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2021

April 2021

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CESifo

Impressum:

CESifo Working Papers
ISSN 2364-1428 (electronic version)
Publisher and distributor: Munich Society for the Promotion of Economic Research - CESifo GmbH
The international platform of Ludwigs-Maximilians University's Center for Economic Studies and the ifo Institute
Poschingerstr. 5, 81679 Munich, Germany
Telephone +49 (0)89 2180-2740, Telefax +49 (0)89 2180-17845, email office@cesifo.de
Editor: Clemens Fuest
https://www.cesifo.org/en/wp
An electronic version of the paper may be downloaded
· from the SSRN website: www.SSRN.com
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CESifo *Working Paper No. 9021*

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Abstract

We analyze strategic leaks due to spying out a rival's bid in a first-price auction. Such leaks induce sequential bidding, complicated by the fact that the spy may be a counterspy who serves the interests of the spied at bidder and reports strategically distorted information. This ambiguity about the type of spy gives rise to a non-standard signaling problem where both sender and receiver of messages have private information and the sender has a chance to make an unobserved move. Whereas spying without counterspy exclusively benefits the spying bidder, the potential presence of a counterspy yields a collusive outcome, even if the likelihood that the spy is a counterspy is arbitrarily small. That collusive impact shows up in all equilibria and is strongest in the unique pooling equilibrium which is also the payoff dominant equilibrium.

JEL-Codes: L120, L130, L410, D430, D440, D820.

Keywords: auctions, tacit collusion, espionage, second-mover advantage, signaling, incomplete information.

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April 12, 2021

Strategic leaks in first-price auctions and tacit collusion: The case of spying and counter-spying*

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1 Introduction

In a competitive environment, spying on rivals' operational information, such as pricing or bidding, is a perennial concern. The incentive for spying is particularly strong in a first-price auction where the winner-takes-all and the winner has to pay his bid, which drives bidders to strategically shade their bids. Generally such bid shading leads to *ex post* regret, either because the winner could have lowered his bid and yet won or some loser could have raised his bid and won while making a positive profit, which could have been avoided if he had known rivals' bids.[1]

*Research support by the Humanities and Social Sciences Research Foundation of the Ministry of Education of China (Grant:19YJA790009) and Korea University (Grant: K1613601) is gratefully acknowledged. We also thank seminar participants at the Universidad de Los Andes (Buenos Aires) and the Academia Sinica (Taipei) for comments and suggestions.

[1]First-price auctions are predominant in procurement. Of course, there a bid is a requested payment and instead of shading their bid, bidders inflate their bids above cost, which is why one also refers to procurement auctions as "reverse auctions".

Although spying is intrinsically a secret operation and bidders often take precautions to control leaks,[2] evidence of spying has surfaced on numerous occasions. For example, bidding for the construction of a new metropolitan airport in Berlin was reopened after investigators found out that *Hochtief AG*, the winner of the auction, had illegally acquired the application documents of the rival bidder *IVG*. Similarly, in 1996 *Siemens AG* was excluded from all public procurements in Singapore for a period of five years after the authorities determined that Siemens had acquired information about rival bids for a major power station construction project.[3]

Circumstantial evidence of bid leakage abounds. Andreyanov, Davidson, and Korovkin (2017) observed that in first-price procurement auctions a bidder is likely to have observed leaked bids if that bidder bid last, close to the deadline, and if, conditional on winning, his bid was close to the runner-up. Based on this pattern they suspect widespread bid leakage in at least 10% of a large sample of 4.3 million procurement auctions that took place in Russia between 2011 and 2016. Using weaker indicators and more sophisticated techniques, Ivanov and Nesterov (2020) confirmed these findings based on another data set of 600,000 Russian procurement auctions that took place between 2014 and 2018 and estimated that the outcome was influenced by leaked bids in around 9% of these auctions.

Commonly the spy who leaks a rival's bid is a "mole" or trusted insider who is driven by financial motives, or takes revenge for unfair treatment as an employee, or because he has been blackmailed into handing over sensitive information. Often, as gullible staff member is lured into passing over inconsequential information and, after having committed a minor offense, is blackmailed into leaking sensitive information. However, the spy may also be a corrupt agent auctioneer who has access to early bids or, for that matter, a "malware tool" that exploits vulnerabilities in computer software to transmit prospective or actual bids prepared on a PC or submitted online.

The techniques used by spies range from low-key activities such as searching through wastebaskets, known as "dumpster diving", gaining access to unattended PCs and laptops, planting sophisticated malware that is able to secretly switch on cameras or recording devices of computers and mobile phones, to participation in the bid preparation by a mole. After the end of the cold war, it has been observed that many underemployed but well-trained spies redirected their activities from military to economic espionage.

Spying is intrinsically coupled with counter-spying. It is not uncommon that a spy actually serves the alleged spied at party and "leaks" strategically distorted information. Alternatively, when the identity of a spy has been exposed, the spy often finds himself between "Scylla and Charybdis", faced with the agonizing choice between either punishment or being "doubled", and, after being doubled, serves the spied at party by leaking distorted information.

Examples of counter-spying abound in military history. A prominent example is that of the Serbian national Duško Popov who enlisted in Germany's military intelligence service during WWII to spy on the British military but actually fed the German "Abwehr" with disinformation in the service of the British "MI6" (see Popov, 1974; Loftis, 2016).

