

Extracting the information: espionage with double crossing

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This paper addresses two very old issues in human society: *espionage* and *double crossing*. Our major conclusion points out that there will be a serious over rewarding problem in the direct mechanism due to double crossing in espionage, and a competitive mechanism with a relative performance regime can possibly mitigate the over rewarding problem and still extract the information.

Keywords: espionage; private investigator; double crossing; renegotiation.

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1. Introduction

In an environment with asymmetric information, hiring a private investigator (PI) to dig out the secret of opponents is probably the most direct and often used method in real life. *Espionage* is prevailing in many areas covering business or industrial intelligence (see Sable 1985; Arensman 2001; Crane 2005; Fellings 2001), matrimonial investigation (see Asian Business 2002; Saywell 1999) and military intelligence (see

Rositzke 1988; Marenches 1992). The impacts of these covert¹ actions have been stronger recently, as computers and the internet have accelerated the transmission of information.

However, it would be interesting to know exactly how much information can be extracted by espionage. The answers can be very complicated, as there can be various aspects to look at espionage. The purpose of this paper is to focus on PI's loyalty and ask if there exists a mechanism to ensure PI's loyalty and extract information. There are mainly two loyalty problems under concern. First, PI might not put in full effort to dig out the truth, and this is the well known *moral hazard* problem. Second, if the value of information is really high, the targeted side might pay PI to keep silent or even to transmit error information which in turn can benefit the targeted side. This is the *double crossing*² problem. There has been an extensive literature addressing the moral hazard problem (see, e.g., Hart and Holmstrom 1987), and the idea is to follow the revelation principle (Myerson 1979) and focus on a direct mechanism where PI is willing to participate. On the contrary, there has been no theoretical discussion on the double crossing problem, despite the fact that there are many documents recording how double crossing is adopted as a successful strategy in real life.

Hence, this paper will start by following the literature and examining whether a direct mechanism can solve both loyalty problems in espionage. This approach will be similar to that of contract *renegotiation* (e.g., Fudenberg and Tirole 1990); we will add an extra double crossing-free constraint in the designing process. Double crossing is de facto a form of renegotiation where PI asks for renegotiation on the terms of contract. The difference between the two concepts is that double crossing is renegotiating with the investigated side, which, if having conflicting interests, will find it beneficial to outbid the reward in the espionage contract and buy the PI's silence to conceal the information. We will demonstrate that, to prevent double crossing in a

1 In some area, espionage is illegal (see, The Espionage Act of 1917 and the Economic Espionage Act of 1996).

2 According to Wikipedia, the free encyclopedia, double agents may be agents of the target organization who infiltrate the controlling organization, or may be previously loyal agents of the controlling organization who have been captured and turned by the target.

direct mechanism is costly and the reward can be too high for a PI to be hired in the first place.

For an example of the “over rewarding” problem we are encountered, consider a situation that a wife suspects her husband having an affair, so she decides to hire a PI to discover the truth. The employment contract has to consider the possibility that the PI might have discovered the affair, but her husband pays more to exchange for a report of “no affair”. Our conclusion suggests that if the husband benefits highly enough from lying (e.g., to save huge divorce settlements), it is impossible for a wife with a worse economic status to hire a PI to discover her husband’s affair in a direct mechanism!

To solve the over rewarding problem, it is important to observe that the direct mechanism has implicitly assumed that the PI has larger bargaining power (by double crossing), so the controlling side needs to pay a very high rent for information. Both the controlling and targeted sides are actually engaged in a price competition for the only PI’s loyalty, so the reward is pushed up due to competition. If some competition can be introduced to the PI side, the controlling side’s bargaining power will be increased and it will not necessarily pay the PI the highest possible ransom. However, according to Holmstrom (1982), “forcing agents (i.e., PIs) to compete with each other is valueless if there is no common underlying uncertainty”, and the keypoint for information extraction is to “create information systems that separate out individual contributions”. Hence, according to Holmstrom’s suggestion, “competition among agents with relative evaluation has merit as a device to extract information optimally”. In the second part of this paper, we will demonstrate how a competitive mechanism, where the controlling side hires two PIs and introduces a relative performance regime (Holmstrom 1982; Eichberger et al. 1999), can extract information and mitigate the over rewarding problem in the direct mechanism.

Overall, our major conclusion is to point out that double crossing in espionage will cause a serious over rewarding problem in direct mechanism, and a competitive mechanism with a relative performance regime can possibly mitigate the over rewarding problem and still extract the information. In addition, there are two interesting results concerning the details of espionage contract. First, in the case without a double crossing problem, we show that espionage is most beneficial when the uninformed side has only small suspicion; when the suspicion is too high

to turn the action against the targeted side, hiring a PI is only wasting money. Second, we will consider two scenarios of double crossing in direct mechanism: (a) bluffing is possible and a request can be made without presenting the actual evidence in hand; (b) bluffing is impossible and all requests must be accompanied with concrete evidence. Bluffing is not only a realistic possibility but also creates extra uncertainty to the targeted side. It can be concluded that if bluffing is possible, then a double crossing-free contract assigns a *higher* effort level and a *higher* probability of discovery, and the total expected reward is *much higher* than the optimal contract without double crossing (denoted as c^*). However, if bluffing is impossible, then a double crossing-free contract assigns the same effort level and the same probability of discovery, but the controlling side's expected reward is *higher* than in c^* . This is contrary to conclusions in the contract renegotiation literature (for example, Fudenberg and Tirole 1990) describing that the existence of contract renegotiation will discourage the agent's effort input. Our result suggests that when contract renegotiation is offered by the opponent, a renegotiation of this sort will enhance effort investment. Moreover, similar to Hart and Tirole (1988), Dewatripont (1989) and Laffont and Tirole (1990) we assert that double crossing-freeness always implies lower surpluses.

Related literature: In our model, espionage is used to grasp the rival's private information in cases with asymmetric information, while in Solan and Yariv (2004) and Matsui (1989), espionage is used to obtain the information about the rival's strategy. Solan and Yariv (2004) considered a normal form game where a player can spy on his opponent and purchase noisy information about his opponent's decisions concerning future policies. Matsui (1989) considered a two-person repeated game in which there is a small probability of espionage, i.e., that one or both of the players will be informed of the other's supergame strategy and have a chance to revise his strategy on the basis of this information before the game begins. It is shown that in such a game any subgame perfect equilibrium payoff is Pareto efficient provided that the probability of espionage is sufficiently small. Finally, Whitney and Gaisford (1999) studied the welfare effect of economic espionage; They showed that economic espionage can yield desirable strategic effects as well as cost savings for firms in a spying country. When two producing firms spy on each other, it is possible that

both will be better off because of the technology transfer³ implicit in espionage. Economic espionage is generally beneficial to consumers.

