1992).[1] One limitation of their analysis is the assumption that firms' cost reductions induced by the innovation are completely known to all firms prior to bidding.

Later, Jehiel and Moldovanu (2000) introduced incomplete information at the auction stage, but maintained the assumption that cost reductions become known after the auction and before the oligopoly game is played. This gap was closed by Das Varma (2003), Goeree (2003), and Katzman and Rhodes-Kropf (2008) who assumed that firms can infer the winner's cost reduction only indirectly by observing the winning bid, which gives rise to a signaling issue.[2] They showed that, in Cournot oligopoly, firms have an incentive to signal strength by bidding high, and conversely, signal weakness by bidding low in Bertrand oligopoly.

The present paper examines the information revealed by publishing the winning or the losing or no bid, assuming a differentiated goods duopoly with substitutes. We consider three bid disclosure rules: full disclosure, which happens to be equivalent to disclosing the winning bid, partial disclosure, which is equivalent to disclosing the second-highest bid, and no disclosure. These disclosure rules are intimately linked to standard auction formats, ranging from Dutch to English and to standard sealed-bid auctions (either first- or second-price). We rank disclosure rules and find that, regardless of the mode of competition, it is never optimal to unconditionally disclose the winning bid. In fact, under Bertrand competition, it is always optimal to disclose no bid. The same applies to Cournot competition for a substantial range of parameter values, although there are parameter values for which it is optimal to conditionally disclose the winning bid if the winning bid is above a certain threshold level.

If the winning bid is revealed, firms benefit from signaling either strength or weakness through their bids, depending upon the downstream market game. In a Cournot market game, if a bidder inflates his bid and wins the auction, his bid signals a higher cost reduction to his rival. This indicates that the winner of the auction will play a more aggressive output strategy, which in turn induces the loser of the auction to reduce his output. Whereas in a Bertrand market game, bidders benefit from deflating their bids, because signaling a low cost reduction induces the rival to raise his price. Of course, inflating one's bid makes winning more costly (yet increases the chance of winning), whereas deflating one's bid is costly because it reduces the chance of winning (yet, makes winning less expensive). In equilibrium, the marginal benefits of unilaterally changing one's bid are in perfect balance with its marginal cost.

If the losing bid is disclosed, in the event of losing the auction, one's bid reveals the cost reduction one would have had if one had won the auction. This is, of course, not interesting, in and by itself. However, the winner can make use of that information because it informs him about the loser's

[1]However, Giebe and Wolfstetter (2008) and Fan, Jun, and Wolfstetter (2013, 2014a) found, in a variety of models, that amending auctions with royalty contracts to the losers of the auction generally increases the innovator's expected profit.

[2]Similarly, our own contributions to licensing mechanism under incomplete information also assume that the innovator discloses the winning bid.

beliefs concerning the winner's cost reduction. Therefore, the losing bid signals the updated beliefs of the loser about the winner's cost reduction.

Under both modes of competition, publishing the losing bid contributes to deflate bids. However, as the loser only knows that the winner's cost reduction is higher than his own, the loser remains uncertain about the winner's cost reduction. This affects the profit premium of winning, which also exerts a strong effect on equilibrium bids. In particular, under Cournot competition that uncertainty makes winning more profitable for relatively low cost reductions and less profitable for high cost reductions, and *vice versa* in the case of Bertrand competition.

Finally, if no bid is revealed, no signaling occurs through bids. Bidders can only update their beliefs after learning that they either lost or won the auction. In that case, uncertainty about the winner's cost reduction and about the loser's beliefs prevail. However, the updating of beliefs depends upon the bid with which one either won or lost the auction. This invites strategic experimentation with one's bid with the intention to learn from the observed event of winning and losing at one's bid. Again, the incentives for experimentation affect the equilibrium bid function in a way that depends on the market game.

The role of bid disclosure has also been explored in the context of asymmetric first-price auctions with resale opportunities (see Hafalir and Krishna, 2008, Lebrun, 2010), where resale is driven by the notorious inefficiency of the first-price auction. There, the choice of disclosure rule also affects equilibrium bids. However, unlike in the present paper, the choice of disclosure rule neither affects the allocation nor expected payoffs.[3]

Our analysis also bears a relationship to the literature on information sharing in oligopoly. That literature assumed that firms can commit to reveal their private information before they draw that information. The main finding was that in a Cournot oligopoly with substitutes firms have an incentive to reveal information concerning their private cost, whereas firms prefer not to reveal information concerning product demand (see Shapiro, 1986, Gal-Or, 1985, Vives, 1984, 1990). A critical assumption of that literature is that firms can commit to reveal information, good or bad, before it becomes available, and that the revealed information is verifiable.

However, in license auctions the auctioneer can commit to indirectly reveal cost information by choosing an auction rule that automatically reveals some bids or no bid. Information sharing is thus a byproduct of bidding, which also bypasses the verifiability required in the information exchange literature.

The plan of the paper is as follows: In Section 2 we state the model and solution procedure. In Sections 3 and 4 we analyze the impact of different disclosure rules assuming the downstream market game is either subject to Bertrand or Cournot competition. In Section 5 we compare and interpret the equilibrium bid functions across disclosure rules and market games, and in Section 6 summarize the revenue ranking of disclosure rules and show that standard auctions are not revenue equivalent because they imply different disclosure rules. In addition we rank disclosure rules by consumer surplus and social surplus. In Section 7 we generalize by introducing conditional disclosure rules that disclose information depending on the level of the winning bid, and characterize the optimal disclosure rule. The paper closes with a discussion.

[3] In the behavioral literature, the role of bid disclosure has also been explored. There it was claimed that publishing either the winning or the losing bid may boost revenue, on the ground that bidders anticipate either loser or winner regret (Engelbrecht-Wiggans and Katok, 2008, Filiz-Ozbay and Ozbay, 2007). However, in a recent experiment, Katuscak, Michelucci, and Zajicek (2015) showed that such feedback manipulation does not systematically affect bids.

2 Model and solution procedure

An outside innovator employs a standard first-price auction to sell the exclusive right to use a process innovation to one of two risk neutral firms. The innovator sets a disclosure rule that commits him to reveal some or all or no bids. After the relevant outcome of the auction has been disclosed, firms play either a Bertrand or a Cournot duopoly game with differentiated products.

Three bid disclosure rules are considered: the innovator either discloses

- the winning bid (full disclosure[4]), or
- only the losing bid (partial disclosure), or
- neither the winning nor the losing bid (no disclosure).

The timing of the licensing game is as follows: 1) The innovator announces the bid disclosure rule. 2) Firms draw their cost reduction and simultaneously submit their bids. 3) The innovator awards the license to the highest bidder who pays his bid (the losing bidder pays nothing), and discloses information concerning bids according to the announced disclosure rule. 4) Firms play either a Bertrand or a Cournot duopoly game, simultaneously choosing unit prices p_1, p_2, resp. outputs, q_1, q_2.

Firms produce differentiated products which are substitutes. They face demand functions in which the direct effect of price on demand is stronger than the indirect effect.

Prior to the innovation, firms have the same unit cost $c > 0$. Using the innovation reduces one's unit costs by an amount x_i that depends on who uses it. Potential cost reductions are firms' private information, unknown to their rival and to the innovator. They are *i.i.d.* random variables, drawn from the uniform distribution $F : [d, c] \to [0, 1]$, where d is bounded away from zero (as further specified below). The innovation is non-drastic, i.e., its adoption cannot propel a monopoly.

We illustrate results with demand functions, Q_i, and the underlying utility function, U, introduced by Shubik and Levitan (1980):[5]

$$Q_i(p_i, p_j) := \frac{a}{b} - \frac{1}{b(1-s)}(p_i - sp_j), \quad s \in (0,1),\ a, b > 0 \tag{1}$$

$$U(q_i, q_j) = a(q_i + q_j) - \frac{b}{2(1+s)}(q_i^2 + q_j^2 + 2sq_iq_j). \tag{2}$$

The linearity of demand is essential for obtaining closed form solutions of equilibrium bid functions and for the payoff ranking of different disclosure rules.[6]

In these demand functions, a represents consumers' maximum willingness to pay, s the degree of product substitutability, and $1/b$ the size of the market. The substitution parameter s ranges from $s = 0$, when products are independent, to s approaching 1, when goods become perfect substitutes. The corresponding inverse demand functions are: $P_i(q_i, q_j) := a - \frac{b}{1+s}(q_i + sq_j)$.

The Shubik-Levitan specification has been designed to remedy an undesirable feature of the often used Bowley specification (Bowley, 1924, Singh and Vives, 1984), in which an increase in the

[4]Revealing the winning bid is as informative as revealing the winning *and* the losing bids.

[5]We express the Shubik-Levitan demand function in the slightly more convenient yet equivalent form, introduced by Collie and Le (2015).

[6]For the same reason linearity of demand is assumed in the older as well as in the latest information exchange literature (see Bagnoli and Watts, 2015).

measure of substitutability reduces the size of the market and makes it shrink away completely as products become perfect substitutes.

In a Cournot market game an innovation is non-drastic if the equilibrium output of the firm that did not get the innovation is positive, for all x. Similarly, in a Bertrand market game, an innovation is non-drastic if the equilibrium price of the firm that did not get the innovation is greater than its unit cost, c. The innovation is non-drastic for all cost reductions x if it is non-drastic for the highest possible cost reduction, $x = c$. Therefore, assuming the above demand functions, the following conditions are necessary and sufficient for a non-drastic innovation:

$$\text{Cournot:} \quad c < \frac{a(2-s)}{2}, \quad \text{Bertrand:} \quad c < \frac{a(2-s-s^2)}{2-s^2}. \tag{3}$$

Evidently, if the innovation is non-drastic under Bertrand competition, it is also non-drastic under Cournot competition.

In the following we solve the equilibrium bid functions for the considered disclosure rules and downstream market games, employing the following solution procedure.
1) As a working hypothesis, suppose the auction games have symmetric equilibria with strictly increasing equilibrium bid functions, β, (which will be confirmed).
2) Suppose one firm, say firm 1, unilaterally deviates from equilibrium bidding, while its rival plays the equilibrium bid strategy, β. Without loss of generality we restrict deviating bids to the set $[\beta(d), \beta(c)]$, because bidding outside that range is dominated.
3) Unilateral deviations from equilibrium bidding lead into duopoly subgames that are off the equilibrium path. Therefore, in order to compute the payoff of the firm that unilaterally deviates one must first solve all duopoly subgames, on and off the equilibrium path.
4) For β to be an equilibrium strategy, it must be such that no unilateral deviation is profitable. Using this requirement allows us to find the equilibrium.