Similarly, counter-spying has surfaced in economic espionage. A prominent example is that of the Swiss national Paul Soupert, who enlisted in the service of the East German economic espionage ring known as "Operation Brunnhilde" but was actually doubled and spread strategically distorted information. The latter case became known after East Germany collapsed and subsequently East

[2]In high profile auctions, such as spectrum auctions, bidders typically set up a high security "war room" in a secret location, carefully screen their staff and external advisors, and make them sign stiff secrecy agreements.

[3]These and further examples are documented in Lengwiler and Wolfstetter (2010).

German spying activities were publicly scrutinized (see Wright, 1987). A comprehensive survey of cases that exemplify different kinds and techniques of economic espionage and counter-espionage is in Nasheri (2005) and Andrew (2019).

In the theoretical literature, spying on rivals' bids has been thoroughly analyzed in the context of corruption, where a dishonest agent auctioneer either allows a predetermined favored bidder to adjust his bid after reporting rivals' bids to him (as, for example, in Burguet and Perry, 2007; Arozamena and Weinschelbaum, 2009) or flexibly seeks a deal with the bidder who gains the most by either lowering or increasing his bid (as in Lengwiler and Wolfstetter, 2010).[4]

Recently, Fischer, Güth, Kaplan, and Zultan (2021) compared the effects of spying in first- and second-price auctions, using the same framework as in Arozamena and Weinschelbaum (2009), where a corrupt auctioneer leaks a rival's bid to a favored bidder. However, while Arozamena and Weinschelbaum (2009) consider only a first-price auction, and show that leaked information does not affect the behavior of the spied at bidder, the main focus of Fischer, Güth, Kaplan, and Zultan (2021) is the role of behavioral assumptions in second-price auctions and their testing in a controlled lab experiment.[5]

Of course, spying in second-price auctions can only make a difference if bidders do not play the weakly dominant strategy of truthful bidding and instead engage in spiteful bidding or abstain from bidding if they see no chance to win. Interestingly, in their experiments spiteful bidding plays a significant role.[6] However, one wonders whether this would also be observed if the experiment were designed in such a way that the leaked information is subject to noise or if there were a chance that the spy strategically reports disinformation, in which case spiteful bidders were at risk of suffering losses.

One limitation of the existing literature is the implicit assumption that the spy faithfully reports the bid of the spied at bidder. This is where the present paper steps in. The distinct feature of our analysis is that we take into account that the spy may be counterspy who serves the interests of the spying bidder and reports strategically distorted information. Therefore, the bidder who receives the spy's report cannot be sure that the leaked bid is actually the true submitted bid. Naturally, the spy hides his type and the reported bid is only an imperfect signal of the type of spy and the spied at bidder's value. This gives rise to a peculiar signaling problem where the sender of messages has a chance to take another action with some probability.

The resulting game admits a unique pooling equilibrium and multiple partially separating equilibria. Remarkably, whereas spying without counterspy exclusively benefits the spying bidder, the potential presence of a counterspy yields a collusive outcome, even if the likelihood that the spy is a counterspy is arbitrarily small. That collusive impact shows up in all equilibria and is strongest in the unique pooling equilibrium which happens to be the payoff dominant equilibrium.

Finally, we mention that the analysis of spying on bids is complementary to the large literature on the disclosure of bidders' valuations or signals to some or all bidders, pioneered by Vickrey (1961, pp. 17-20 and Appendix III), Milgrom and Weber (1982), Engelbrecht-Wiggans, Milgrom, and Weber (1983), and Persico (2000). Among the more recent contributions we mention Kim

[4] If the spread between the two highest bids is sufficiently large, it is most profitable to let the highest bidder match the second highest bid, whereas if that spread is sufficiently small, due to bid shading, it is most profitable to let the second highest bidder match the highest bid.

[5] Second-price auctions have a continuum of equilibria other than truthful bidding (see Plum, 1992; Blume and Heidhues, 2004) which are however generally not trembling hand perfect.

[6] If a bidder observes a leaked bid that exceeds his own valuation, he engages in "spiteful bidding" if he bids close to the observed bid with the sole purpose to hurt a rival bidder.

(2008) and Jun, Wolfstetter, and Zamir (2020) who show, in different frameworks, how observing a rival bidder's valuation or signal may have negative value, and the analysis of bid disclosure in license auctions with downstream interaction by Fan, Jun, and Wolfstetter (2016) and in sequential first-price auctions by Bergemann and Hörner (2018).

The plan of the paper is as follows: In Section 2 we state the model. Section 3 summarizes two benchmark games: the game without spy and the game with spy but without counterspy. In Section 4 we solve the game with (counter-)spy and fully characterize the unique pooling and the multiple partially separating equilibria. Section 5 summarizes the collusive impact of spying and counter-spying on bidders' and the seller's payoffs. In Section 6 we check robustness and explain why both kinds of equilibria satisfy the intuitive criterion and are not driven by unreasonable off-equilibrium beliefs. The paper closes in Section 7 with a discussion.

2 Model

Consider a first-price sealed-bid auction with two risk neutral bidders, 1 and 2. Bidders have binary private values, $V_1, V_2 \in \{0, v\}, v > 0$, that are independently drawn with positive probabilities less than one.

Bidder 2 has access to the service of a spy who observes the bid submitted by bidder 1, b_1, and sends a message about b_1 to bidder 2 before the latter submits his own bid, b_2.

The presence of the spy induces a sequential moves game and confers bidder 2 a second-mover advantage. The spy may, however, be a counterspy who serves the interests of bidder 1 and reports strategically distorted information while bidder 1 has the chance to submit a bid other than the reported bid. Therefore, when bidder 2 receives the spy's message he does not know whether that message is accurate or distorted information.