In reality double crossing has been used as a useful strategy in wars or business. As mentioned by the great military thinker Sun Tzu in *The Art of War*, “counter espionage is done by the spied party to protect their own secrets, and is considered as important as the obtaining of the adversary’s”. The Double Cross System of the UK was one of the greatest intelligence coups of the Second World War. Initially the Double Cross System was used for counter-espionage purposes, but its comprehensive success provided an excellent conduit for strategic deception, culminating in the D-Day deception operation (Masterman 1995; Shulsky and Schmitt 2002; Aldrich 1998). As a recent example, a Chinese–American woman, Katrina Leung, who was recruited to steal secrets from China in 1982, was believed to have become a double agent. Mrs Leung was recruited to be an FBI agent providing intelligence on China, and was paid \$1.7 million for her information over the years (CNN News 2003).

The organization for the rest of the paper is as follows. Section 2 describes the incomplete information game that provides the motivation for espionage. Section 3 first characterizes the optimal contract without a double crossing problem and Sect. 3.2 considers the possibility of double crossing, and addresses the over rewarding problem in the double crossing-free contract. Section 4 presents the competitive mechanism and characterizes a perfect Bayesian equilibrium where the controlling side’s overall cost can be less than hiring one agent, followed by concluding remarks in the last section.

2. The model

This section describes a simple two-player game with one-sided private information. The purposes for this setup are two: (a) By comparing the payoffs in both complete and asymmetric information cases, we can justify the necessity for hiring a PI; (b) The game introduces a competitor with a conflicting interest, who has the motivation to make a counter offer to the PI in the interim stage, and the payoff difference in the game will serve as an upper limit for counter offer.

³ Harris (1998) described how industrial espionage helped the technology transfer between Britain and France in the eighteenth century.

To illustrate, consider the following scenario of industrial espionage. There are two high-tech companies (*I* and *II*) in the market, both of which need to simultaneously determine whether to manage a good relation (*G*) with the other or to engage in severe price competition (*B*). There has been a rumor that firm II could have developed a new technology that can break the balance of two companies in the market. Whether there is such a new technology or not is only privately known by firm II. Let $T = \{Y, N\}$ denote the state of truth, where *Y* indicates that there is a new technology and *N* for none. Firm I, on the other hand, has only a prior belief $\pi \in (0, 1)$ that the truth is *Y* and $1 - \pi$ for the state *N*.

Each firm's payoff is affected by two firms' actions as well as the state of truth. That is, let $S_i = \{G, B\}$, $i = I, II$ be each firm's action set. For every action profile $s \in S_1 \times S_2$ and $t \in T$, each firm's payoff is defined by $u_i(s, t)$, where $u_i : S_1 \times S_2 \times T \rightarrow R$. As an example, $u_i(BB, N)$ describes firm *i*'s payoff when two firms engage in severe price competition but in fact firm II does not have the new technology. To motivate the necessity for espionage, we make the following assumption.

Assumption 1: (i) $u_2(s_1B, Y) > u_2(s_1G, Y)$ and $u_2(s_1G, N) > u_2(s_1B, N)$, $\forall s_1 \in S_1$. (ii) $u_1(GB, Y) < u_1(BG, N) < u_1(BB, Y) < u_1(GG, N)$.

Part (i) of the Assumption is to ensure that for firm II, *G* is strictly dominated for $t = Y$ and *B* is strictly dominated for $t = N$. Thus the information obtained by the PI will play a critical role in determining firm I's action. Part (ii) describes that firm I would rather treat its rival with a correct manner; namely, if firm II has developed a new technology, firm I would prefer a price competition. On the other hand, if firm II does not have the new technology, firm I would prefer to remain in peace.

Firms' decisions: Under Assumption 1, firm II will take the dominant strategy *B* for $t = Y$ and *G* for $t = N$. Firm I, on the other hand, will take a cut-off strategy before engaging in espionage, i.e.,

$$\text{to choose } G \text{ if } \pi \leq \pi^* \text{ and choose } B \text{ if otherwise.} \quad (1)$$

The threshold value π^* is determined by the payoff indifference⁴ condition, i.e., $\pi^* = (1 + \frac{u_1(BB, Y) - u_1(GB, Y)}{u_1(GG, N) - u_1(BG, N)})^{-1}$. Notice that firm I's equilib-

⁴ To have a sensible discussion, it is assumed that $u_1(BB, Y) - u_1(GB, Y) \neq u_1(BG, N) - u_1(GG, N)$.

rium payoff is less than the complete information payoff. For instance, for $\pi > \pi^*$ firm I's payoff is $\pi u_1(BB, Y) + (1 - \pi)u_1(BG, N)$. This is less than if it were certain that the firm II owns the new technology: $u_1(BB, Y)$. This payoff difference is exactly the motivation for firm I to hire a PI to unravel the truth, provided that the PI can report truthfully. In the next section, we will follow the revelation principle (Myerson 1979) by focusing on a direct mechanism where the PI can truthfully provide the information.

3. Direct mechanism

In a direct mechanism (see, Holmstrom and Milgrom 1990), firm I offers to a PI an espionage contract on a “take it or leave it” basis. If the contract is taken, PI needs to make an effort decision which will affect the chance of discovering the truth. We will first discuss the optimal contract without double crossing, and then examine how the possibility of double crossing will change the information extraction in a direct mechanism.

Specifically, let $c \equiv \{R(r), r \in T\}$ denote the espionage contract offered to PI. The contract specifies an end of contract reward $R(r)$ as a function of observable variable, i.e., the report $r \in T$. If c is accepted by PI, he then needs to make an effort decision denoted by $e \in E$ with $E = [0, \bar{e}]$. Putting in effort is costly and the cost is captured by an increasing and *convex* function $\phi(e)$, where it is assumed that $\phi(0) = 0$ and $\phi'(0) = 0$. The output of investigation $p(e|t)$ is a state contingent probability of discovering the new technology. It is assumed that if $t = Y$, then $p(e|Y)$ is increasing and concave in e with $p(0|Y) = 0$ and $p(\bar{e}|Y) = 1$; however if $t = N$, $p(e|N) = 0$ for every possible e . The interpretation of this assumption is: if firm II has developed the new technology, the probability of discovering the evidence will be increasing in the effort level; but if firm II is innocent, it is impossible to fabricate any evidence. Throughout the paper, it is assumed that this effort level is *neither observable nor contractible*. Notice also that the rewards will depend on the content of report rather than on the accuracy of report. Since the content of report will vary with the state of truth and the PI's effort on investigation, the accuracy of report is not observable if the state is N . Moreover, if the state is N , PI's effort will not change the report (i.e., remaining N). By linking rewards to the content of report, we have

implicitly assumed that firm I is only concerned with the accuracy of report in state Y.