3 Bertrand competition

If the downstream market game is subject to Bertrand competition, firms play price strategies, and firms' payoff functions in the duopoly subgames are: $\pi_i(p_i, p_j; c_i) := Q_i(p_i, p_j)\,(p_i - c_i)$.

For each disclosure rule we first solve the equilibria of all possible duopoly subgames on the equilibrium path, i.e., if firms stick to equilibrium bids, and off the equilibrium path, when a firm unilaterally deviates from equilibrium bidding. Computing the reduced form equilibrium profit functions for all possible duopoly subgames, we then solve the bidding game.

3.1 Full disclosure

Because the equilibrium bid function, β_f^B, is strictly increasing, by hypothesis, the winning bid informs the loser about the winner's cost reduction. The winner's equilibrium price is increasing in his unit cost. Therefore, if the loser observes a high bid, he infers that the winner has a high cost reduction and thus predicts the winner to set a low price. In turn this induces the loser to respond with a low price. Anticipating this response, bidders have an incentive to strategically deflate their bids in order to signal that they have a low cost reduction if they win, which then induces the loser to quote a high price.

3.1.1 Downstream duopoly subgames

In a first step we solve the equilibrium price strategies, $p_W^{ef}(x), p_L^{ef}(x)$, of the duopoly subgames on the equilibrium path. The superscript e is mnemonic for "on the equilibrium path". Suppose the winner of the auction had drawn cost reduction x and bid $\beta_f^B(x)$, while the loser had drawn $y < x$ and bid $\beta_f^B(y)$. Then, $p_W^{ef}(x), p_L^{ef}(x)$ must solve the equilibrium requirements:

$$p_W^{ef}(x) = \arg\max_p \pi_i(p, p_L^{ef}(x); c - x), \quad p_L^{ef}(x) = \arg\max_p \pi_j(p, p_W^{ef}(x); c).$$

In the linear model: $p_W^{ef}(x) = \frac{(2+s)(a+c-as)-2x}{4-s^2}$, $p_L^{ef}(x) = \frac{(2+s)(a+c-as)-sx}{4-s^2}$.

Now consider a firm, say firm 1, with cost reduction x, that unilaterally deviated from equilibrium and bid $\beta_f^B(z)$ rather than $\beta_f^B(x)$, while firm 2, with cost reduction y, played the strictly increasing equilibrium bidding strategy and bid $\beta_f^B(y)$. Then, the following subgames occur, depending upon the pretended cost reduction of firm 1, z, and the cost reduction parameter of firm 2, y.

Firm 1 won the auction ($\mathbf{z \geq y}$) In that case firm 2 believes that the cost reduction of firm 1 is equal to z and thus plays the strategy $p_L^{ef}(z)$. However, firm 1 privately knows that its cost reduction is x and therefore plays its best reply to $p_2 = p_L^{ef}(z)$:

$$p_W^f(x,z) := \arg\max_p \pi_1 \left(p, p_L^{ef}(z); c - x\right).$$

$p_W^f(x,z)$ is decreasing in x and in z. In the linear model: $p_W^f(x,z) = \frac{(2+s)(2c+2a(1-s))-(4-s^2)x-s^2z}{2(4-s^2)}$.

Firm 1 lost the auction ($\mathbf{z < y}$) In that case the roles of firm 1 and firm 2 are reversed. The only difference is that firm 2 does not deviate from equilibrium and thus signals its true cost reduction, y. Therefore, $p_L^f(y) = p_L^{ef}(y)$. Note that $p_L^f(y)$ is decreasing in y.

Altogether the reduced form equilibrium profit functions of firm 1, contingent upon winning/losing the auction, are:

$$\pi_W^f(x,z) := \pi_1 \left(p_W^f(x,z), p_L^{ef}(z); c - x\right), \quad \pi_L^f(y) := \pi_1 \left(p_L^f(y), p_W^{ef}(y); c\right).$$

In the linear model: $\pi_W^f(x,z) = \frac{1}{b(1-s)} \left(p_W^f(x,z) - c + x\right)^2$, $\pi_L^f(y) = \frac{1}{b(1-s)} \left(p_L^{ef}(y) - c\right)^2$.

3.1.2 Equilibrium bid strategy

Using the solution of the duopoly subgames, the expected payoff of a bidder with cost reduction x who bids as if his cost reduction were equal to z, while his rival follows the equilibrium strategy, β_f^B, is:

$$\Pi_f(x,z) = F(z) \left(\pi_W^f(x,z) - \beta_f^B(z)\right) + \int_z^c \pi_L^f(y) dF(y). \tag{4}$$

Invoking the equilibrium requirement: $x = \arg\max_z \Pi_f(x,z)$, the equilibrium bid strategy β_f^B must satisfy the first-order conditions:

$$\left(\beta_f^B(x) F(x)\right)' = F'(x) \left(\pi_W^f(x,x) - \pi_L^f(x)\right) + F(x) \partial_z \pi_W^f(x,z)\Big|_{z=x}, \quad \forall x. \tag{5}$$

In the linear model, second-order conditions are satisfied, because $\Pi_f(x,z)$ is pseudo-concave in z, for all x (see Appendix A.1).[7]

The equilibrium requirement (5) has a nice interpretation. In equilibrium, the bid function must be such that the marginal benefit of increasing one's bid (RHS) equals its marginal cost (LHS), so that it never pays to deviate from bidding $\beta_f^B(x)$.

The marginal benefit has two components: as z is increased, 1) it becomes more likely to win the auction and earn a higher profit premium (first term); 2) in the event of winning, the rival is led to believe that he faces a stronger player, with a higher cost reduction, which makes him reduce his price – to the disadvantage of the winner. Therefore, the second term, the marginal benefit of signaling, $F(x)\partial_z\, \pi_W^f(x,z)\Big|_{z=x}$, is negative.

Altogether we find that disclosing the winning bid gives firms an incentive to signal a low cost reduction which exerts a downward pressure on the equilibrium bid function. In equilibrium, no false signals are sent. This is achieved by choosing the bid function in such a way that the marginal benefits and costs of sending false signals are equalized at each point of that function.

Integration of (5) yields, for all $x \in (d,c]$, the equilibrium bid function:

$$\beta_f^B(x) = \int_d^x \left(\pi_W^f(y,y) - \pi_L^f(y)\right) \frac{F'(y)}{F(x)} dy + \int_d^x \partial_z\, \pi_W^f(y,z)\Big|_{z=y} \frac{F(y)}{F(x)} dy. \tag{6}$$

In the linear model, $\beta_f^B(x)$ is a quadratic equation. Its coefficients are spelled out in Appendix A.1, equation (A.1). In that Appendix we also show that the assumed strict monotonicity of the bid function confirms and that non-negativity of bids is assured. Therefore, β_f^B is indeed an equilibrium bid function.

3.2 Partial disclosure

Because revealing only the winning bid implies full disclosure, partial disclosure means disclosing only the losing bid.

As the equilibrium bid function, β_p^B, is strictly increasing, by hypothesis, the losing bid informs the winner about the loser's cost reduction. Of course, the winner does not care about the cost reduction the loser would have enjoyed if he had won the auction. However, knowing the loser's cost reduction allows the winner to infer that the loser believes the winner's cost reduction to be greater than the loser's signal. Therefore, when the losing bid is revealed, the loser of the auction signals his beliefs about the cost reduction of the winner.

Specifically, a higher losing bid indicates to the winner that he is seen as stronger, which has an adverse effect on the loser's profit. Taking this into account, bidders have an incentive to strategically deflate their bids.

3.2.1 Downstream duopoly subgames

The equilibrium price strategies on the equilibrium path, $p_W^{ep}(x,y), p_L^{ep}(y)$, must solve the equilibrium requirements:

$$p_W^{ep}(x,y) = \arg\max_p \pi_i(p, p_L^{ep}(y); c-x), \quad p_L^{ep}(y) = \arg\max_p \int_y^c \pi_j(p, p_W^{ep}(x,y); c)^{F'(x)}/(1-F(y))dx.$$

[7]Pseudo-concavity of $\Pi(x,z)$ in z means that Π is increasing in z for $z < x$ and decreasing for $z > x$; hence, the solutions of the first-order conditions yield global maxima.

In the linear model, $p_W^{ep}(x,y) = \frac{4a(2-s-s^2)+c(8+4s-s^2)-2(4-s^2)x-s^2y}{4(4-s^2)}$, and $p_L^{ep}(y) = \frac{2a(1-s)(2+s)+c(4+s)-sy}{2(4-s^2)}$.

Similar to the analysis of full disclosure, suppose firm 1 had drawn the cost reduction x and unilaterally deviated from equilibrium and bid $\beta_p^B(z)$, while firm 2, with cost reduction y, bid $\beta_p^B(y)$. Then, the following subgames occur, depending upon y and z.

Firm 1 won the auction (z > y) In that case firm 2 believes that the cost reduction of firm 1 is in the set $(y,c]$, and firm 1 knows this because it observes $\beta_p^B(y)$. Therefore, firm 2 plays the strategy $p_L^{ep}(y)$ and firm 1 plays its best reply to that strategy:

$$p_W^p(x,y) := \arg\max_p \pi_1(p, p_L^{ep}(y); c-x) = p_W^{ep}(x,y). \tag{7}$$

Note that $p_W^p(x,y)$ is decreasing in x and y.

Firm 1 lost the auction (y > z) In that case firm 1 believes that firm 2's cost reduction is in the set $(z,c]$, and firm 2 knows this.

By the above reasoning (reversing the roles of firms 1 and 2) we find that the equilibrium strategy of firm 1 is $p_L^p(z) = p_L^{ep}(z)$ and that of firm 2 is $p_W^p(y,z)$. Note that $p_L^p(z)$ is decreasing in z.

Altogether, the reduced form profit functions, contingent upon winning/losing are:

$$\pi_W^p(x,y) := \pi_1(p_W^p(x,y), p_L^{ep}(y); c-x), \quad \pi_L^p(z) := \int_z^c \pi_1(p_L^p(z), p_W^p(y,z); c)\frac{dF(y)}{1-F(z)}.$$

In the linear model: $\pi_W^p(x,y) = \frac{1}{b(1-s)}(p_W^p(x,y)-c+x)^2$, $\pi_L^p(z) = \frac{1}{b(1-s)}(p_L^{ep}(z)-c)^2$.

3.2.2 Equilibrium bid strategy

The expected payoff of a bidder with cost reduction x who unilaterally deviates and bids $\beta_p^B(z)$ is:

$$\Pi_p(x,z) = \int_d^z \left(\pi_W^p(x,y) - \beta_p^B(z)\right) dF(y) + (1-F(z))\pi_L^p(z). \tag{8}$$

Again, invoking the equilibrium requirement: $x = \arg\max_z \Pi_p(x,z)$, β_p^B must satisfy:

$$\left(\beta_p^B(x)F(x)\right)' = F'(x)\left(\pi_W^p(x,x) - \pi_L^p(x)\right) + (1-F(x))\left.\pi_L^{p\prime}(z)\right|_{z=x}, \quad \forall x. \tag{9}$$

Second-order conditions are satisfied (see Appendix A.1).