The presence of the spy and potential presence of a counterspy are common knowledge, but bidder 1 does not know the identity of the spy unless the spy is a counterspy.

We refer to bidder 1 with spy but without counterspy as type n (mnemonic for "no" counterspy) and with spy *and* counterspy as type c, and to bidders with value v as type h and value zero as type ℓ (mnemonic for "high" and "low"). Therefore, the type set of bidder 1 is $T_1 = \{n\ell, nh, c\ell, ch\}$ and that of bidder 2 is $T_2 = \{\ell, h\}$.

The time-line is as follows:

1. Nature independently draws bidders' types, $(t_1, t_2) \in T_1 \times T_2$, and each bidder privately observes his own type.
2. Bidder 1 submits his bid and bidder 1 type c instructs the spy what bid to report to bidder 2.
3. The spy reports the bid of bidder 1 to bidder 2 (either as instructed if bidder 1 is type c or the true bid if bidder 1 is type n).
4. Bidder 2 submits his bid and payoffs are realized according to the rules of a first-price auction.

Bidders' prior probability of drawing the high value, v, is equal to $\theta \in (0,1)$ and that of the spy being a counterspy is $\mu \in (0,1)$. Value V_1 and type of spy are stochastically independent and the prior probabilities of T_1 are $(\Pr\{ch\}, \Pr\{c\ell\}) = \mu(\theta, 1-\theta)$, $(\Pr\{nh\}, \Pr\{n\ell\}) = (1-\mu)(\theta, 1-\theta)$.

As in other discontinuous games we need to invoke a particular tie-breaking or sharing rule to assure existence of equilibrium. Simon and Zame (1990, p. 861) argue convincingly that " ... payoffs should be viewed as only partially determined, and that whenever the economic nature of the problem leads to indeterminacies, the sharing rule should be determined *endogenously*, i.e., as part of the *solution* to the model rather than as part of the *description* of the model."

We follow this advice and apply the following type-dependent tie-breaking rule:[7]

Tie-breaking rule (R): *In the event of a tie the item is awarded to the bidder with the higher value and, if this fails to break the tie, the item is awarded to bidder 2.*

We denote bids (actions) by the letters b_i, pure bidding strategies that map bidders' values into bids by the functions β_i, and mixed bidding strategies that prescribe a *c.d.f.* of bids by the functions F_i.

3 Benchmark games without counterspy

We first consider two benchmark games: the standard auction game without spy (game A), followed by the game with spy but without counterspy (game S).

3.1 Benchmark game without spy (A)

The benchmark bidding game without spy is a symmetric simultaneous moves game with the reduced type sets $T_1 = T_2 = \{\ell, h\}$. It has a unique symmetric equilibrium: bidders type ℓ bid zero and bidders type h play the mixed bidding strategy $F(b)$ (see Maskin and Riley, 1985, Sect. I):

$$\beta(0) = 0; \quad F(b) = \frac{(1-\theta)b}{\theta(v-b)}, \quad b \in [0, b^*],\ b^* := \theta v. \tag{1}$$

The equilibrium outcome is efficient and bidders' *ex ante* expected equilibrium payoffs, Π_i^A and the seller's expected revenue, Π_0^A, are:

$$\Pi_i^A = \theta(1-\theta)v, \quad i \in \{1,2\} \tag{2}$$

$$\Pi_0^A = v\left(1-(1-\theta)^2\right) - 2\Pi_i^A = \theta^2 v. \tag{3}$$

3.2 Benchmark game with spy but without counterspy (S)

The benchmark game with spy but without counterspy is a sequential game with the reduced type sets $T_1 = \{n\ell, nh\}$, $T_2 = \{\ell, h\}$. The perfect equilibrium of that bidding game is: bidder 1 bids zero, regardless of his type; bidder 2 type ℓ also bids zero and bidder 2 type h matches the bid of bidder 1 (but does not bid more than v):

$$\beta_1(v) = \beta_1(0) = \beta_2(0) = 0, \quad \beta_2(v, b_1) = \min\{v, b_1\}. \tag{4}$$

In equilibrium bidder 1 wins if and only if $V_1 = v$ and $V_2 = 0$; otherwise, bidder 2 wins. In either case, the highest bid is equal to zero, the equilibrium outcome is efficient, and the seller earns no revenue. Therefore,

Proposition 1. *The equilibrium outcome of game S exhibits a strong second-mover advantage; the spying bidder 2 fully extracts the seller's payoff,* Π_0^S*, while the payoff of the spied at bidder 1,* Π_1^S*, is not affected by spying:*

$$\Pi_2^S = \left(\theta(1-\theta)+\theta^2\right)v = \Pi_2^A + \Pi_0^A, \quad \Pi_0^S = 0, \quad \Pi_1^S = \theta(1-\theta)v = \Pi_1^A. \tag{5}$$

[7] This rule can easily be implemented without knowing bidders' valuations.

Only the spying bidder 2 gains; therefore, spying without counter-spying does not yield a collusive outcome for which all *bidders would have to gain, at the expense of the seller.*

4 The game with counterspy (C)

The bidding game is more intricate if the spy may be a counterspy who serves the interests of the spied at bidder 1 and reports strategically distorted information. In that case bidder 2 cannot be sure that the bid reported by the spy, denoted by b^r, is actually the bid submitted by bidder 1. Naturally, the counterspy hides his type and the reported bid is only an imperfect signal of the type of spy and the spied at bidder's value.