Finally, to distinguish between the investigation result and the report handed to firm I, let $d \in T$ denote PI's discovery and $r \in T$ as the report. In Sect. 3.1, we will focus on the case $r = d$, where there is only a moral hazard problem. Later in Sect. 3.2, we will address the case $r \neq d$ and both moral hazard and double crossing problems will be considered. Notice that the effort level is not observable by firm I. According to the revelation principle, we will concentrate on a direct mechanism where both the individual rationality and incentive compatibility constraints are satisfied. Firm I will firstly choose a contract (c) to implement an arbitrary effort of PI, and then determine the optimal effort e^* that maximizes its expected payoff.

Firm I's decision: Firstly, firm I's posterior belief after hearing the report from PI can be derived by the Bayes' rule; that is, if $r = Y$, then firm I's belief becomes $\frac{\pi p(e|Y)}{\pi p(e|Y)} = 1$; if $r = N$, then the posterior⁵ is denoted by $\hat{\pi}(e) \equiv \frac{\pi(1-p(e|Y))}{\pi(1-p(e|Y))+(1-\pi)}$. Since $1 - p(e|Y) \leq 1$, we have $\hat{\pi}(e) \leq \pi$. According to firm I's decision rule in Eq. (1), B will be chosen if Y is reported, but if N is reported, then the decision will depend on whether $\hat{\pi}(e) \geq \pi^*$.

To judge whether $\hat{\pi}(e) \geq \pi^*$, we need a further discussion on firm I's prior belief. Since $\hat{\pi}(e) \leq \pi$, there can be three cases: $\hat{\pi}(e) \leq \pi \leq \pi^*$, $\pi^* \leq \hat{\pi}(e) \leq \pi$ and $\hat{\pi}(e) < \pi^* < \pi$. Lemma 2 presents a comparison of firm I's payoffs before and after the investigation for all three cases. The case of $\hat{\pi}(e) < \pi \leq \pi^*$ is illustrated as follows. Let $U_1(e, c)$ denote firm I's payoff after investigation for offering contract c . Given $\hat{\pi}(e) < \pi \leq \pi^*$, firm I will choose G for *both* before or after hearing the report N , and hence

$$U_1(e, c) = \pi p(e|Y)[u_1(BB, Y) - R(Y)] + [\pi(1-p(e|Y)) + (1-\pi)] [\hat{\pi}(e)u_1(GB, Y) + (1-\hat{\pi}(e))u_1(GG, N) - R(N)]. \quad (2)$$

Later in Lemma 2 we will explain why the analysis will focus on this case.

⁵ $\hat{\pi}(e)$ is decreasing in e , as $\partial(\frac{\pi(1-p(e|Y))}{\pi(1-p(e|Y))+(1-\pi)})/\partial e = \frac{-\pi(1-\pi)p'(e|Y)}{[\pi(1-p(e|Y))+(1-\pi)]^2} < 0$.

3.1 Optimal espionage contract without double crossing

By the revelation principle, we concentrate on a direct mechanism $c \equiv \{R(Y), R(N)\}$ satisfying both PI's individual rationality (IR) and incentive compatibility (IC) constraints. The derivation of end-of-contract rewards, denoted by $R^*(r)$, is standard. First, given $R(r)$, PI's expected payoff is $U_0(e)$, where

$$U_0(e) = \pi p(e|Y)R(Y) + [(\pi)(1 - p(e|Y)) + (1 - \pi)]R(N) - \phi(e).$$

It can be checked that $U_0(0) = R(N)$. Second, PI's individual rationality (IR) and incentive compatibility⁶ constraints (IC) are defined respectively by

$$\begin{aligned} U_0(e) &\geq 0, \quad \text{for all } e, \\ U'_0(e) &= 0, \end{aligned}$$

where $U'_0(e) = \pi p'(e|Y)(R(Y) - R(N)) - \phi'(e)$. Notice that the reservation payoff in the IR constraint is assumed to be zero, implying that there is no severe opportunity cost. The IC constraint ensures that the effort implemented by the contract will maximize PI's payoff.

Third, let the IR constraint and the IC constraint bind and hence

$$\pi p(e|Y)(R(Y) - R(N)) + R(N) - \phi(e) = 0, \quad (\text{IR})$$

$$\pi p'(e|Y)(R(Y) - R(N)) - \phi'(e) = 0. \quad (\text{IC})$$

These two equations will determine the optimal compensations: $R^*(N) = \phi(e) - \pi p(e|Y) \frac{\phi'(e)}{\pi p'(e|Y)}$ and $R^*(Y) = \phi(e) + (1 - \pi p(e|Y)) \frac{\phi'(e)}{\pi p'(e|Y)}$. Note that the compensation difference⁷ $R^*(Y) - R^*(N) = \frac{\phi'(e)}{\pi p'(e|Y)}$ is a function of the marginal cost of effort and the marginal probability of discovery. The higher (lower) the marginal cost of effort (probability of discovery), the smaller this difference is.

Finally, given $R^*(Y)$ and $R^*(N)$ above, firm I would like to implement an effort level e^* that can maximize its payoff, i.e., $\partial U_1(e, c^*) / \partial e = 0$. To simplify the notations, we will abbreviate $U_1(e^*, c^*)$ as $U_1(c^*)$ in what follows.

⁶ The second-order condition will be satisfied, as $U''_0(e) = \pi p''(e|Y)(R(Y) - R(N)) - \phi''(e) < 0$.

⁷ This term is useful for comparing the effort levels in different contracts.

Whether it is worthy to engage in espionage depends on the relative sizes of payoffs for before and after the investigation. Lemma 2 gives a summary of comparisons between $U_1(c^*)$ and the payoff without investigation for all three cases. Notice that the conclusions are made under the assumption that there is no double crossing problem in this section.

Lemma 2: (i) Espionage is not worthy if $\pi^* \leq \hat{\pi}(e) < \pi$; (ii) The benefit from espionage is the highest for $\hat{\pi}(e) < \pi \leq \pi^*$.

In the proof, we calculate the differences between $U_1(c^*)$ and the payoff without investigation for all three ranges of π . This difference is the greatest for $\hat{\pi}(e) < \pi \leq \pi^*$, but it is always negative for $\pi^* \leq \hat{\pi}(e) < \pi$. In other words, from an *ex-ante* point of view, investigation should be encouraged when suspicion (π) is only minor. If the suspicion is too strong such that firm I chooses to engage in price competition, the benefit from investigation will be small. Therefore, in the following discussion on double crossing, we will focus on the case $\hat{\pi}(e) < \pi \leq \pi^*$ and assume that the difference $u_1(BB, Y) - u_1(GB, Y)$ is sufficiently large⁸ to ensure that investigation is profitable.