Like in the case of full disclosure, the RHS of (9) states the marginal benefit of raising one's bid; the LHS states its marginal cost. The first term of the marginal benefit has the same interpretation as in the full disclosure case. The second term indicates the signaling aspect of the losing bid: as one increases z to z' and yet loses the auction, one's inference concerning the set of rival's type is changed from $(z,c]$ to $(z',c]$; therefore, one infers that the rival has, on average, a higher cost reduction and thus sets, on average, a lower price, which reduces one's expected profit. Therefore, the marginal signaling benefit, $(1-F(x))\left.\pi_L^{p\prime}(z)\right|_{z=x}$, is negative.

Integration yields, for all $x \in (d,c]$:

$$\beta_p^B(x) = \int_d^x \left(\pi_W^p(y,y) - \pi_L^p(y)\right)\frac{F'(y)}{F(x)}dy + \int_d^x \left.\pi_L^{p\prime}(z)\right|_{z=y}\frac{1-F(y)}{F(x)}dy. \tag{10}$$

In the linear model β_p^B is a quadratic function. Its coefficients are spelled out in Appendix A.1. There we also confirm the strict monotonicity of β_p^B and, provided d is sufficiently bounded away from zero, the non-negativity of bids. In that case, β_p^B is indeed an equilibrium bid function.

3.3 No disclosure

If bids are not disclosed, there is no signaling through bids. Updating of prior beliefs occurs only in response to winning and losing. The loser of the auction can only infer that the winner's cost reduction is greater than his own true resp. pretended cost reduction from which he can draw an inference concerning the winner's average price. Similarly, the winner can only infer that the loser's cost reduction is lower than his own true resp. pretended cost reduction from which he can draw an inference concerning the loser's average price. Because the inferences that one draws in the event of winning or losing depend upon the pretended bid, bidders have an incentive to engage in strategic experimentation through their bids.

Firms play price strategies conditional on winning and losing.

3.3.1 Downstream duopoly subgames

Consider a firm with cost reduction x that won the auction while the loser has drawn the cost reduction y. Both firms do not know each others' cost reductions. They only observe their own draw and whether they won or lost.

The equilibrium strategies *on the equilibrium path* are:

$$p_W^{en}(x) = \arg\max_p \int_d^x \pi_i(p, p_L^{en}(y); c-x)\frac{dF(y)}{F(x)},\ p_L^{en}(y) = \arg\max_p \int_y^c \pi_j(p, p_W^{en}(x); c)\frac{dF(x)}{(1-F(y))}.$$

In the linear model:

$$\begin{aligned} p_W^{en}(x) &= \frac{a(16-s^2)(1-s)(2+s)+c(2-s)s(8+s)+32c-2ds^2-(32-8s^2)x}{64-20s^2+s^4} \\ p_L^{en}(y) &= \frac{a(16-s^2)(1-s)(2+s)+c(32+(2-s)s(4+s))-ds^3-(8s-2s^3)y}{64-20s^2+s^4}. \end{aligned}$$

Again, consider one firm, say firm 1, with cost reduction x that unilaterally deviated from equilibrium and bid $\beta_n^B(z)$. If that firm won the auction, its equilibrium strategy *off the equilibrium path*, $p_W^n(x,z)$, solves the best-reply requirement:

$$p_W^n(x,z) = \arg\max_p \int_d^z \pi_1(p, p_L^{en}(y); c-x)\frac{dF(y)}{F(z)}.$$

Whereas if it lost the auction, its equilibrium price strategy *off the equilibrium path* is $p_L^n(z) = p_L^{en}(z)$. Note that $p_W^n(x,z)$ is decreasing in x and z and $p_L^n(z)$ is decreasing in z.

Altogether, the reduced form profit functions of firm 1, conditional on winning/losing, are:

$$\begin{aligned} \pi_W^n(x,z) &:= \int_d^z \pi_1(p_W^n(x,z), p_L^{en}(y); c-x)\frac{dF(y)}{F(z)} \\ \pi_L^n(z) &:= \int_z^c \pi_1(p_L^n(z), p_W^{en}(y); c)\frac{dF(y)}{1-F(z)}. \end{aligned}$$

In the linear model, $p_W^n(x,z) = \frac{32c+a(16-s^2)(1-s)(2+s)+s(c(2-s)(8+s)-2ds)}{2(64-20s^2+s^4)} - \frac{x}{2} - \frac{s^2 z}{2(16-s^2)}$, $\pi_W^n(x,z) = \frac{1}{b(1-s)}\left(p_W^n(x,z)-c+x\right)^2$, $\pi_L^n(z) = \frac{1}{b(1-s)}\left(p_L^n(z)-c\right)^2$.

3.3.2 Equilibrium bid strategy

The expected payoff of a bidder with cost reduction x who unilaterally deviates and bids $\beta_n^B(z)$ is:

$$\Pi_n(x,z) = F(z)\left(\pi_W^n(x,z) - \beta_n^B(z)\right) + (1-F(z))\pi_L^n(z). \tag{11}$$

Invoking the equilibrium requirement $x = \arg\max_z \Pi_n(x,z)$, gives, for all x:

$$\left(\beta_n^B(x)F(x)\right)' = F'(x)\left(\pi_W^n(x,x) - \pi_L^n(x)\right) + F(x)\partial_z\, \pi_W^n(x,z)\big|_{z=x} + (1-F(x))\, \pi_L^{n\prime}(z)\Big|_{z=x}. \tag{12}$$

Second-order conditions are satisfied (see Appendix A.1).

The RHS of (12) represents the marginal benefit of increasing one's bid and the LHS represents its marginal cost.

The marginal benefit has three components: The *first* term is positive and has the same interpretation as in the case of full disclosure. The two other terms reflect the marginal benefits of *experimentation*; these terms are negative for the following reasons.

As one increases one's bid from $\beta_n^B(z)$ to $\beta_n^B(z')$ and wins the auction, the inferred set of the rival's types increases from $[d,z)$ to $[d,z')$; depending upon his type y the rival updates his prior belief about x to $x \in [y,c]$; a higher y makes the rival more pessimistic about the winner's type, and induces him to compete more fiercely and set a lower price. Therefore, winning with a higher bid induces the winner to predict that the loser quotes on average lower prices, which reduces the winner's expected profit. This explains why the *second* term is negative.

In turn, if one loses the auction after increasing one's bid, the inferred set of the rival's types reduces from $(z,c]$ to $(z',c]$; therefore, one infers that the rival is, on average, stronger and sets on average a lower price, which reduces one's expected profit. This explains why the *third* term is also negative.

Integration of (12) yields, for all $x \in (d,c]$:

$$\begin{aligned}\beta_n^B(x) = &\int_d^x \left(\pi_W^n(y,y) - \pi_L^n(y)\right)\frac{F'(y)}{F(x)}dy \\ &+ \int_d^x \partial_z\, \pi_W^n(y,z)\big|_{z=y}\frac{F(y)}{F(x)}dy + \int_d^x \pi_L^{n\prime}(z)\big|_{z=y}\frac{1-F(y)}{F(x)}dy.\end{aligned} \tag{13}$$

In the linear model $\beta_n^B(x)$ is a quadratic function. Its coefficients are spelled out in Appendix A.1, equation (A.3). There, we also show that, in the linear case, β_n^B is strictly increasing; the non-negativity of bids follows provided d is sufficiently bounded away from zero. In that case, β_n^B is indeed an equilibrium bid function.

4 Cournot competition

If the downstream market game is subject to Cournot competition, firms play output strategies and firms' payoff functions in the duopoly subgames are: $\pi_i(q_i,q_j;c_i) := (P_i(q_i,q_j) - c_i)q_i$. The derivation of equilibrium bid functions is similar to that in the Bertrand case. However, one must carefully work out the equilibria and reduced form equilibrium profit functions of the duopoly subgames which differ across market games.

Altogether we find that the signaling and experimentation effects have, with some exceptions, opposite signs, and (not surprisingly) Bertrand competition is fiercer, which reflects in lower revenues of the innovator.

In order to avoid repetition of similar arguments we give a brief summary of results in the main text and relegate the detailed computations of equilibrium bid functions to Appendix A.2. Unlike in the case of Bertrand competition, equilibrium bids are non-negative for all $d \geq 0$.

4.1 Full disclosure

Using a similar solution procedure as in the case of Bertrand competition, one can compute the equilibrium strategies, $q_W^f(x,z)$, $q_L^f(y)$, and reduced form profit functions. In the linear model: $\pi_W^f(x,z) = \frac{b}{(1+s)} q_W^f(x,z)^2$, $\pi_L^f(y) = \frac{b}{(1+s)} q_L^f(y)^2$. Note that, $q_W^f(x,z)$ increases in x and in z, whereas $q_L^f(y)$ decreases in the rival's cost reduction y.

The equilibrium bid function can be expressed in exactly the same form as in the corresponding Bertrand case, equation (6). However, the functions $\pi_W^f(x,z)$ and $\pi_L^f(y)$ differ and the sign of the signaling benefit is reversed, i.e., $\partial_z \pi_W^f(x,z)\Big|_{z=x} > 0$.

The sign reversal of the signaling benefit is due to the fact that if a bidder signals a higher cost reduction and wins the auction, the rival responds by reducing his output, which increases the winner's profit, whereas in the corresponding Bertrand case, it induces the rival to set a lower price.

The equilibrium bid function accounts for this incentive by making it sufficiently costly to inflate one's bids. Therefore, unlike in the Bertrand case, the signaling effect contributes to an upward shift of the equilibrium bid function.

4.2 Partial disclosure

Again, one can compute the equilibrium strategies, $q_W^p(x,y)$, $q_L^p(z)$, and reduced form profit functions of firm 1, $\pi_W^p(x,y)$, $\pi_L^p(z)$, as spelled out in Appendix A.2.

Note, $q_W^p(x,y)$ increases in x and in y and $q_L^p(z)$ decreases in z.

The equilibrium bid function can be expressed in exactly the same form as in the corresponding Bertrand case, equation (10). However, the functions $\pi_W^p(x,y)$, $\pi_L^p(z)$ differ and the size of the signaling effect differs. The sign of the signaling effect, $\pi_L^{p\prime}(z)\big|_{z=x} < 0$ is the same as in the Bertrand case. This is due to the fact that if a bidder signals a higher cost reduction and loses the auction, the rival observes one's bid and learns that one is more pessimistic about his cost reduction, which induces the rival to supply more output, which reduces the profit of firm 1.