We indicate the reporting strategy of bidder 1 type c, which describes what that bidder instructs the spy to report to bidder 2, by $\beta^r(V_1)$ and denote posterior beliefs concerning the type of firm 1 by $\Pr\{t_1|b^r\}$, $t_1 \in T_1$.

The potential presence of a counterspy induces a non-standard signaling game. It admits pooling and partially separating perfect equilibria.

4.1 Pooling equilibrium

In the *pooling* equilibrium the bids of bidder 1 type n are not type dependent, and the reporting strategy of bidder 1 type c mimics the bid strategy of type n; consequently, in equilibrium the bid reported by the spy is completely uninformative.

Applying the concept of a perfect equilibrium we obtain the following pooling equilibrium:

Proposition 2 (Pooling equilibrium)**.**
There is a unique pooling equilibrium.
Bidder 1: *type n bids zero:* $\beta_1^n(0) = \beta_1^n(v) = 0$*. Type c mimics n and reports a zero bid:* $\beta^r(v) = \beta^r(0) = 0$*; type* $c\ell$ *bids zero and type* ch *plays the mixed bidding strategy:*

$$F_1(b) = \frac{(1-\theta\mu)b}{\theta\mu(v-b)}, \quad b \in [0,\bar{b}],\ \bar{b} := \mu\theta v. \tag{6}$$

Bidder 2: *type* ℓ *bids zero and type h plays the mixed bidding strategy:*

$$F_2(b) = \begin{cases} \frac{(1-\theta)b+(1-\mu)\theta v}{\theta(v-b)}, b \in [0,\bar{b}], & \text{if he observed } b^r = 0 \\ F(b) \quad \text{if he observed } b^r > 0, \end{cases} \tag{7}$$

where $F(b)$ *is the equilibrium strategy of benchmark game A stated in equation* (1).

Posterior beliefs: *If the spy reported* $b^r = 0$ *prior beliefs are confirmed:* $\Pr\{t_1|b^r\} = \Pr\{t_1\}$ *for all* $t_1 \in T_1$*; if he reported an off-equilibrium bid,* $b^r > 0$*, bidder 1 is believed to be type c and* $\Pr\{ch|b^r\} = \theta$*,* $\Pr\{c\ell|b^r\} = 1-\theta$*.*

Proof. 1) It is obvious that a bidder type ℓ must bid zero and that the supports of the mixed strategies F_1, F_2 must be the same.

2) Consider bidder 2 type h. We confirm that the asserted equilibrium strategy is a best response to the other players' equilibrium strategies, for all observed bids, b^r, on and off the equilibrium path.

If he observed $b^r = 0$ (which implies that prior beliefs are confirmed), he is indifferent between all bids $b \in [0, \bar{b}]$ because his payoff, π_2^h, is equal to:

$$\pi_2^h = (1 - \mu + \mu(1 - \theta + \theta F_1(b)))(v - b) = (1 - \theta\mu)v, \quad \forall b \in [0, \bar{b}]. \tag{8}$$

Bidding more than $\bar{b}$ is dominated by bidding $\bar{b}$. Therefore, if he observed $b^r = 0$, all mixed strategies with support $[0, \bar{b}]$, and in particular $F_2(b)$, are best replies to the other players' profile of equilibrium strategies.

If bidder 2 type h observed an off-equilibrium bid $b^r > 0$, he believes that bidder 1 is type c. Therefore he ignores the reported bid and concludes that he plays the benchmark game A. In that case it is optimal for him to play the mixed strategy $F(b)$.

3) Consider bidder 1 type nh. If he bids $b = 0$, as advised by his equilibrium strategy, his payoff is

$$\pi_1^{nh} = (1 - \theta)v. \tag{9}$$

If he deviates and bids $b > 0$, his payoff is at most equal to that in the equilibrium of benchmark game A, $(1 - \theta)v$, which is not an improvement.

4) Consider bidder 1 type ch. If he plays the asserted equilibrium strategy and reports $b^r = 0$, for all bids $b \in [0, \bar{b}]$ his payoff is equal to:

$$\pi_1^{ch} = (1 - \theta + \theta F_2(b))(v - b) = (1 - \theta\mu)v, \quad \forall b \in [0, \bar{b}]. \tag{10}$$

Therefore, he is indifferent between all probability distribution of bids with support $[0, \bar{b}]$.

Bidding more than $\bar{b}$ is dominated by bidding $\bar{b}$.

He may deviate and report an off-equilibrium bid $b^r > 0$. In that case, bidder 2 assumes that he is type c and plays the equilibrium strategy of benchmark game A. In that case, his payoff is at most equal to his equilibrium payoff in the benchmark game A, which is equal to $(1 - \theta)v$ and hence lower than π_1^{ch}.

Therefore, the asserted equilibrium strategy $(b^r = 0, F_1(b))$ is a best reply to the profile of the other players' equilibrium strategy.