3.2 Double crossing-free contract

To consider the possibility of double crossing, we add in an extra step into the delegating process. That is, after the effort decision (PI may or may not know the truth), PI decides whether to reveal his identity to firm II and ask for a counter offer. To illustrate, imagine that PI approaches to firm II, saying “Believe it or not: I’ve got you! Pay me or I’ll tell firm I”. Firm II, upon receiving this request but *not observing the effort decision*, has to determine whether to believe it and make a counter offer. Then, depending on the size of counter offer by firm II, PI decides whether to report truthfully or to lie to firm I (i.e., $r = d$ or $r \neq d$). After hearing PI’s investigation report, firm I and II play the incomplete information game in Sect. 2. An important question⁹ to ask is why firm I cannot make a

⁸ From part (i) of the proof of Lemma 2: $[u_1(BB, Y) - u_1(GB, Y)] \geq \frac{1}{\pi} \left(\frac{c(e)}{p(e|Y)} - \frac{2c'(e)}{p'(e|Y)} \right)$.

⁹ The author is grateful for the referee’s comment on this point.

counter offer in this setting? The answer is because firm I does not know for sure whether there is a new technology, and therefore making a counter counter offer will not happen in the subgame. Firm I can only prevent double crossing ex ante by properly designing a double crossing-free contract.

The game is solved by backward induction. First of all, after hearing the investigation report, firm I's posterior belief is denoted by π_r for $r = Y, N$. Then, similar to Eq. (1), firm I will choose B or G in the incomplete information game, depending on whether $\pi_r \geq \pi^*$. The explicit form of π_r will depend on firm II action upon receiving the request by PI (details to be presented shortly).

Secondly, whether firm II will make a counter offer depends on whether firm II believes that PI has actually held the evidence of new technology. Since the outcome of effort is uncertain, there is a possibility $1 - p(e|t)$ that no evidence can be found. Hence, we consider two possibilities: (i) bluffing is possible; (ii) bluffing is impossible. The difference between two cases is that in case (i), PI can make a request without providing the actual evidence in hand; while in case (ii), all requests must be accompanied with concrete evidence of new technology. The latter is a special case of the former, and the difference lies in firm II's belief about PI's decisions.

3.2.1 Bluffing is possible

Since there is a possibility that PI is only bluffing, let δ denote firm II's belief that PI has really uncovered the new technology and $(1 - \delta)$ that PI is simply bluffing. Since now firm II has been informed about the espionage contract, it can be calculated by Bayes' rule that $\delta = p(e|Y)$. Given such a belief, firm II's decision to accept or reject PI's request will be type contingent. If $t = N$, it is impossible for PI to fabricate the evidence and hence it is dominant for firm II to reject the request. On the other hand, if $t = Y$, making a counter offer can possibly turn PI's report from Y to N , if the evidence is discovered. The expected payoffs for accepting and rejecting PI's request are derived as follows.

Firm II's decision: Firm II's expected payoff will depend on how firm I thinks about the investigation report. Considering the possibility of double crossing, firm I's posterior belief can be derived by the Bayes' rule. Let $\text{prob}(II \text{ accept})$ and $\text{prob}(II \text{ reject})$ denote the probabilities

that firm II accepts and rejects PI's request, respectively. Firm I's posterior beliefs after hearing report Y and N are given by $\pi_Y = \frac{\pi p(e|Y)\text{prob}(\text{II reject})}{\pi p(e|Y)\text{prob}(\text{II reject})} = 1$ and $\pi_N = \frac{\pi\{p(e|Y)\text{prob}(\text{II accept}) + (1-p(e|Y))\}}{\pi\{p(e|Y)\text{prob}(\text{II accept}) + (1-p(e|Y))\} + (1-\pi)}$, respectively. Since $\text{prob}(\text{II accept}) \geq 0$, we have $\pi_N \geq \hat{\pi}(e)$. According to Eq. (1), firm I will choose B upon hearing report Y , and will choose B or G after hearing report N , depending on whether $\pi_N \gtrless \pi^*$.

(i) If firm II has type Y, its expected payoff for *accepting* PI's request and making a counter offer is

$$\text{prob}(\pi_N \geq \pi^*)u_2(BB, Y) + (1 - \text{prob}(\pi_N \geq \pi^*))u_2(GB, Y) - Q,$$

where $Q = R(Y) + \varepsilon$, with ε arbitrarily small, is the counter offer paid to PI. Here it is assumed that PI always likes a higher offer, and therefore there will be a sort of price competition between the contract reward and counter offer. Given that firm II accepts the request, we have $\text{prob}(\text{II accept}) = 1$ and therefore by the Bayes' rule, $\pi_N = \pi$. As we have focused on the case $\pi \leq \pi^*$, firm II's expected payoff for accepting can be simplified as

$$u_2(GB, Y) - Q. \quad (3)$$

(ii) If firm II has type Y and rejects PI's request, PI will report truthfully and depending on his effort, the report can be N or Y. Hence firm II's expected payoff is:

$$p(e|Y)u_2(BB, Y) + (1 - p(e|Y))\{\text{prob}(\pi_N > \pi^*)u_2(BB, Y) + (1 - \text{prob}(\pi_N > \pi^*))u_2(GB, Y)\}.$$

Given that firm II rejects the request, we have $\text{prob}(\text{II accept}) = 0$ and hence $\pi_N = \hat{\pi}(e)$. As we have focused on the case $\pi \leq \pi^*$ and because $\hat{\pi}(e) < \pi$, firm II's expected payoff for accepting the request can be simplified as

$$p(e|Y)u_2(BB, Y) + (1 - p(e|Y))u_2(GB, Y). \quad (4)$$

Hence, firm II's decision will depend on the relative sizes of payoffs in Eqs. (3) and (4). In particular, let $\underline{Q}(e)$ denote the maximum counter offer where firm II is indifferent between accepting and rejecting, that is,

$$\underline{Q}(e) = p(e|Y)[u_2(GB, Y) - u_2(BB, Y)]. \quad (5)$$

Firm II's decision is hence to reject¹⁰ the request if $\underline{Q} \geq \underline{Q}(e)$ and to accept it otherwise.

PI's blackmail decision: If bluffing is possible, then since firm II cannot tell whether PI has really discovered the truth, the expected payment for making the request is at least $R(r)$, while that for not requesting is at most $R(r)$. Hence, PI will make the request.