4.3 No disclosure

Similarly, one can compute the equilibrium strategies, $q_W^n(x,z)$, $q_L^n(z)$, and the associated reduced form profit functions, $\pi_W^n(x,z)$, $\pi_L^n(z)$, as explained in Appendix A.2. Note, $q_W^n(x,z)$ increases in x and in z, whereas $q_L^n(z)$ decreases in z.

The equilibrium bid function has the same form as in the corresponding Bertrand case, equation (13). However, the functions π_W^n and π_L^n differ and the sign of the first experimentation benefit is reversed, i.e., $\partial_z\, \pi_W^n(x,z)\big|_{z=x} > 0$.

The signs of the experimentation benefits can be interpreted as follows: If one increases one's bid and wins the auction, one infers that the loser's type set is enlarged; because the loser's output decreases in his type, it follows that the loser produces, on average, a lower output, which increases one's expected profit. Similarly, if one increases one's bid and loses the auction, one becomes more pessimistic and expects the winner to produce more, which reduces one's expected profit.

Note that $\beta_n^C(d) > 0$ for all $d \geq 0$. This indicates that firms have a positive willingness to pay for winning the auction even if the innovation has no intrinsic value.

5 Comparison of bid functions

We now summarize and interpret the relationship between equilibrium bid functions which is illustrated in Figure 1, focusing on the comparison of full and no disclosure.[8]

Proposition 1. *The equilibrium bid function β_n^C intersects β_f^C exactly once, from above. The function β_n^B intersects β_f^B function exactly once, from below, provided d is sufficiently bounded away from zero.*

Proof. $\Delta_C(x) := \beta_n^C(x) - \beta_f^C(x)$ is a quadratic and strictly concave function of x with $\Delta_C(d) > 0$ and $\Delta_C(c) < 0$. Therefore, Δ_C has exactly one root in (d,c). Similarly, $\Delta_B(x) := \beta_f^B(x) - \beta_n^B(x)$ is a quadratic and strictly concave function of x with $\Delta_B(c) < 0$ and, if d is sufficiently bounded away from zero, $\Delta_B(d) > 0$. Therefore, if d is sufficiently bounded away from zero, Δ_B has exactly one root in (d,c). □

These properties can be interpreted as follows.

Consider Cournot competition. If a bidder has drawn a relatively low cost reduction, in the event of winning the auction he is better off if he keeps his rival uncertain, because that uncertainty induces the rival to supply a lower output. Whereas a bidder with a high cost reduction is better off if he can communicate this fact to his rival and thus induce him to supply a lower output. Hence, $\beta_n^C(x) > \beta_f^C(x)$ if x is low and $\beta_f^C(x) > \beta_n^C(x)$ if x is high.

All of this is reversed under Bertrand competition. There, in the event of winning, a bidder with a high cost reduction prefers to keep the rival uncertain about his cost reduction, in order to prevent the rival from competing fiercely by quoting a low price. Whereas, if he has a low cost reduction he prefers full to no disclosure, because signaling a low cost reduction induces the rival to set a high price. Hence, $\beta_f^B(x) > \beta_n^B(x)$ if x is low and $\beta_f^B(x) < \beta_n^B(x)$ if x is high.[9]

Another notable feature is that if the winning bid is not revealed, bidders earn a positive profit premium of winning, $\int_d^x (\pi_W(y,y) - \pi_L(y))\, {}^{F'(y)}/_{F(x)} dy$, under Cournot as well as under Bertrand competition, even if the innovation has no intrinsic value, which happens if x is close to d and d close to zero. The reason is that if one wins with a cost reduction close to zero, the loser, whose cost reduction is even closer to zero, believes the winner to be strong in the sense that his updated belief about the winner's cost reduction is almost the same as his prior belief.

In the case of Cournot competition, the profit premium of winning is greater than the negative signaling effect (in the partial information régime) resp. greater than the negative experimentation effect (in the no disclosure régime), even when the intrinsic value of the innovation, x, is close to zero. This is why the bid functions β_p^C, β_N^C have a positive intercept for $d = 0$.

That feature is, however, not present under Bertrand competition. In fact, there one cannot assure non-negative bids unless d is sufficiently bounded away from zero. This is due to the fact that Bertrand competition is fiercer than Cournot competition, which gives rise to a lower profit

[8] The plots of the Bertrand case assume $(a,b,s,c,d) = (1,1,.87,.2,0.05)$, and the plots of the Cournot case $(a,b,s,c,d) = (1,1,.9,.4,0.05)$.

[9] In the case of Bertrand, if d is not sufficiently high, one cannot exclude the possibility that $\Delta_B(d)$ is negative; however, in that case, Δ_B is still positive for low values of x except for values close to d.

premium of winning to such an extent that, for x close to d and d close to zero, the profit premium of winning, does not outweigh the negative signaling effect, $\int_d^x \pi_L^{p\prime}(z)\big|_{z=y} {}^{(1-F(y))}/{}_{F(x)}dy$, resp. the experimentation effect, $\int_d^x \pi_L^{n\prime}(z)\big|_{z=y} {}^{(1-F(y))}/{}_{F(x)}dy$ (note, the other experimentation benefit vanishes as x goes to d).

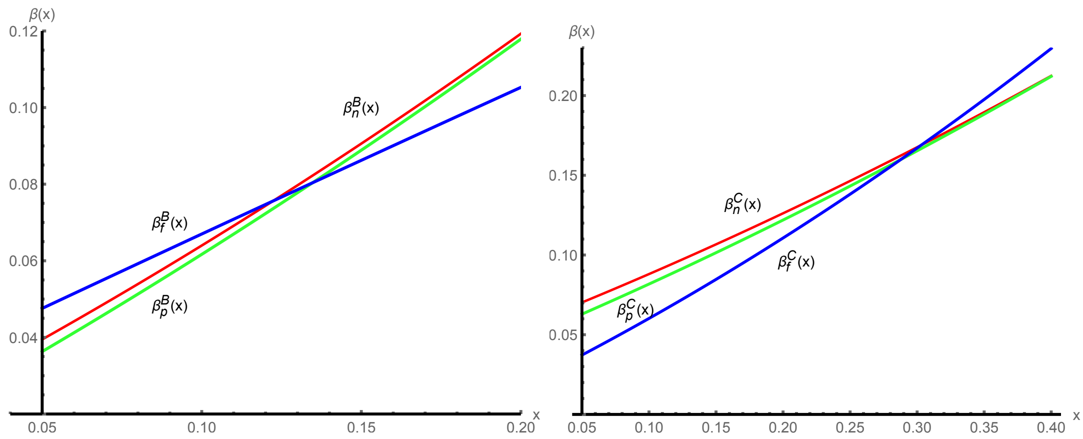

Figure 1: Equilibrium bid functions (Bertrand: left, Cournot: right)

6 Optimal bid disclosure

Even though the bid pattern differs radically across the two market games, we find that the innovator most prefers no disclosure, for a large range of parameter values. For this purpose we compute the innovator's expected revenues, $R_i := \int_d^c \beta_i(x) 2F(x) dF(x)$. Define:

$$\varphi(a,d,s) := \frac{12a(2-s)(16-s^2)s + d(64-124s^2+9s^4)}{64+384s-124s^2-24s^3+9s^4}.$$

Proposition 2. *The innovator ranks disclosure rules as follows:*

Bertrand: $R_n^B > R_p^B > R_f^B$

Cournot: $R_n^C > R_f^C > R_p^C$ *if* $c < \varphi(a,d,s)$

$R_f^C > R_n^C > R_p^C$ *if* $c > \varphi(a,d,s)$.

The proof is in Appendix A.3.

The parameter set for which $R_n^C > R_f^C$ is illustrated in Figure 2. The area under the top line depicts the set of parameters that are consistent with a non-drastic innovation, and the curve below depicts the parameter set for which $R_n^C = R_f^C$. If $s \geq 0.733$, one has $c < \varphi(a,d,s)$ for all parameter values. However, as one can readily see from Figure 2, this condition is far from necessary. The plots assume that $d = 0$. If d is increased, the lower curve is shifted upwards and the area in which $R_n^C > R_f^C$ is enlarged.

Altogether our analysis indicates that the ranking of the innovator's expected revenues across disclosure rules is not exclusively driven by the impact of signaling on bids, which has been the focus of the literature on signaling in license auctions. Disclosure rules also affect the profit premium of winning and this effect is decisive, except if the degree of substitutability is "low".

Disclosure rules are intimately connected to auction formats. In an open, descending bid (Dutch) auction the highest bid is automatically revealed to bidders, and in an open, ascending bid (English) and second-price sealed-bid (Vickrey) auction the second highest bid is revealed to bidders, whereas

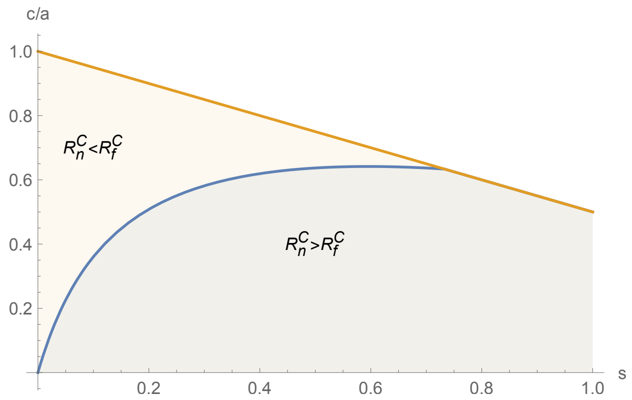

Figure 2: Parameter values for which $R_n^C > R_f^C$

in a first-price sealed-bid auction bids are invisible (unless the auctioneer chooses to disclose information). Because the considered auction formats are revenue equivalent if one controls for the disclosed information, we find the following revenue ranking of auction formats:

Corollary 1. *The innovator's revenue ranking of standard auction formats is:*

Bertrand:	*1-st price sealed-bid* $\succ$ *English/Vickrey* $\succ$ *Dutch*	
Cournot:	*1-st price sealed-bid* $\succ$ *Dutch* $\succ$ *English/Vickrey*	*if* $c < \varphi(a,d,s)$
	Dutch $\succ$ *1-st price sealed-bid* $\succ$ *English/Vickrey*	*if* $c > \varphi(a,d,s)$.

Hence, due to differences between the implied information disclosure, the standard auctions are not revenue equivalent.

We mention that the innovator is better off if he licenses to firms that compete in a Cournot market game.