5) The equilibrium is unique, because the game admits no equilibrium in pure strategies and there exists no other pair of mixed strategies, F_1, F_2, that satisfies all indifference requirements for an equilibrium in mixed strategy. □

The resulting *ex ante* expected equilibrium payoffs, $\left(\Pi_1^P, \Pi_2^P, \Pi_0^P\right)$ are (there, P is mnemonic for "pooling equilibrium"):

$$\Pi_1^P = \theta\left(\mu\pi_1^{ch} + (1 - \mu)\pi_1^{nh}\right) = (1 - \theta + \theta\mu(1 - \mu))\,\theta v \tag{11}$$

$$\Pi_2^P = \theta\pi_2^h = \theta\,(1 - \theta\mu)\,v \tag{12}$$

$$\Pi_0^P = \left(1 - (1 - \theta)^2\right)v - \Pi_1^P - \Pi_2^P = \theta^2\mu^2 v. \tag{13}$$

They relate to those in benchmark games A and S as follows:

$$\Pi_1^P > \Pi_1^S = \Pi_1^A, \quad \Pi_2^S > \Pi_2^P > \Pi_2^A, \quad \Pi_0^S < \Pi_0^P < \Pi_0^A. \tag{14}$$

We conclude: *In the unique pooling equilibrium the potential presence of a counterspy gives rise to a collusive outcome where spying and spied at bidders mutually benefit from spying at the expense of the seller. Unlike in the case of spying without potential counterspy, spying and spied at bidders enjoy a symbiotic relationship and have common interest to maintain spying.*

4.2 Partially separating equilibria

While the game admits no fully separating equilibrium, it has, however, equilibria where the bid reported by the spy conveys some information that allows updating of prior beliefs on the equilibrium path of the game. We now confirm that such equilibria exist and characterize the family of partially separating equilibria.

Proposition 3 (Partially separating equilibria)**.**
Bidder 1: *type $n\ell$ bids $b=0$ and type nh bids $b=b^*$ with probability q and $b=0$ otherwise; type $c\ell$ reports $b^r=b^*$ and bids $b=0$; type ch reports $b^r=b^*$ with probability ρ and $b^r=0$ otherwise, and plays the mixed bidding strategy $F_1(b)$ with support $[0,\bar{b}]$:*

$$q\in(0,\bar{q}], \quad \bar{q}:=\frac{1-\sqrt{1-4\theta\mu(1-\mu)}}{2\theta(1-\mu)}, \quad \rho=\frac{(1-\theta)\mu}{1-\theta\big(q+\mu(1-q)\big)} \tag{15}$$

$$F_1(b)=\frac{1-\theta\,(\mu+q(1-\mu))}{\theta\mu}\frac{b}{v-b}, \quad \bar{b}:=\frac{\theta\mu v}{1-\theta q(1-\mu)}<b^*. \tag{16}$$

Bidder 2: *type ℓ bids zero and type h plays the mixed bidding strategy $F_2(b)$ with support $[0,\bar{b}]$:*

$$F_2(b)=F_2(0)+\frac{1-\theta(\mu+q(1-\mu))}{\theta(1-q\theta(1-\mu))}\frac{b}{v-b}, \quad F_2(0)=\frac{(1-q\theta)(1-\mu)}{1-q\theta(1-\mu)}>0, \tag{17}$$

if the spy reported $b^r\in\{0,b^*\}$ and the equilibrium strategy of benchmark game A, $F(b)$, if the spy reported an off-equilibrium bid, $b^r\notin\{0,b^*\}$.

Posterior Beliefs: *See Table 1.*

	$b^r=0$	$b^r=b^*$	$b^r\notin\{0,b^*\}$
$\Pr\{n\ell \vert b^r\}$	$\frac{(1-\mu)(1-\theta)}{\Pr\{b^r\}}=\frac{(1-\theta)(1-q\theta(1-\mu)-\theta\mu)}{(1-q\theta)(1-q\theta(1-\mu))}$	0	0
$\Pr\{nh \vert b^r\}$	$\frac{(1-\mu)\theta(1-q)}{\Pr\{b^r\}}=\frac{(1-q)\theta(1-q\theta(1-\mu)-\theta\mu)}{(1-q\theta)(1-q\theta(1-\mu))}$	$\frac{(1-\mu)\theta q}{\Pr\{b^r\}}=\frac{q\theta(1-\mu)(1-q\theta(1-\mu)-\theta\mu)}{\mu+\theta(q(1-q\theta)(1-\mu)^2-\mu)}$	0
$\Pr\{c\ell \vert b^r\}$	0	$\frac{\mu(1-\theta)}{\Pr\{b^r\}}=\frac{(1-\theta)\mu(1-q\theta(1-\mu)-\theta\mu)}{\mu+\theta(q(1-q\theta)(1-\mu)^2-\mu)}$	$1-\theta$
$\Pr\{ch \vert b^r\}$	$\frac{\mu\theta(1-\rho)}{\Pr\{b^r\}}=\frac{\theta\mu}{1-q\theta(1-\mu)}$	$\frac{\mu\theta\rho}{\Pr\{b^r\}}=\frac{(1-\theta)\theta\mu^2}{\mu+\theta(q(1-q\theta)(1-\mu)^2-\mu)}$	θ
$\Pr\{b^r\}$	$(1-\mu)(1-\theta+\theta(1-q))+\mu\theta(1-\rho)$	$(1-\mu)\theta q+\mu(1-\theta+\theta\rho)$	0

Table 1: Posterior beliefs

Proof. 1) It is obvious that bidders with a value $V=0$ must bid zero and that the supports of the mixed strategies $F_1(b),F_2(b)$ must be the same.

2) Consider bidder 2 type h. We confirm that his asserted equilibrium strategy is indeed optimal for all observed bids, b^r, on and off the equilibrium path.