Overall, the following situation will be referred as *successful double crossing*: When $t = Y$, PI's request is accepted by firm II, the investigation report is changed to $r \neq d$, and firm I chooses G in the incomplete information game. The following lemma describes the probability for successful double crossing.

Lemma 3: The probability of successful double crossing is increasing in PI's effort level, and decreasing in π .

Proof: See the Appendix. □

Double crossing-free contract (with bluffing): We are interested in designing a direct mechanism to avoid successful double crossing. In addition to the IR and IC constraints, and an extra constraint is added to prevent firm II from making an counter offer.

Definition 4: In a double crossing-free contract, firm I maximizes $U_1(e, c)$ subject to the IR, IC and the “double crossing-free” constraint,¹¹ i.e., $R(r) \geq \underline{Q}(e)$.

To distinguish, we will denote the double crossing-free contract with bluffing in this subsection as c^b where $c^b \equiv \{R^b(Y), R^b(N)\}$, and the double crossing-free contract without bluffing in Sect. 3.2.2 as c^{nb} where $c^{nb} \equiv \{R^{nb}(Y), R^{nb}(N)\}$.

To determine the optimal contract, it is important to determine which constraints will be binding. Recall $c^* = \{R^*(Y), R^*(N)\}$ from Sect. 3.1. For an arbitrary e , we can identify three cases according to whether the

¹⁰ Here, we assume the usual breaking rule according to equilibrium.

¹¹ If $R < \underline{Q}(e) + \varepsilon$, it is possible and profitable for country II to accept the PI's request and pay the ransom.

double crossing-free constraint will bind under contract c^* , i.e., $\underline{Q}(e) > R^*(Y)$, $R^*(N) \leq \underline{Q}(e) \leq R^*(Y)$ or $\underline{Q}(e) < R^*(N)$. The last case is trivial, as all constraints are satisfied under contract c^* , and the rewards remain the same as in c^* . For the first two cases, firm II can make a successful counter offer, so the rewards are reset by having the double crossing-free constraint bind¹² for $R(N)$, that is, $R^b(N) = \underline{Q}(e)$. Substitute this reward into the IC constraint, we have $R^b(Y) = \underline{Q}(e) + \frac{\phi'(e)}{\pi p'(e|Y)}$. Therefore in a double crossing-free contract, if $\underline{Q}(e)$ is not too small, an extra reward¹³ will be paid for the double crossing problem: $\pi p(e|Y)(\frac{\phi'(e)}{\pi p'(e|Y)}) + \underline{Q}(e) - \phi(e)$. The double crossing-free contract with bluffing is defined as $c^b = \{R^b(Y), R^b(N)\}$.

Since the partial differentiation of $\pi p(e|Y)(\frac{\phi'(e)}{\pi p'(e|Y)}) + \underline{Q}(e) - \phi(e)$ with respect to e is positive, the effort level will be higher than without a double crossing problem (given the concavity of firm I's expected payoff). Accordingly, together with the assumption that $p(e|t)$ is increasing in e , the probability of discovery will be greater than in c^* . This is contrary to the conclusions in the contract renegotiation literature (for example, Fudenberg and Tirole 1990) describing that the existence of contract renegotiation will discourage the agent's effort input. Here, we suggest that when contract renegotiation is offered by the opponent, a renegotiation of this sort will enhance effort investment.

3.2.2 Bluffing is impossible

In this case, firm II's belief upon receiving the request from PI is $\delta = 1$ by Bayes' rule. Given π_r as defined previously, firm II's decision for $t = N$ is to reject any request. On the other hand, if $t = Y$, the expected payoff for making a successful counter offer is $u_2(\overline{GB}, Y) - \underline{Q}$ and the expected payoff for rejecting is $u_2(\overline{BB}, Y)$. Denote \overline{Q} as the maximum ransom for firm II to be indifferent between turning down the request from PI and accepting it, where

12 If the double crossing free constraint is binding for $R(N)$, then according to IC, this condition will also be satisfied for $R(Y)$.

13 Replace $R^b(Y)$ and $R^b(N)$ into $U_1(e, c)$ in Eq. (2).

$$\overline{Q} = [u_2(GB, Y) - u_2(BB, Y)]. \quad (6)$$

Hence, firm II's decision is to reject the request if $Q \geq \overline{Q}$ and to accept it otherwise. It is easily seen that $\overline{Q} > \underline{Q}(e)$.

Since bluffing is impossible, only the PI who has found the evidence will make the request.

Double crossing-free contract (without bluffing): For the PI who cannot provide the evidence, double crossing cannot bring any further income (since fabricating the evidence is impossible) and therefore in the double crossing-free contract, the reward for reporting N is determined by having the IR bind. On the other hand, for the PI who has really discovered the evidence, double crossing gives him at most \overline{Q} , as defined in Eq. (6). Hence the rewards are reset by having the double crossing-free constraint bind¹⁴ for $R(Y)$, which gives $R(Y) = \overline{Q} + \varepsilon$. Denote this optimal choice by $R^{nb}(Y)$. Substituting $R^{nb}(Y)$ into the IR constraint, we have $R^{nb}(N) = \frac{\phi(e) - \pi p(e|Y)\overline{Q}}{1 - \pi p(e|Y)}$ and the reward difference will be $R^{nb}(Y) - R^{nb}(N) = \frac{\overline{Q} - \phi(e)}{1 - \pi p(e|Y)}$. We denote $c^{nb} = \{R^{nb}(Y), R^{nb}(N)\}$ as the double crossing-free contract when bluffing is impossible.

Replace $R^{nb}(Y)$ and $R^{nb}(N)$ into $U_1(e, c)$ in Eq. (2). It can be concluded that since \overline{Q} is not a function of e , the effort level will remain the same as in c^* , and the probability of discovery is the same as in c^* .

Finally, the following proposition provides a comparison between c^* (the optimal contract without a double crossing problem), c^b and c^{nb} (the double crossing-free contracts for two possibilities of bluffing).

Proposition 5: When bluffing is possible, a double crossing-free contract assigns a higher effort level, a higher probability of discovery than those in c^* , and firm I's total expected reward is also much higher. However, if bluffing is impossible, then a double crossing-free contract assigns the same effort level, the same probability of discovery, but the expected reward is higher than in c^* .