Proposition 3. *For each disclosure rule, the innovator's equilibrium expected revenue is higher under Cournot than under Bertrand competition:* $R_r^C > R_r^B$, $r \in \{f,p,n\}$.

This finding is not surprising because firms compete more fiercely in a Bertrand market game.

Finally, we also rank disclosure rules by firms' expected profits, Π^*, expected consumer surplus, CS, and expected social surplus, S:

Proposition 4. *In both market games, firms prefer more information disclosure and consumers prefer less:*

$$\Pi_f^* > \Pi_p^* > \Pi_n^*, \quad CS_n > CS_p > CS_f.$$

The rankings of social surplus, S, are:

$$\textit{Bertrand: } S_p > S_n > S_f, \quad \textit{Cournot: } S_f > S_p > S_n.$$

Proof. To facilitate the computations, note that the surplus to be shared by firms and the innovator, T, is equal to the expected value of the sum of firms' profits (gross, before deducting the winning bid). Firms' expected profits are $\Pi^* = 1/2(T-R)$. Consumer surplus, CS, is equal to the difference between consumers' expected utility and their expected payments to firms. Social surplus, S, is equal to $T + CS$. The detailed computations are outlined in Appendix A.3. $\square$

Evidently, more information improves efficiency. While firms prefer more information, the innovator typically prefers the least efficient regime of no information disclosure. This indicates a sharp conflict of interest.

Remark. *In the special case of Cournot with perfect substitutes the rankings by consumer and social surplus have a nice interpretation. In this case:*

$$\begin{aligned} T &:= E((1-Q)Q) - E(cq_L + (c - X_{(1)})q_W), \quad Q := q_W + q_L \\ &= (1 - E(Q))E(Q) - \operatorname{Var}(Q) - \bar{C}, \quad \bar{C} := E(cq_L + (c - X_{(1)})q_W) \\ CS &= {}^1\!/_2 E\left(Q^2\right) = {}^1\!/_2 (E(Q)^2 + \operatorname{Var}(Q)), \quad S = E(Q) - {}^1\!/_2(E(Q)^2 + \operatorname{Var}(Q)) - \bar{C}. \end{aligned}$$

The expected value of aggregate output is the same for all three disclosure rules, whereas, not surprisingly, the variance of aggregate output and the expected value of aggregate cost decrease as more information is disclosed:[10] $E(Q^n) = E(Q^p) = E(Q^f)$, $\operatorname{Var}(Q^n) > \operatorname{Var}(Q^p) > \operatorname{Var}(Q^f)$, $\bar{C}^n > \bar{C}^p > \bar{C}^f$. *The rankings by S and CS follow immediately.*

In order to gain more insight into what drives the revenue rankings, it is useful to break down the revenue, R, into its constituent components:

$$R_f = P_f + B_f, \quad R_n = P_n + B_n^W + B_n^L.$$

There, P denote the expected profit premium, B_f the expected signaling benefit, B_n^W the expected experimentation benefit when winning, and B_n^L the expected experimentation benefit when losing.[11]

In the case of Bertrand competition one has $P_n > P_f$ and even though $B_n^W + B_n^L$ may be smaller than B_f for some parameter values, the difference between P_n and P_f is stronger, so that $R_n > R_f$ holds without qualification.

In the case of Cournot competition, the profit premium is higher under no disclosure, $P_n > P_f$, whereas the sum total of the experimentation benefits is lower than the signaling benefit, $B_f > 0 > B_n^W + B_n^L$. The difference between P_n and P_f contributes to make no disclosure more profitable, whereas the difference between B_f and $B_n^W + B_n^L$ has the opposite effect. If the degree of substitutability, s, is sufficiently high, the profit premium is so much higher under no disclosure that it outweighs the difference between the experimentation and the signaling benefits, which implies $R_n > R_f$. However, as s is reduced, goods become more independent, competition becomes less intense, and the difference between the profit premiums, $P_n - P_f$, melts away. This occurs at a faster rate than the reduction of $B_f - (B_n^W + B_n^L)$, so that, if s is sufficiently small, the revenue ranking between f and n is reversed (as illustrated in Figure 2).

7 Generalization: Conditional bid disclosure

A comparison of the equilibrium bid functions plotted on the right-hand side of Figure 1 indicates that under Cournot competition full disclosure induces the highest bids for high cost reductions, whereas no disclosure yields the highest bids for low cost reductions. This suggests that, in the Cournot case, "mixing" the two disclosure rules, by disclosing the winning bid if the winner's bid

[10] For simplicity, assume $a = 1, b = 2$, together with $s = 1$. Then, $E(Q) = (6-4c)/9$, $Var(Q^f) = c^2/162$, $Var(Q^p) = Var(Q^f) + 5c^2/864$, $Var(Q^n) = Var(Q^p) + 19c^2/21600$, $\bar{C}^f = (4c-5c^2)/9$, $\bar{C}^p = \bar{C}^f + c^2/144$, $\bar{C}^n = \bar{C}^p + c^2/2160$.

[11] Using the equilibrium bid functions and the definition of R one has $P := \int_d^c \int_d^x (\pi_W(y,y) - \pi_L(y))\, 2dF(y)dF(x)$, $B_f := \int_d^c \int_d^x \partial_z\, \pi_W^f(y,z)\big|_{z=y} 2F(y)dydF(x)$, $B_n^W := \int_d^c \int_d^x \partial_z\, \pi_W^n(y,z)\big|_{z=y} 2F(y)dydF(x)$, $B_n^L := \int_d^c \int_d^x \pi_L^{n\prime}(z)\big|_{z=y} 2(1 - F(y))dydF(x)$.

is above a certain cutoff value and not disclosing any bid otherwise, may increase the innovator's expected profit. This leads us to consider a conditional disclosure rule.

Because equilibrium bid functions are strictly increasing, such a disclosure rule induces a threshold level of the winner's cost reduction, $t \in [d,c]$, such that the winning bid is disclosed if the winner's cost reduction, x, is above that threshold level and no bid is disclosed if x is below t. Stating the disclosure rule in this form covers unconditional disclosure as special cases, obtained for $t = d$ (full disclosure) and $t = c$ (no disclosure).

To prepare the construction of the equilibrium bid function under Cournot competition, for each given threshold level t, we first construct "auxiliary" bid functions β_n, β_f that make "small" unilateral deviations unprofitable.

Specifically, let β_n be the bid function that makes small unilateral deviations unprofitable, for all $x < t$. Similarly, let β_f be the bid function that makes "small" unilateral deviations from bidding $\beta_f(x)$ unprofitable for all $x \geq t$. Thereby "small" means that the deviation does not induce a change in disclosure regime, either from full disclosure (f) to no disclosure (n) or from n to f.

Using a solution procedure that corresponds closely to the derivation of β_n^C and β_f^C in Sections 4.1 and 4.3, we find β_n and β_f, which are non-negative and strictly increasing, and are stated in Appendix A.4.[12]

Proposition 5. *For a given threshold level, t, the equilibrium bid function under conditional disclosure is:*

$$\beta(x) := \begin{cases} \beta_n(x) & \text{if} \quad x < t \\ \beta_f(x) & \text{if} \quad x \geq t \end{cases} \tag{14}$$

Proof. The bid functions β_n and β_f have been constructed to rule out profitable unilateral deviations in z from x that do not induce a change in the disclosure regime (either from f to n or from n to f). To complete the proof it remains to be shown that the bid function (14) assures that "large" deviations are not profitable either.

Let:

$$\Pi(x,z) = \begin{cases} \Pi_f(x,z) & \text{if } z \geq t \\ \Pi_n(x,z) & \text{if } z < t. \end{cases} \tag{15}$$

Consider the two possible profiles of "large" deviations: $z > t > x$ and $z < t < x$. We show that in both cases $\Pi(x,z) < \Pi(x,x)$.

In order to prepare the proof, note that $\Pi_f(t,t) = \Pi_n(t,t)$, and that Π_f and Π_n are pseudo-concave in z because: $\partial_{zx}\Pi_f(x,z) > 0$, and $\partial_{zx}\Pi_n(x,z) > 0$, as shown in Appendix A.4. Thus, one has $\partial_z\Pi_f(x,z),\ \partial_z\Pi_n(x,z) \lesseqgtr 0 \iff z \gtreqless x$. Moreover, as we also show in Appendix A.4, $\Pi_f(x,t) - \Pi_n(x,t) \gtreqless 0 \iff x \gtreqless t$. Hence, by combining all of the above,

$$\begin{aligned} &\Pi(x,x) > \Pi_n(x,t) > \Pi_f(x,t) > \Pi_f(x,z) = \Pi(x,z) \quad \text{for } z > t > x \quad \text{and} \\ &\Pi(x,z) < \Pi_n(x,t) < \Pi_f(x,t) < \Pi_f(x,x) = \Pi(x,x) \quad \text{for } z < t < x. \end{aligned}$$

This completes the proof that β is the equilibrium strategy. □

[12] In deriving these functions keep in mind that if the winner's cost reduction is less than t this fact becomes common knowledge. Therefore, in this case, the loser does not only know that the winner's cost reduction is higher than his own, but also that it is lower than t. Moreover, in computing the initial condition for β_f one needs to use the fact that $\Pi_n(t,t)$ must be equal to $\Pi_f(t,t)$.

Having solved the equilibrium bid function for each possible threshold level t we can now compute the innovator's expected revenue, as a function of t, and characterize the optimal disclosure rule by maximizing that revenue with respect to t.

Proposition 6. *The optimal disclosure rule, t^*, prescribes either no disclosure ($t^* = c$) or conditional disclosure with $d < t^* < c$, as summarized in Figure 3.*[13] *The optimal disclosure rule never prescribes full disclosure.*

Proof. The innovator's expected revenue is equal to:

$$R(t) = \int_d^t \beta_n(x) 2F(x) dF(x) + \int_t^c \beta_f(x) 2F(x) dF(x),$$

which is a polynomial of order 4, stated in Appendix A.4. The derivative of $R(t)$ is a polynomial of order 3 that has a negative coefficient of the cubic term, t^3. This polynomial has three roots: $t_1 < t_2 = d < t_3$. The root t_3 is the maximizer of R if $t_3 \leq c$. If $t_3 > c$, the maximizer is the corner solution $t^* = c$. Because R has a local minimum at $t = d$, full disclosure is never optimal. □

When one restricts the analysis to unconditional disclosure rules, in the Cournot case one cannot rule out that full disclosure is optimal (see Figure 2). However, as we generalize and allow for conditional disclosure, in the Cournot case, like in the Bertrand case, it is never optimal to prescribe full disclosure.