If bidder 2 type h observed $b^r\in\{0,b^*\}$ he is indifferent between all bids $b\in[0,\bar{b}]$, because his payoffs, denoted by $\pi_2^h(b\mid b^r)$, are equal to:[8]

$$\pi_2^h(b|0)=\big(\Pr\{n|0\}+\Pr\{c\ell|0\}+\Pr\{ch|0\}F_1(b)\big)(v-b)=\frac{v\,(1-q\theta(1-\mu)-\theta\mu)}{1-q\theta(1-\mu)} \tag{18}$$

$$\pi_2^h(b|b^*)=\left(\Pr\{c\ell|b^*\}+\Pr\{ch|b^*\}F_1(b)\right)(v-b)=\frac{v(1-\theta)\mu(1-q\theta(1-\mu)-\mu\theta)}{\mu(1-\theta)+\theta q(1-q\theta)(1-\mu)^2}. \tag{19}$$

[8]Recall that $\Pr\{nh|b^*\}=0$ because $\bar{b}<b^*$.

Therefore, he is also indifferent between all probability distributions of bids with support $[0,\bar{b}]$.

Bidder 2 type h may deviate and bid $b > \bar{b}$. If he observed $b^r = 0$ deviating to bid higher than $\bar{b}$ is obviously dominated by bidding $b = \bar{b}$. If he observed $b^r = b^*$, the same is true for all $b \in (\bar{b}, b^*)$ and $b > b^*$. However, if he deviates and bids $b = b^*$ he can win for sure (due to the assumed tie-rule) and earn a payoff equal to $(v - b^*) = v(1-\theta)$. Yet, because bidder 1 type nh bids $b = b^*$ only with a probability, $q \leq \bar{q} < 1$, and:

$$q \leq \bar{q} \Rightarrow \pi_2^h(b|b^*) \geq v(1-\theta) \quad \text{for all } b \in [0,\bar{b}], \tag{20}$$

this deviation is not profitable either.

We conclude that if bidder 2 type h observed $b^r \in \{0, b^*\}$ all mixed bidding strategies with support $[0,\bar{b}]$, and in particular $F_2(b)$, are best replies to the strategy profile of bidder 1.

If bidder 2 type h observed an off-equilibrium bid $b^r \notin \{0, b^*\}$, he believes that bidder 1 is type c. In that case he ignores the observed bid and plays the equilibrium strategy of benchmark game A and earns a payoff equal to $((1-\theta) + \theta F(b^*))\,(v - b^*) = v - b^* = v(1-\theta)$.

3) Next consider bidder 1 type nh. If he bids $b = b^*$, he wins for sure and earns the payoff

$$\pi_1^{nh} = v - b^* = (1-\theta)v, \tag{21}$$

because bidder 2 never bids more than $\bar{b} < b^*$. If he bids $b = 0$ he earns the same payoff because in that case he wins if and only if $V_2 = 0$. Therefore, he is indifferent between $b = b^*$ and $b = 0$, and thus also between all probability distributions of bids with support $\{0, b^*\}$.

He may deviate and bid $b' \in (0, b^*)$. In that case bidder 2 believes that bidder 1 is type c and plays the equilibrium strategy of benchmark game A. This yields:

$$\pi_1' = \left(1 - \theta + \theta F(b')\right)(v - b') = (1-\theta)v = \pi_1^{nh}, \tag{22}$$

which is not an improvement. He may also deviate and bid $b > b^*$, which is however dominated by bidding $b = b^*$.

We conclude that the asserted equilibrium strategy, q, is a best reply to the other players' strategy profile. (We already explained why q is less than or equal to $\bar{q}$.)

4) Finally, consider bidder 1 type ch. If he plays the asserted equilibrium strategy, for all reports $b^r \in \{0, b^*\}$ and all bids $b \in [0,\bar{b}]$ his payoff is equal to

$$\pi_1^{ch} = (\theta + (1-\theta)F_2(b))\,(v - b) = \frac{v\,(1 - \theta q(1-\mu) - \theta\mu)}{1 - \theta q(1-\mu)}. \tag{23}$$

Therefore, he is indifferent between all probability distributions of reported bids with support $\{0, b^*\}$ and all probability distributions of bids with support $[0,\bar{b}]$.

He may deviate and report an off-equilibrium bid, $b^r \notin \{0, b^*\}$. In that case bidder 2 believes that he is type c and plays the equilibrium strategy of the benchmark game A. Then, the payoff of bidder 1 type ch is $\pi_1' = (\theta + (1-\theta)F(b^*))\,(v - b^*) = v(1-\theta)$, which is less than π_1^{ch}, because

$$\pi_1' - \pi_1^{ch} = -\frac{v\theta(1 - q\theta)(1-\mu)}{1 - q\theta(1-\mu)} < 0. \tag{24}$$

He may also deviate and bid more than $\bar{b}$. In that case, the only relevant deviation is to bid $b = b^*$ (which is greater than $\bar{b}$). Then, he wins for sure, yet reduces his payoff to $v - b^* = v(1-\theta)$.

We conclude that the asserted equilibrium strategy, $(\rho, F_1(b))$, is a best reply to the profile of the other players' equilibrium strategies. $\square$

Remark 1. *We mention that in* constructing *the equilibrium we allowed the probability distributions of bids, F_1, F_2, to depend upon the reported bid, $b^r \in \{0, b^*\}$. After extensive use of the technique used by Maskin and Riley (1985) we found that the required indifference of bidder 1 type ch between reporting $b^r = 0$ and $b^r = b^*$ implies the mixed strategy ρ stated in* (15) *, which in turn dictates that, for all $q \in (0, \bar{q}]$, the strategies F_1, F_2 are indeed independent of the reported bid.*

Remark 2. *The above partially separating equilibrium does not apply for $q = 0$. However, there is a partially separating equilibrium with $q = 0$. Because this is a borderline case, we do not spell out the details. A detailed account of this case is available upon request from the authors.*