The chance of double crossing has created an outside opportunity for PI. If bluffing is possible, then both types of PI have the access to this opportunity,

¹⁴ Since \overline{Q} is not related to effort level, we assume this is higher than $R^*(Y)$.

and hence the double crossing-free contract needs to assign for each type the maximum ransom that PI can obtain. But in order to motivate the efficient effort, a higher reward is given to the PI who can discover the evidence in such a way that the IC is satisfied. Since both types of PI are granted for extra rewards to avoid double crossing, and these extra rewards are positively related to effort level, it can therefore be concluded that both the effort level and the probability of discovery will be higher than in c^* . However, if bluffing is impossible, then only the PI who can discover the evidence has access to this outside opportunity, and therefore a double crossing-free contract needs to assign for this type of PI the maximum ransom he can obtain. For the PI who cannot find the evidence, the double crossing-free contract assigns him the least reward characterized by the IR constraint. The overall rewards have been increased, but since the effort level has no marginal influence on this extra cost, both the effort level and the probability of discovery will remain the same as in c^* .

Essentially, to avoid double crossing, the direct mechanism needs to assign a sufficiently high reward to compete with the offer that firm II can make, and this is similar to the design of a renegotiation free contract where high enough rewards are assigned to ensure the interim rationality and incentive compatibility constraints. In other words, when facing PI, firm I and firm II are actually engaged in a sort of price competition; Firm II has the motive to outbid firm I's reward to buy PI's silence, while firm I has to reward high enough so that firm II cannot outbid. The result is hence similar to that of price competition: one of the two firms will offer its highest benefit¹⁵ associated with private information, and the firm with the largest benefit will win.

4. Competitive mechanism

In a direct mechanism, information can be possibly extracted, but since it is implicitly assumed that PI has larger bargaining power, firm I needs to pay a very high rent for information. When two firms are engaged in a price competition for the only PI's loyalty, the rewards will be pushed up, causing the over rewarding problem. Now, if some competition is introduced to the PI side, then firm I's bargaining power can be increased

¹⁵ For firm I, the benefit is $U_1(c) - U_1(\pi)$; For firm II, the benefit is: \bar{Q} or $\underline{Q}(e)$.

and it will not necessarily pay PI the highest possible ransom as reward. However, according to Holmstrom (1982), “forcing agents (i.e., PIs) to compete with each other is valueless if there is no common underlying uncertainty”, and the keypoint for information extraction is to “create information systems that separate out individual contributions”. Hence, according to Holmstrom’s suggestion, “competition among agents with relative evaluation has merit as a device to extract information optimally”. In this section, we will demonstrate how a competitive mechanism, where firm I hires two PIs and introduces a relative performance regime (Holmstrom 1982; Eichberger et al. 1999), can extract the information and mitigate the over rewarding problem in a direct mechanism.

The environment: Let PI_1 and PI_2 denote the two detectives, and they will be rewarded according to their relative performance. That is, let (r_1, r_2) , $r_i \in \{Y, N\}$ denote the reports by PI_1 and PI_2 respectively, and $R(r_1, r_2)$ denote the rewards for each combination of reports, as summarized in Fig. 1. The interpretation is: if both PIs provide the evidence of firm II’s new technology, both are equally rewarded R^M ; If both of them find no evidence, both will get $X > 0$; If only one of them finds out the evidence, he is to be paid $R^H (> R^M)$ and the other is paid some service fee, which is normalized to zero. All rewards are to be determined in the model.

Whether $R(r_1, r_2)$ is high enough for both PIs to participate is crucial for the success of espionage. Here, to have an unambiguous result, we will make the following simplification on both PIs’ effort sets and the probabilities of discovery. First, we will consider an alternative discrete effort set: $\bar{E}_i = \{0, 1\}$ for $i = 1, 2$. Second, the probabilities of discovery

		N	Y
N		(X, X)	$(0, R^H)$
Y		$(R^H, 0)$	(R^M, R^M)

Fig. 1. The relative performance regime

are assumed to be the same for both PIs; that is, for $t = N$, $p(e_i|N) = 0$ for all e_i , and for $t = Y$, $p(0|Y) = 0$ and $p(1|Y) = 1$. Finally the effort costs are simplified to be $\phi_i(0) = 0$ and $\phi_i(1) = e$, with $e > 0$. Accordingly, the IR constraints can be rewritten as

$$R^H - e \geq X, \quad \text{and} \quad R^M - e \geq 0. \quad (7)$$

Finally, according to Sect. 3, the “over rewarding” problem from double crossing is most severe when bluffing is possible, so we will focus on this case in this section. Remind that we have been focusing on the case $\hat{\pi}(e) < \pi \leq \pi^*$ according to the discussion in Sect. 3.1.

Timing: We will consider the following timing of the game: (1) Firm I offers a relative performance regime to PI_1 and PI_2 . Then, PI_1 and PI_2 choose their efforts to put in investigation simultaneously (*the effort stage*). (2) After effort decisions (PI_i will know the truth if $e_i = 1$), each PI decides whether to reveal his identity to firm II and ask for a counter offer (*the request stage*). Firm II, upon receiving the requests, has to determine

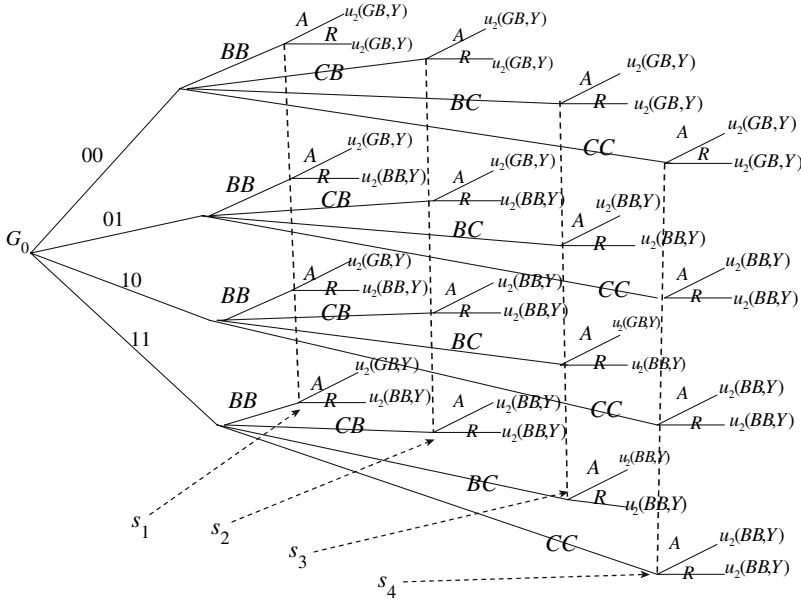


Fig. 2. The effort stage and the request stage

whether to accept the requests and make counter offers. Then, depending on the sizes of counter offers each PI decides whether to report truthfully or to lie to firm I (i.e., $r_i = d$ or $r_i \neq d$). (3) After hearing two PI's investigation reports, firm I and II play the incomplete information game described in Sect. 2.