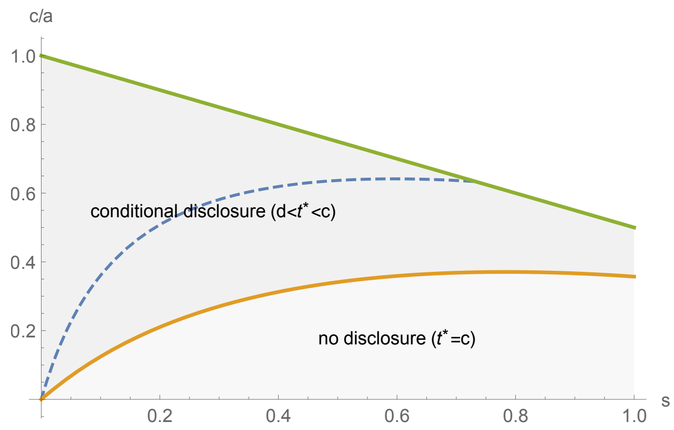

Figure 3: Optimal disclosure rule under Cournot competition

8 Discussion

Compared to the information exchange literature we show that in a license auction information exchange is implied by the publication of bids. Information exchange does not require that firms commit to exchange information, good and bad, and that information is verifiable by the recipient. The innovator can commit to administer the exchange of information simply by choosing a particular auction rule, such as a Dutch auction. The innovator may thus be viewed as a mediator who indirectly administers the information exchange between bidders by choosing a particular auction format.

[13]Figures 2 and 3 assume $d = 0$.

If the innovator were an impartial mediator who pursued the interests of bidders, he would apply an open auction format that reveals the winning bid. However, as the innovator pursues his own agenda, it is not in his own best interest to always reveal the winning bid.

Compared to the literature on license auctions with downstream interaction, we show that, for a substantial range of parameter values, revealing the winning bid is not optimal for the innovator. Although, under Cournot competition, revealing the winning bid gives rise to a signaling benefit that contributes to increase bids, this is not all that matters to determine which disclosure rule maximizes the innovator's expected revenue.

Under Cournot competition, not revealing the winning bid considerably increases the profit premium of winning, because it makes winning valuable even if the winner has a minimal cost reduction. Moreover, if no bid is revealed, there is an experimentation benefit that contributes to increase equilibrium bids. Altogether, these effects on bidding are sufficiently high to outweigh the signaling benefit of disclosing the winning bid.

As we introduce conditional bid disclosure, revealing the winning bid is never optimal, not even in Cournot competition with a low degree of substitutability of goods.

The analysis of information disclosure is relevant for the design of patent license auctions in industry. License auctions are an important method to transfer intellectual property rights. These auctions are often the last stage of an elaborate selling mechanism that involves a lengthy search and screening process, followed by shortlisting a small number of promising bidders, until bids are solicited. Simple, standardized patent auctions have been used for some time by *NASA*, the licensing offices of major universities, and in bankruptcy proceedings, for example by the *IRS* to recover back taxes, to name just a few.

In recent years, standardized patent auctions have become more common with the rise of Internet platforms such as *OceanTomo* and *IdeaBuyer*. These auctions are typically open ascending bid or first-price sealed-bid auctions which automatically disclose either the losing bid or no bid. As far as we know, the bid disclosure issue analyzed in the present paper has so far not been addressed in the applied literature (not to speak of sophisticated schemes like conditional disclosure). This may, in part, be due to the fact that bidders often request that neither the winning bid nor the identity of the winning bidder are disclosed, on the ground that they fear litigation from losers or patent trolls.[14]

A Appendix

All computations spelled out here use the linear model.

A.1 Supplements to Bertrand competition

Full disclosure The payoff function $\Pi_f(x,z)$ is pseudo-concave in z because

$$\partial_{zx}\Pi_f(x,z) = \frac{2(a-c)(2-s-s^2)+4x-s^2(x+2z-d)}{2b(c-d)(1-s)(4-s^2)} > 0,$$

by the assumption that the innovation is not drastic (see (3)). Therefore, the equilibrium bid function can be determined by using the first-order approach developed in the text.

[14]Quoting a paper by Rubenstein (1995), in their survey of patent auctions, Jarosz et al. (2010, p. 19) report that when the IRS auctioned the high profile patent portfolio of the bankrupt disk drive manufacturer *Orca Technology, Inc.*, "anonymity was required because the likely bidders were companies that manufacture infringing products ... the winning bidder would see losers as candidates for lawsuits."

Using the reduced form equilibrium profit functions contingent upon winning or losing the auction, $\pi_W(x,z), \pi_L(y)$, the coefficients of the quadratic bid function, $\beta_f^B(x) = \mu^f\left(\lambda_0^f + \lambda_1^f x + \lambda_2^f x^2\right)$, are:

$$\begin{aligned}
\mu^f &= \frac{1}{6b(1-s)(4-s^2)^2} > 0 \\
\lambda_0^f &= 3(a-c)d(1-s)(2+s)(4+2s-s^2) + d^2(8-8s^2+s^4) > 0 \\
\lambda_1^f &= 3(a-c)(1-s)(2+s)(4+2s-3s^2) + d(8-8s^2+s^4) > 0 \\
\lambda_2^f &= 2(4-7s^2+2s^4).
\end{aligned} \tag{A.1}$$

The asserted strict monotonicity of β_f^B confirms because $\beta_f^{B\prime}$ is linear and positive at the two endpoints d and c:

$$\begin{aligned}
\beta_f^{B\prime}(d)\frac{1}{\mu^f} &= 3a(8-s^2(12-s-3s^2)) - 8(3c-3d) - s^2(36d-9ds^2-3c(12-s-3s^2)) \\
&> 3(2(c-d)s^2 + cs(4-3s^2) + d(2-s^2)(4-3s^2)) > 0, \quad \text{by (3)} \\
\beta_f^{B\prime}(c)\frac{1}{\mu^f} &= 3a(8-s^2(12-s-3s^2)) - c(8-s^2(8-s(3+s))) + d(8-8s^2+s^4) \\
&> c(16+s(12-s(22+s(9-8s)))) + d(8-8s^2+s^4), \quad \text{by (3)} \\
&> 3d(2-s)(1+s)(4-3s^2) > 0, \quad \text{because } c > d.
\end{aligned}$$

To prove the non-negativity of bids note that $\mu^f > 0$, $\lambda_0^f > 0$ and $\lambda_1^f > 0$. If λ_2^f is positive, $\beta_f^B(d)$ is obviously positive. If $\lambda_2^f < 0$, one has, by the fact that $\beta_f^{B\prime}(d) = \mu^f(\lambda_1^f + 2\lambda_2^f d) > 0$:

$$\beta_f^B(d) = \mu^f\left(\lambda_0^f + d\left(\lambda_1^f + \lambda_2^f d\right)\right) > \mu^f\left(\lambda_0^f + d\left(\lambda_1^f + 2\lambda_2^f d\right)\right) > 0.$$

Partial disclosure The payoff function $\Pi_p(x,z)$ is pseudo-concave in z because

$$\begin{aligned}
\partial_{zx}\Pi_p(x,z) &= \frac{4a(2-s-s^2) - c(8-s(4+3s)) + 8x - s^2(2x+z)}{4b(c-d)(1-s)(4-s^2)} \\
&> \frac{8x + s(c(4-s) - s(2x+z))}{4b(c-d)(1-s)(4-s^2)}, \quad \text{by (3)} \\
&\geq \frac{4c(1-s)s + 8x}{4b(c-d)(1-s)(4-s^2)} > 0, \quad \text{because } x, z \leq c.
\end{aligned}$$

Using the solution for $\pi_W(x,y), \pi_L(z)$ the coefficients of the quadratic bid function, $\beta_p^B(x) = \mu^p\left(\lambda_0^p + \lambda_1^p x + \lambda_2^p x^2\right)$, are:

$$\begin{aligned}
\mu^p &= \frac{1}{48b(1-s)(4-s^2)^2} > 0 \\
\lambda_2^p &= 64 - 60s^2 + 9s^4 > 0 \\
\lambda_1^p &= 64(3a-3c+d) - 12(18a-5(3c-d))s^2 - 12(a-c)s^3 + 9(4a-3c+d)s^4 \\
&\quad > d(64-60s^2+9s^4) + 3cs(32+s(4-3(4-s)s)) > 0, \quad \text{by (3)} \\
\lambda_0^p &= 3c^2s^2(20-s(8+7s)) - 12a(2-s-s^2)(2cs^2 - d(8+s(4-3s))) \\
&\quad + 12cds^3 + d(d-3c)\lambda_2^p.
\end{aligned} \tag{A.2}$$

Monotonicity follows from $\lambda_1^p, \lambda_2^p > 0$. To prove that the non-negativity of bids is assured note that

$$\begin{aligned}
\partial_d(\beta_p^B(d)) &= 6\mu_p \left(64(a-c+d) - 12(6a-5c+5d)s^2 - 4(a-c)s^3 + 3(4a-3c+3d)s^4\right) \\
&> d(64-60s^2+9s^4) + cs(32+s(4-3(4-s)s)) > 0, \quad \text{by (3)} \\
\lim_{d\to c} \beta_p^B(d) &= \frac{(2a-c)c(1+s)}{b(4-s^2)} > 0.
\end{aligned}$$

Therefore, if d is sufficiently bounded away from zero, one has $\beta_p^B(d) \geq 0$.