Remark 3. *For simplicity we imposed that bidder 1 type $c\ell$ reports $b^r = b^*$ with probability 1. However, one can also construct partially separating equilibria where bidder 1 type $c\ell$ reports $b^r = b^*$ with probability less than 1.*

The *ex ante* expected equilibrium payoffs are (there, PS is mnemonic for "partially separating" equilibrium):

$$\Pi_1^{PS}(q) = \theta\left(\mu\pi_1^{ch} + (1-\mu)\pi_1^{nh}\right) = \left(1 - \theta(1-\mu) - \frac{\theta\mu^2}{1-(1-\mu)\theta q}\right)\theta v \tag{25}$$

$$\Pi_2^{PS}(q) = \theta\left(\Pr\{b^*\}\,\pi_2^h(\bar{b}|b^*) + \Pr\{0\}\,\pi_2^h(\bar{b}|0)\right) = (1 - q\theta(1-\mu) - \theta\mu)\,\theta v \tag{26}$$

$$\Pi_0^{PS}(q) = \left(1-(1-\theta)^2\right)v - \Pi_1^{PS}(q) - \Pi_2^{PS}(q) = \frac{q\left(1-q\theta(1-\mu)^2\right) - \mu(q-\mu)}{1-q\theta(1-\mu)}\theta^2 v. \tag{27}$$

They relate to those in benchmark games A and S and the pooling equilibrium P as follows:

$$\Pi_1^P > \Pi_1^{PS} > \Pi_1^S = \Pi_1^A, \quad \Pi_2^S > \Pi_2^P > \Pi_2^{PS} > \Pi_2^A \tag{28}$$

$$\Pi_0^A > \Pi_0^{PS} > \Pi_0^P > \Pi_0^S = 0. \tag{29}$$

5 Collusive impact of spying and counter-spying

Whereas spying without counterspy exclusively benefits the spying bidder, the ranking of expected payoffs in (28)-(29) makes clear that the the potential presence of a counterspy yields a collusive outcome where bidders mutually benefit from spying, even if the likelihood that the spy is a counterspy is arbitrarily small. That collusive impact shows up in all equilibria.

Among all equilibria in the game with counterspy, the pooling equilibrium has the strongest collusive impact. Among all partially separating equilibria, the collusive impact is diminishing in q and, as q approaches zero, the equilibrium expected payoffs approach those of the unique pooling equilibrium:

$$\partial_q \Pi_i^{PS} < 0,\, i \in \{1,2\},\; \partial_q \Pi_0^{PS} > 0, \text{ and } \lim_{q\to 0} \Pi_i^{PS} = \Pi_i^P,\; i \in \{0,1,2\}. \tag{30}$$

Note that the collusive impact occurs even if the probability that the spy is a counterspy is arbitrarily small, as long as that probability is positive.

6 Equilibrium selection

Like other signaling games, the game with counterspy has multiple equilibria – pooling and partially separating.

In classical signaling games, such as the seminal "Job Market Signaling" game by Spence (1973), the multiplicity of equilibria is driven by "unreasonable" out-of-equilibrium beliefs and one can eliminate pooling equilibria by invoking standard equilibrium refinements such as the intuitive criterion by Cho and Kreps (1987). As an aside, we mention that this does not apply to the present game in which, unlike in standard signaling games, both sender and receiver of messages have private information, the type space of bidder 1 is two-dimensional, and the sender, bidder 1, has a chance to make an unobserved move, his true bid, independent of his reported bid.

The idea of the intuitive criterion is that a belief system is unreasonable if one can identify a type $t \in \{n\ell, nh, c\ell, ch\}$ of bidder 1 who can convince bidder 2, by choosing a particular off-equilibrium action, that he should recognize him as the type who he is, because triggering this belief change is beneficial only to him. We now sketch briefly why, in the present model, this criterion has no bite.[9]

Consider the pooling equilibrium. Obviously, type $n\ell$ cannot benefit from an off-equilibrium bid $b > 0$ that triggers bidder 2 to recognize his type. If type nh makes an off-equilibrium bid $b > 0$ and triggers bidder 2 to recognize him, then bidder 2 type h will match his bid, and he cannot be better off. Similarly, type $c\ell$ cannot benefit either.

If type ch makes an off-equilibrium report, $b^r > 0$, and is thus recognized by bidder 2, bidder 2 will ignore the spy's report, and bidder 2 type h plays the equilibrium mixed strategy of game A, while bidder 1 plays a mixed strategy with mass point at zero (see Maskin and Riley, 1985, p. 153) which yields the payoff $(1-\theta)v$, which is smaller than his equilibrium payoff, $(1-\mu\theta)v$. Therefore, the equilibrium satisfies the intuitive criterion also in this case.

While there is a continuum of partially separating equilibria, their equilibrium payoff converges to those of the unique pooling equilibrium, as q approaches zero. As one can see from (28), that pooling equilibrium is payoff dominant which suggests that it may be a plausible selection of equilibrium.

7 Discussion

In the present paper we examined the impact of spying in a first-price auction, assuming the spy may be a counterspy who serves the interests of the spied at bidder and reports strategically distorted information. Whereas spying without counterspy benefits the spying bidder only, the potential presence of a counterspy and resulting ambiguity about the type of spy gives rise to a collusive outcome where spying and spied at bidders mutually benefit and have a vested interest in maintaining their symbiotic relationship. This indicates that the effects of counter-spying are very different from the effects of spying or, in general, the observability of bids by rival bidders.