To illustrate, Fig. 2 summarizes two PIs' decisions in the effort and request stages, following by firm II's decisions to accept or to reject the requests, given $t = Y$. In Fig. 2, there are four possible combinations of efforts in the effort stage, i.e., $(e_1, e_2) \in \{00, 01, 10, 11\}$. Following each combination of efforts is the request stage, where each PI makes a decision whether to blackmail (B) or to stay clean (C). Then given each combination of blackmailing decisions (i.e., BB, CB, BC , or CC), firm II makes the decision whether to accept (A) the request and make a counter offer to PI_i , or to reject (R) it. Notice that Fig. 2 is *not* a proper extensive form of the game, as only firm II's payoffs are presented for illustration, and more details will be presented shortly.

4.1 Characterization of equilibrium

The game is solved by backward induction, and we are interested in an equilibrium where firm I is better off hiring two detectives and the information is extracted.

Firstly, after hearing the investigation reports (r_1, r_2) , firm I forms a posterior belief which is denoted by π_{r_1, r_2} . Then, similar to Eq. (1), firm I chooses B or G in the incomplete information game, depending on whether $\pi_{r_1, r_2} \geq \pi^*$. The exact level of π_{r_1, r_2} will depend on PIs' blackmail decisions as well as firm II's responses upon receiving requests from PIs.

Explicitly, the calculation of posterior beliefs will follow Bayes' rule, taking into account the actions by PIs and firm II. Due to its complication, the intuition of the calculation is provided here. There can be four possible combinations of (r_1, r_2) : YY, YN, NY, NN . Given that firm II has type Y , there are overall $4 \times 4 \times 2$ possible combinations of actions by PIs and firm II (see Fig. 3), among which 5 combinations will give the reports YY , 7 combinations will give the reports YN , 7 combinations will give the reports NY , and 13 combinations will give the reports NN . Moreover, for the reports YY , since all of the five combinations have (1,1) in the effort stage, we will have $\pi_{YY} = 1$ by Bayes' rule. Similarly, for reports YN or NY , there is at least

Reports Efforts	Y Y	Y N	N Y	N N
(0,0)				8
(0,1)			6	2
(1,0)		6		2
(1,1)	5	1	1	1

Fig. 3. Combinations of effort and reports

one PI putting in effort, and hence $\pi_{YN} = \pi_{NY} = 1$. For the reports NN , similar to the discussion of π_N in Sect. 3, it can be verified that $\pi_{NN} \leq \pi$.

If firm II has type N, it will reject all requests; but if firm II has type Y, the decision will depend on whether it believes that the PI has actually hold the evidence of new technology. When bluffing is possible, firm II cannot deduce PIs' effort decisions from their requests. For example, requests BB can possibly follow four different effort decisions 00, 01, 10 or 11. Hence in Fig. 2, there are four possibilities following each combination of requests, and we denote them by four information states: S_1 , S_2 , S_3 and S_4 , respectively. Firm II's decision for each information state in Fig. 2 is discussed as follows.

Firm II's decisions (given $t = Y$):

(i) In state S_4 , no request has been made by any PI. Therefore, no matter how firm II believes about the effort choices in the effort stage, it is indifferent between accepting and rejecting.

(ii) In state S_3 , only PI_1 comes forward to make a request. Firm II's counter offer decision will depend on the level of expected payoff for each alternative. Let $P = (p_1, p_2, p_3, p_4)$, with $p_i \geq 0$ and $\sum p_i = 1$, denote firm II's beliefs that the effort decisions have been 00, 01, 10 and 11, respectively, and by the definition of distribution, let $p_4 = 1 - p_1 - p_2 - p_3$. Hence, if firm II accepts the request and makes a counter offer,¹⁶ denoted by Q_{BC}^1 , to PI_1 , its expected payoff will be: $p_1 u_2(GB, Y) + p_2 u_2(BB, Y) + p_3 u_2(GB, Y) + (1 - p_1 - p_2 - p_3) u_2$

¹⁶ The superscript in Q_{BC}^1 indicates PI_1 and the subscript denotes the request combination BC.

$(BB, Y) - Q_{BC}^1$. If firm II rejects the request, its payoff will be: $p_1 u_2(GB, Y) + p_2 u_2(BB, Y) + p_3 u_2(BB, Y) + (1 - p_1 - p_2 - p_3) u_2(BB, Y)$. Hence, firm II will be indifferent between two alternatives if

$$p_3 [u_2(GB, Y) - u_2(BB, Y)] = Q_{BC}^1. \quad (8)$$

(iii) In state S_2 , the situation is similar to S_3 but now only detective PI_2 comes forward to make a request. Without loss of generality, it is assumed that firm II has the same beliefs about the effort decisions as in S_3 . Hence, if firm II accepts the request and makes a counter offer, denoted by Q_{CB}^2 , its expected payoff is: $p_1 u_2(GB, Y) + p_2 u_2(GB, Y) + p_3 u_2(BB, Y) + (1 - p_1 - p_2 - p_3) u_2(BB, Y) - Q_{CB}^2$; if firm II rejects the request, its payoff is: $p_1 u_2(GB, Y) + p_2 u_2(BB, Y) + p_3 u_2(BB, Y) + (1 - p_1 - p_2 - p_3) u_2(BB, Y)$. Firm II will be indifferent between two alternatives if

$$p_2 [u_2(GB, Y) - u_2(BB, Y)] = Q_{CB}^2. \quad (9)$$

(iv) In state S_1 , both detectives make the requests. Denote $\bar{P} = (\bar{p}_1, \bar{p}_2, \bar{p}_3, \bar{p}_4)$, with $\bar{p}_i \geq 0$ and $\sum \bar{p}_i = 1$, as firm II's beliefs that the effort choices have been 00, 01, 10 and 11, respectively. Again by the definition of distribution, let $\bar{p}_4 = 1 - \bar{p}_1 - \bar{p}_2 - \bar{p}_3$. Therefore, if firm II accepts the requests and makes counter offers to PI_1 and PI_2 , denoted respectively by Q_{BB}^1 and Q_{BB}^2 , its expected payoff is $\bar{p}_1 u_2(GB, Y) + \bar{p}_2 u_2(GB, Y) + \bar{p}_3 u_2(GB, Y) + (1 - \bar{p}_1 - \bar{p}_2 - \bar{p}_3) u_2(GB, Y) - Q_{BB}^1 - Q_{BB}^2$; if firm II rejects both requests,¹⁷ it receives $\bar{p}_1 u_2(GB, Y) + \bar{p}_3 u_2(BB, Y) + \bar{p}_2 u_2(BB, Y) + (1 - \bar{p}_1 - \bar{p}_2 - \bar{p}_3) u_2(BB, Y)$. Firm II will be indifferent between two alternatives if

$$(1 - \bar{p}_1) [u_2(GB, Y) - u_2(BB, Y)] = Q_{BB}^1 + Q_{BB}^2. \quad (10)$$

The following lemma summarizes the conditions for firm II to accept one request but reject two requests. It can be checked that if firm II rejects all requests, firm I cannot benefit by hiring two detectives with the presence of a double crossing problem. The full characterization of the latter case will be similar to the discussion below.