No disclosure The payoff function $\Pi_n(x,z)$ is pseudo-concave in z because, using (3) and the fact that $z \leq c$:

$$\begin{aligned}
\partial_{zx}\Pi_n(x,z) = {}& \frac{1}{2b(c-d)(1-s)(64-20s^2+s^4)} \Big(2a(1-s)(2+s)(16-s^2) \\
& - 2c(32-s(16+s(14-s-s^2))) - ds^4 + (64-20s^2+s^4)x - 2(4-s^2)s^2z\Big) \\
> {}& \frac{s(32c-16cs-2cs^2+2cs^3-ds^3)+(64-20s^2+s^4)x}{2b(c-d)(1-s)(64-20s^2+s^4)} > 0.
\end{aligned}$$

Using $\pi_W^n(x,z), \pi_L^n(z)$, the coefficients of the quadratic bid function, $\beta_n^B(x) = \mu^n \left(\lambda_0^n + \lambda_1^n x + \lambda_2^n x^2\right)$, are:

$$\begin{aligned}
\mu^n &= \frac{1}{6b(1-s)(16-s^2)^2(4-s^2)} > 0 \\
\lambda_2^n &= 4(16-s^2)(4-s^2)(2-s^2) > 0 \\
\lambda_1^n &= 3a(4-s)^2(1-s)(2+s)(4+s)(4+3s) - 512(3c-d) \\
&\quad + s^2(3c(16-s^2)(26+s(5-3s)) - d(416-46s^2+s^4)) \\
&> 3cs(256+32s-64s^2-4s^3+3s^4) + d(512-416s^2+46s^4-s^6) > 0, \quad \text{by (3)} \\
\lambda_0^n &= d^2(16-s^2)(32-24s^2+s^4) - 3a(16-s^2)(1-s)(8cs^2-d(4+s)(8+(6-s)s)) \\
&\quad - 3cd(512-(16-s^2)s^2(26+(3-s)s)) + 24c^2s^2(20-s(16+(1-s)s)).
\end{aligned} \tag{A.3}$$

Again, the monotonicity is assured because $\lambda_1^n, \lambda_2^n > 0$. The non-negativity of bids is not assured for all parameter values if $d = 0$. However, if d is sufficiently bounded away from zero, non-negativity follows because, using (3),

$$\begin{aligned}
\partial_d(\beta_n^B(d)) = {}& 12\mu^n \Big(a(256-256s^2-32s^3+31s^4+2s^5-s^6) \\
& - c(256-208s^2-32s^3+29s^4+2s^5-s^6) + d(256-208s^2+29s^4-s^6)\Big) \\
> {}& 12\mu^n \Big(\frac{cs(256+160s-48s^2-28s^3+s^4+s^5)}{2+s} + d(256-208s^2+29s^4-s^6)\Big) > 0 \\
\lim_{d\to c} \beta_n^B(d) = {}& \frac{(2a-c)c(1+s)}{b(4-s^2)} > 0.
\end{aligned}$$

A.2 Supplements to Cournot competition

Full disclosure Suppose the firm that won the auction had drawn the cost reduction x and the firm that lost had drawn y. Then, the equilibrium strategies in the subsequent duopoly subgame *on the equilibrium path* are:

$$q_W^{ef}(x) := \arg\max_q \pi_i\big(q, q_L^{ef}(x); c-x\big), \quad q_L^{ef}(x) := \arg\max_q \pi_j\big(q, q_W^{ef}(x); c\big)$$

This gives:

$$q_W^{ef}(x) = \frac{(1+s)((a-c)(2-s)+2x)}{b(4-s^2)}, \quad q_L^{ef}(x) = \frac{(1+s)((a-c)(2-s)-sx)}{b(4-s^2)}.$$

Suppose firm 1 with cost reduction x unilaterally deviated from equilibrium and bid $\beta_f^C(z)$. If firm 1 won the auction, it plays its best reply to the predicted output strategy of firm 2, $q_L^{ef}(z)$:

$$q_W^f(x,z) := \arg\max_q \pi_1\left(q, q_L^{ef}(z); c-x\right) = \frac{(1+s)(2(a-c)(2-s)+(4-s^2)x+s^2z)}{2b(4-s^2)}.$$

Whereas if it lost the auction, it plays $q_L^f(y) = q_L^{ef}(y)$, while firm 2 plays $q_W^{ef}(y)$. Therefore, for all combinations of x and z, the reduced form equilibrium payoffs of firm 1, contingent upon winning or losing, are:

$$\begin{aligned}
\pi_W^f(x,z) &:= \pi_1\left(q_W^f(x,z), q_L^{ef}(z); c-x\right) = \frac{b}{1+s} q_W^f(x,z)^2 \\
\pi_L^f(y) &:= \pi_1\left(q_L^f(y), q_W^{ef}(y); c\right) = \frac{b}{1+s} q_L^f(y)^2.
\end{aligned}$$

Using these, one can compute the expected payoff function of bidder 1, $\Pi_f(x,z)$, which has the same form as under Bertrand competition. $\Pi_f(x,z)$ is pseudo-concave in z because

$$\partial_{zx}\Pi_f(x,z) = \frac{(1+s)(2(a-c)(2-s)+(4-s^2)x+2s^2z-ds^2)}{2b(c-d)(4-s^2)} > 0.$$

Using $\pi_W^f(x,z), \pi_L^f(y)$ and (6) one finds the coefficients of the equilibrium bid function β_f^C:

$$\begin{aligned}
\mu^f &= \frac{1+s}{6b(4-s^2)^2} > 0 \\
\lambda_0^f &= d(4d(2-s^2)+3(a-c)(8-(4-s)s^2)) > 0 \\
\lambda_1^f &= 4d(2-s^2)+3(a-c)(8-s^3) > 0 \\
\lambda_2^f &= 2(4+s^2) > 0.
\end{aligned} \tag{A.4}$$

Therefore, the assumed strict monotonicity and non-negativity of β_f^C confirm.

Partial disclosure Suppose the firm that won the auction had drawn the cost reduction x and the firm that lost had drawn y. Then, the equilibrium strategies in the subsequent duopoly subgame *on the equilibrium path* must solve the requirements:

$$q_W^{ep}(x,y) = \arg\max_q \pi_i\left(q, q_L^{ep}(y); c-x\right), \quad q_L^{ep}(y) = \arg\max_q \int_y^c \pi_j\left(q, q_W^{ep}(x,y); c\right) \frac{dF(x)}{1-F(y)}.$$

This yields:

$$\begin{aligned}
q_W^{ep}(x,y) &= \frac{(1+s)(4a(2-s)-c(8-4s-s^2)+2(4-s^2)x+s^2y)}{4b(4-s^2)} \\
q_L^{ep}(y) &= \frac{(1+s)(2a(2-s)-c(4-s)-sy)}{2b(4-s^2)}.
\end{aligned}$$

Now suppose one firm, say firm 1, with cost reduction x, unilaterally deviated from equilibrium and bid $\beta_p^C(z)$ rather than $\beta_p^C(x)$. If firm 1 won the auction, it plays its best reply to the predicted strategy of firm 2, $q_L^{ep}(y)$, which gives $q_W^p(x,y) = q_W^{ep}(x,y)$. Whereas if firm 1 lost the auction, it plays $q_L^p(z) = q_L^{ep}(z)$ while firm 2 plays $q_W^{ep}(y,z)$. Note that $q_W^p(x,y)$ is increasing in x and y and $q_L^p(z)$ is decreasing in z.

Altogether, the reduced form payoff functions of firm 1, contingent upon winning/losing, are:

$$\pi_W^p(x,y) := \pi_1(q_W^{ep}(x,y), q_L^{ep}(y); c-x) = \frac{b}{1+s} q_W^{ep}(x,y)^2$$
$$\pi_L^p(z) := \int_z^c \pi_1(q_L^{ep}(z), q_W^{ep}(y,z); c) \frac{dF(y)}{1-F(z)} = \frac{b}{1+s} q_L^{ep}(z)^2.$$

Using these, one can compute the expected payoff function of bidder 1, $\Pi_p(x,z)$, which has the same form as under Bertrand competition. The payoff function $\Pi_p(x,z)$ is pseudo-concave in z because

$$\partial_{zx}\Pi_p(x,z) = \frac{(1+s)(4(a-c)(2-s)+cs^2+2(4-s^2)x+s^2z)}{4b(c-d)(4-s^2)} > 0.$$

Using $\pi_W^p(x,y), \pi_L^p(z)$, (10), and (3), one finds the coefficients of the equilibrium bid function β_p^C:

$$\begin{aligned}
\mu^p &= \frac{1+s}{48b(4-s^2)^2} > 0 \\
\lambda_0^p &= 12a(2-s)(2cs^2+d(8+4s-s^2)) - 3c^2s^2(12-8s-s^2) \\
&\quad + d^2(64-28s^2+s^4) - 3cd(64-28s^2+4s^3+s^4) \\
&\quad > d^2(64-28s^2+s^4) + 3c^2s^2(4+s(8+s)) + 3cds(32+s(20-s(4+s))) > 0 \\
\lambda_1^p &= 12a(16-6s^2+s^3) + d(64-28s^2+s^4) - 3c(64-28s^2+4s^3+s^4) \\
&\quad > d(64-28s^2+s^4) + 3cs(32+s(20-s(4+s))) > 0 \\
\lambda_2^p &= 64-28s^2+s^4 > 0.
\end{aligned} \tag{A.5}$$

Evidently $\beta_p^C(x)$ is strictly increasing and non-negative. Therefore, β_p^C is indeed an equilibrium.

No disclosure Again, suppose the firm that won the auction had drawn the cost reduction x and the firm that lost had drawn y. Then, the equilibrium strategies in the subsequent duopoly subgame *on the equilibrium path* are:

$$q_W^{en}(x) = \arg\max_q \int_d^x \pi_i(q, q_L^{en}(y); c-x) \frac{dF(y)}{F(x)}, \quad q_L^{en}(y) = \arg\max_q \int_y^c \pi_j(q, q_W^{en}(x); c) \frac{dF(x)}{1-F(y)}.$$

This yields:

$$q_W^{en}(x) = \frac{(1+s)((a-c)(32-16s-2s^2+s^3)+4cs^2+2ds^2+(32-8s^2)x)}{b(16-s^2)(4-s^2)}$$
$$q_L^{en}(y) = \frac{(1+s)((a-c)(32-16s-2s^2+s^3)-8cs-ds^3-2s(4-s^2)y)}{b(16-s^2)(4-s^2)}.$$

Again, suppose one firm, say firm 1, with cost reduction x, unilaterally deviated from equilibrium and bid $\beta_n^C(z)$ rather than $\beta_n^C(x)$ and won the auction, it plays its best reply to the predicted strategy of firm 2, $q_L^{en}(y)$:

$$q_W^n(x,z) = \arg\max_q \int_d^z \pi_1(q, q_L^{en}(y); c-x) \frac{dF(y)}{F(z)}.$$

This yields:

$$q_W^n(x,z)=\frac{(1+s)(2(a-c)(32-16s-2s^2+s^3)+4(2c+d)s^2+(64-20s^2+s^4)x+s^2(4-s^2)z)}{2b(16-s^2)(4-s^2)}.$$

Note that $q_W^n(x,z)$ is increasing in x and z.

Whereas if firm 1 lost, it plays $q_L^n(z)=q_L^{en}(z)$, which is decreasing in z, and firm 2 plays $q_W^{en}(y)$.