Finally, we mention that the present game has another equilibrium with a type-dependent tie-breaking rule à la Maskin and Riley (2000) where, in the event of a tie, bidders have to play a Vickrey auction.[10] In that equilibrium both bidders bid the high value, v, regardless of their type, which results in a tie, followed by a Vickrey auction where each bids his true value. The resulting

[9] For a rigorous adaption of the intuitive criterion to signaling games with a similar structure we refer to Fan, Jun, and Wolfstetter (2021).

[10] With the proviso that, if the Vickrey auction is played, it determines the price and the item is awarded to a particular bidder at that price if the Vickrey auction fails to resolve the tie.

equilibrium outcome is the same as that of a Vickrey auction and spying has no effect whatsoever. However, that equilibrium fails to be trembling hand perfect and is not reasonable.

The seller may respond to the adverse impact of spying on his payoff and replace the first-price by a Vickrey auction. However, Vickrey auctions pose their own problems and are also susceptible to direct or tacit collusion between bidders (see, for example, Rothkopf, Teisberg, and Kahn, 1990; Garratt, Tröger, and Zheng, 2009).

References

Andrew, C. (2019). *The Secret World: A History of Intelligence*. New Haven: Yale University Press.

Andreyanov, P., A. Davidson, and V. Korovkin (2017). *Detecting Auctioneer Corruption: Evidence from Russian Procurement Auctions*. mimeo. UCLA.

Arozamena, L. and F. Weinschelbaum (2009). "The Effect of Corruption on Bidding Behavior in First-Price Auctions". *European Economic Review* 53, pp. 645–657.

Bergemann, D. and J. Hörner (2018). "Should First-Price Auctions be Transparent?" *American Economic Journal: Microeconomics* 10, pp. 177–218.

Blume, A. and P. Heidhues (2004). "All Equilibria of the Vickrey Auction". *Journal of Economic Theory* 114, pp. 170–177.

Burguet, R. and M. Perry (2007). "Bribery and Favoritism by Auctioneers in Sealed-Bid Auctions". *The B.E. Journal of Theoretical Economics* 7.1.

Cho, I.-K. and D. Kreps (1987). "Signaling Games and Stable Equilibria". *Quarterly Journal of Economics* 102, pp. 179–221.

Engelbrecht-Wiggans, R., P. Milgrom, and R. Weber (1983). "Competitive Bidding and Proprietary Information". *Journal of Mathematical Economics* 11, pp. 161–169.

Fan, C., B. Jun, and E. Wolfstetter (2016). "Optimal Bid Disclosure in Patent License Auctions under Alternative Modes of Competition". *International Journal of Industrial Organization* 47, pp. 1–32.

– (2021). *Corporate (Counter-)Espionage, Induced Price Leadership, and Tacit Collusion*. Working Paper.

Fischer, S., W. Güth, T. Kaplan, and R. Zultan (2021). "Auctions with Leaks about Early Bids: Analysis and Experimental Behavior". *Economic Inquiry* 59, pp. 722–739.

Garratt, R., T. Tröger, and C. Zheng (2009). "Collusion via Resale". *Econometrica* 77, pp. 1095–1136.

Ivanov, D. and A. Nesterov (2020). *Stealed-Bid Auctions: Detecting Bid Leakage via Semi-Supervised Learning*. Working Paper. arXiv: `1903.00261 [econ.GN]`.

Jun, B., E. Wolfstetter, and S. Zamir (2020). *Detrimental Information in a First-Price Private-Value Auction*. Working Paper.

Kim, J. (2008). "The Value of an Informed Bidder in Common Value Auctions". *Journal of Economic Theory* 143, pp. 585–589.

Lengwiler, Y. and E. Wolfstetter (2010). "Auctions and Corruption: An Analysis of Bid Rigging by a Corrupt Auctioneer". *Journal of Economic Dynamics and Control* 34, pp. 1872–1892.

Loftis, L. (2016). *Into the Lion's Mouth: The True Story of Duško Popov*. New York: Penguin.

Maskin, E. and J. Riley (1985). "Auction Theory with Private Values". *American Economic Review, Papers and Proceedings* 75, pp. 150–155.

– (2000). "Equilibrium in Sealed High Bid Auctions". *Review of Economic Studies* 67, pp. 439–454.

Milgrom, P. and R. Weber (1982). "A Theory of Auctions and Competitive Bidding". *Econometrica* 50, pp. 1089–1122.

Nasheri, H. (2005). *Economic Espionage and Industrial Spying*. New York: Cambridge University Press.

Persico, N. (2000). "Information Acquisition in Auctions". *Econometrica* 68, pp. 135–148.

Plum, M. (1992). "Characterization and Computation of Nash-Equilibria for Auctions With Incomplete Information". *International Journal of Game Theory* 20, pp. 393–418.

Popov, D. (1974). *Spy/Counterspy*. New York: Grosset & Dunlap.

Rothkopf, M., T. Teisberg, and E. Kahn (1990). "Why are Vickrey Auctions Rare?" *Journal of Political Economy* 98, pp. 94–109.

Simon, L. and W. Zame (1990). "Discontinuous Games and Endogenous Sharing Rules". *Econometrica* 58, pp. 861–872.

Spence, M. (1973). "Job Market Signaling". *Quarterly Journal of Economics* 87, pp. 355–374.

Vickrey, W. (1961). "Counterspeculation, Auctions, and Competitive Sealed Tenders". *Journal of Finance* 16, pp. 8–37.

Wright, P. (1987). *Spycatcher*. New York: Viking.