Altogether, the reduced form profit functions of firm 1, contingent upon winning/losing, are:

$$\begin{aligned}\pi_W^n(x,z)&=\int_d^z \pi_1(q_W^n(x,z),q_L^{en}(y);c-x)\frac{dF(y)}{F(z)}=\frac{b}{1+s}q_W^n(x,z)^2\\ \pi_L^n(z)&=\int_z^c \pi_1(q_L^{en}(z),q_W^{en}(y);c)\frac{dF(y)}{1-F(z)}=\frac{b}{1+s}q_L^{en}(z)^2.\end{aligned}$$

$\Pi_n(x,z)$ is pseudo-concave in z:

$$\begin{aligned}\partial_{zx}\Pi_n(x,z)=&\frac{1+s}{2b(c-d)(64-20s^2+s^4)}\Big(2(a-c)(32-16s-2s^2+s^3)\\ &+(64-20s^2+s^4)x+(8c+ds^2)s^2+2s^2(4-s^2)z\Big)>0.\end{aligned}$$

Using $\pi_W^n(x,z),\pi_L^n(z)$, (13) and (3), the coefficients of the quadratic β_n^C function are:

$$\begin{aligned}\mu^n&=\frac{1+s}{6b(16-s^2)^2(4-s^2)}>0\\ \lambda_0^n&=3(a-c)(512d-160ds^2+16ds^3+10ds^4-ds^5)+8d^2(64-20s^2+s^4)\\ &\quad+12as^2(2c(16-s^2)+d(8-s^2))-24c^2s^2(12-s^2)\\ &>\frac{1}{2-s}\Big(8d^2(16-s^2)(2-s)^2(2+s)+24c^2s^2(8+12s-s^3)\\ &\quad+3cds(512+64s-160s^2+8s^3+10s^4-s^5)\Big)>0\\ \lambda_1^n&=2d(256-80s^2+7s^4)+3(a-c)(512-160s^2-16s^3+10s^4+s^5)\\ &\quad+12as^2(8-s^2)>0\\ \lambda_2^n&=8(64-20s^2+s^4)>0.\end{aligned}$$

Obviously, the assumed monotonicity and non-negativity of equilibrium bids confirm.

A.3 Payoff rankings

The innovator's expected revenue is $R=E(\beta(X_{(1:2)})=\int_d^c\beta(x)dF(x)^2$, and one finds:

$$\begin{aligned}R_n^B-R_p^B&=\frac{(c-d)s^3}{96b(1-s)(64-20s^2+s^4)^2}\Big(192a(16-s^2)(1-s)(2+s)\\ &\quad+(c-d)s(1600-204s^2+5s^4)-c(6144-3456s^2+192s^4)\Big)\\ &>\frac{(c-d)^2s^4(1600-204s^2+5s^4)}{96b(1-s)(64-20s^2+s^4)^2}>0,\quad\text{by (3)}\\ R_p^B-R_f^B&=\frac{(c-d)^2s^2(28-5s^2)}{96b(1-s)(4-s^2)^2}>0\end{aligned}$$

$$
\begin{aligned}
R_f^C - R_p^C &= \frac{(c-d)^2 s^2 (1+s)(4-3s^2)}{96b(4-s^2)^2} > 0 \\
R_n^C - R_f^C &= \frac{(c-d)s^2(1+s)}{6b(64-20s^2+s^4)^2}\Big(12a(16-s^2)(2-s)s + d(64-124s^2+9s^4) \\
&\quad - c(64+384s-124s^2-24s^3+9s^4)\Big) \gtreqless 0 \iff c \lesseqgtr \varphi(a,d,s) \\
R_f^C - R_f^B &= \frac{(c-d)s^2(2a(1-s)(4+(2-s)s) - c(2-s)(2-s-2s^2) + d(4-3s^2))}{6b(1-s)(4-s^2)^2} \\
&> \frac{d(2-s)(4-3s^2) + c(2((2-s^2)^2-s^3)+4s-2s^2-s^3)}{2-s} > 0, \quad \text{by (3)} \\
R_p^C - R_p^B &= \frac{(c-d)s^2}{96b(1-s)(4-s^2)^2}\Big(32a(1-s)(4+(2-s)s) + 3d(32-20s^2+s^4) \\
&\quad - c(96-64s-60s^2+32s^3+3s^4)\Big) \\
&> \frac{(c-d)s^2}{96b(1-s)(4-s^2)^2(2+s)}\Big(3d(64+32s-40s^2-20s^3+2s^4+s^5) \\
&\quad + c(64+160s-8s^2-68s^3-6s^4-3s^5)\Big) > 0, \quad \text{by (3)} \\
R_n^C - R_n^B &= \frac{(c-d)s^2}{3b(1-s)(16-s^2)^2(4-s^2)}\Big(2d(96-46s^2+3s^4) \\
&\quad + a(16-s^2)(1-s)(16+8s-s^2) - c(192-128s-92s^2+24s^3+6s^4-s^5)\Big) \\
&> \frac{(c-d)s^2}{3b(1-s)(16-s^2)^2(4-s^2)(2+s)}\Big(2d(2+s)(96-46s^2+3s^4) \\
&\quad + 2c(64+160s-4s^2-50s^3-s^4+2s^5)\Big) > 0, \quad \text{by (3)}\,.
\end{aligned}
$$

Under Bertrand competition the surplus to be shared by firms and the innovator, T, and consumer surplus, CS, are equal to:

$$
\begin{aligned}
T_k^B &= \int_d^c \frac{1}{b(1-s)}\left((p_W^{ek}(x)-c+x)^2 + (p_L^{ek}(x)-c)^2\right)2F(x)dF(x), \quad k\in\{f,p,n\} \\
CS_k^B &= \int_d^c \Big(U(Q_1^k,Q_2^k) - p_W^{ek}(x)Q_1^f - p_L^{ek}(x)Q_2^k\Big)2F(x)dF(x), \quad k\in\{f,p,n\}\,.
\end{aligned}
$$

There, $Q_i^k = Q_i(p_i,p_j), p_1 = p_W^{ek}(x), p_2 = p_L^{ek}(x), k\in\{f,p,n\}$. The Cournot case is similar and hence omitted. We find:

$$
\begin{aligned}
T_f^B - T_p^B &= \frac{(c-d)^2 s^2(4-3s^2)}{96b(1-s)(4-s^2)^2} > 0,\ T_p^B - T_n^B = \frac{(c-d)^2 s^4(64+20s^2-3s^4)}{96b(1-s)(64-20s^2+s^4)^2} > 0 \\
T_f^C - T_p^C &= \frac{(c-d)^2 s^2(1+s)(12-s^2)}{96b(4-s^2)^2} > 0,\ T_p^C - T_n^C = \frac{(c-d)^2 s^4(1+s)(320-60s^2+s^4)}{96b(64-20s^2+s^4)^2} > 0 \\
CS_n^B - CS_p^B &= \frac{(c-d)^2 s^4(192-20s^2-s^4)}{192b(1-s)(64-20s^2+s^4)^2} > 0,\ CS_p^B - CS_f^B = \frac{(c-d)^2 s^2(4+s^2)}{192b(1-s)(4-s^2)^2} > 0 \\
CS_n^C - CS_p^C &= \frac{(c-d)^2 s^4(1+s)(192-20s^2-s^4)}{192b(64-20s^2+s^4)^2} > 0,\ CS_p^C - CS_f^C = \frac{(c-d)^2 s^2(1+s)(4+s^2)}{192b(4-s^2)^2} > 0.
\end{aligned}
$$

A.4 Supplement to conditional disclosure

Here we spell out the parts of the analysis that were not stated in Section 7, without explaining the full construction that is similar to the previous analysis.

The "auxiliary" bid functions are:

$$\beta_n(x) = \mu^n \left(\lambda_0^n + \lambda_1^n x + \lambda_2^n x^2\right)$$

$$\mu^n = \frac{1+s}{6b(16-s^2)^2(4-s^2)}$$

$$\lambda_0^n = 3(a-c)(16-s^2)((6s^2-s^3-32)d-8s^2t) - 8d^2(64-20s^2+s^4) \\ -12ds^2(8-s^2)t - 96s^2t^2$$

$$\lambda_1^n = 2s^2(d(80-7s^2)-6(8-s^2)t) - 3(a-c)(16-s^2)(2-s)(4+s)^2 - 512d$$

$$\lambda_2^n = -8(64-20s^2+s^4)$$

$$\beta_f(x) = \beta_f(t)\frac{t-d}{x-d} + \frac{(1+s)(x-t)}{6b(4-s^2)^2(x-d)}\left(\lambda_0^f + \lambda_1^f x + \lambda_2^f x^2\right)$$

$$\beta_f(t) = \frac{1+s}{6b(64-20s^2+s^4)^2}\left(\tau_0 + \tau_1 t + \tau_2 t^2\right)$$

$$\tau_0 = 8d^2(256-144s^2+21s^4-s^6) + 3(a-c)d(16-s^2)(2-s)(64+32s-20s^2-4s^3+s^4)$$

$$\tau_1 = 2d(1024-768s^2+84s^4-s^6) + 3(a-c)(16-s^2)(2-s)(64+32s+12s^2-s^4)$$

$$\tau_2 = 4(512+96s^2-30s^4+s^6)$$

$$\lambda_0^f = 3(a-c)((8-s^3)t-2d(2-s)s^2) - 6ds^2t + 2(4+s^2)t^2$$

$$\lambda_1^f = 3(a-c)(8-s^3) + 8t - 2s^2(3d-t)$$

$$\lambda_2^f = 2(4+s^2).$$

The functions $\Pi_n(x,z)$, $\Pi_f(x,z)$ have the properties:

$$\partial_{zx}\Pi_n(x,z) = \frac{1+s}{2b(c-d)(64-20s^2+s^4)}\Big(ds^4 + 2(a-c)(2-s)(16-s^2) + 8s^2t \\ +(64-20s^2+s^4)x + 2s^2(4-s^2)z\Big) > 0$$

$$\partial_{zx}\Pi_f(x,z) = \frac{(1+s)(2(a-c)(2-s) - ds^2 + (4-s^2)x + 2s^2z)}{2b(c-d)(4-s^2)} > 0$$

$$\Pi_f(x,z) - \Pi_n(x,z) = \frac{2s^2(1+s)(d-t)^2(x-t)}{b(c-d)(64-20s^2+s^4)}.$$

The innovator's expected revenue function is $R(t) = \mu_R\left(\alpha_0 + \alpha_1 t + \alpha_2 t^2 + \alpha_3 t^3 + \alpha_4 t^4\right)$, where α_0 is a constant and

$$\mu_R = \frac{1+s}{6b(c-d)^2(64-20s^2+s^4)^2}$$

$$\alpha_1 = 4ds^2(6(c^2-a(c-d))(16-s^2)(2-s)s + 4d^2(32-15s^2+s^4) \\ +3cd(64-s(64-(4-s)s(8+3s))))$$

$$\alpha_2 = -6s^2((2-s)((16-s^2)(2c^2s+2asd) + 2c(32d-16as+(a+d)s^3)) + (16-s^2)(12-s^2)d^2)$$

$$\alpha_3 = 4s^2(64(c+4d) - 4(8c+7d)s^2 + cs^4)$$

$$\alpha_4 = -s^2(320-60s^2+s^4).$$

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