17 If firm II accepts only one request, the secret will still be reported.

Lemma 6: The conditions for firm II to accept one request, but reject two requests are $p_3 \geq \frac{Q_{BC}^1}{[u_2(GB,Y)-u_2(BB,Y)]}$ or $p_2 \geq \frac{Q_{CB}^2}{[u_2(GB,Y)-u_2(BB,Y)]}$, $\bar{p}_1 \geq (1 - \frac{Q_{BB}^1 + Q_{BB}^2}{[u_2(GB,Y)-u_2(BB,Y)]})$.

Whether these beliefs are eligible under the requirement by *sequential rationality* (Kreps and Wilson 1982) will depend on the decisions of the two PIs in the effort and request stages. In the following subsection, we will discuss the setting of optimal rewards as well as PIs' effort and request decisions. Notice that our focus is on an equilibrium where firm I is better off hiring two detectives.

Firm II accepts one request but rejects two requests: In this case, firm II will accept the single request and make a counter offer in states S_2 and S_3 . As in Sect. 3, a successful counter offer is assumed to be a form of PI's original reward plus an ε . Thus, we can simplify the effort and request stages as in Fig. 4. The interpretation is: if a PI has put in effort 1 and his request is accepted, he will receive the reward for reporting N from the

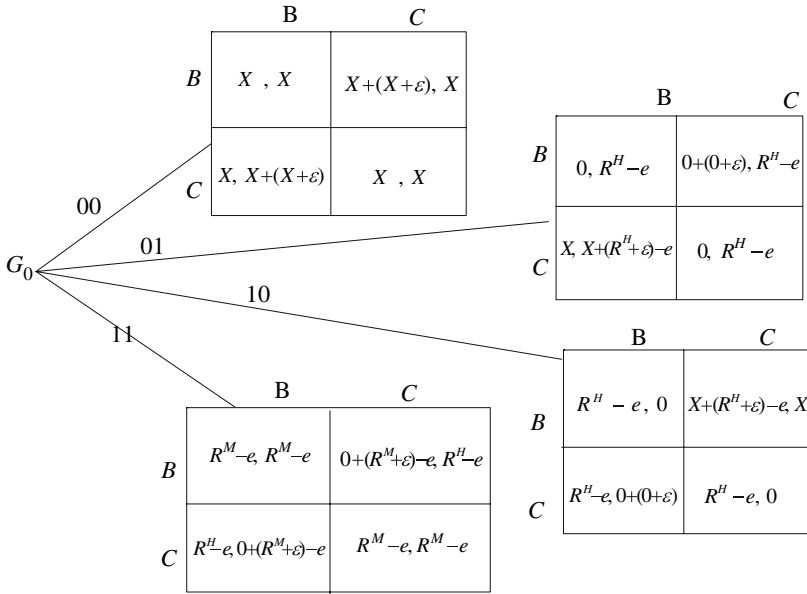


Fig. 4. The effort and the request stages, when firm II accepts 1 but rejects 2 requests

relative performance regime, plus a counter offer from firm II. For example, for the effort combination $(1, 0)$, if both PIs report truthfully then PI_1 's original payoff is R^H , and PI_2 's reward is zero. However, if only PI_1 makes a request (i.e., the profile BC), and his request is accepted by firm II, then the reports become $(r_1, r_2) = NN$. Hence, PI_1 receives a total payoff $X + (R^H + \varepsilon) - e$, and PI_2 receives X .

Notice first that in Fig. 4, C is weakly dominated in the request stage following the effort combination $(0,0)$, hence even though there exist three pure strategy equilibria, BB is the most obvious one. Moreover, there are respectively two pure equilibria (i.e., BC and CB) in the request stage following $(0, 1)$; two pure equilibria (i.e., BC and CB) in the request stage following $(1, 0)$; and two pure equilibria (i.e., BC and CB) in the request stage following $(1, 1)$. Among these various combinations, we will focus on those in which the evidence will be eventually reported to firm I, and the equilibrium rewards are cheaper than the case where firm II rejects all requests. Hence, we will concentrate on the equilibrium BC in the request stage following $(0, 1)$; CB in the request stage following $(1, 0)$, and BC or CB in the request stage following $(1,1)$. Accordingly, there are two possible strategic forms for the effort stage, as depicted by Fig. 5.

Lemma 7: There exists an equilibrium $(1, 1)$ in each game in Fig. 5.

The next proposition describes our main conclusion for the competitive mechanism with two PIs.

	0	1		0	1
0	X, X	$\varepsilon, R^H - e$	0	X, X	$\varepsilon, R^H - e$
1	$R^H - e, \varepsilon$	$R^H - e, R^M + \varepsilon - e$	1	$R^H - e, \varepsilon$	$R^M + \varepsilon - e, R^H - e$
	(BB, BC, CB, CB)			(BB, BC, CB, BC)	

Fig. 5. The effort stage for two different outcomes in the request stage

Proposition 8: There exists a perfect Bayesian equilibrium where firm I hires two PIs, the evidence of new technology (if exists) is reported to firm I and the equilibrium rewards are cheaper than hiring one PI.

Proof: That the evidence (if exists) is reported to firm I and both PIs put in effort but only one of them makes a request follows immediately from the result in Lemma 7. We need to further demonstrate that the equilibrium rewards are *cheaper* than hiring one PI. Given the equilibrium (1, 1) in the effort stage, the *consistency* requirements (Kreps and Wilson 1982) on beliefs are $p_1 = p_2 = p_3 = 0$. On the other hand, from Lemma 5, the beliefs need to satisfy $p_3 \geq \frac{Q_{BC}^1}{[u_2(GB,Y) - u_2(BB,Y)]}$ or $p_2 \geq \frac{Q_{CB}^2}{[u_2(GB,Y) - u_2(BB,Y)]}$, $\bar{p}_1 \geq (1 - \frac{Q_{BB}^1 + Q_{BB}^2}{[u_2(GB,Y) - u_2(BB,Y)]})$ for firm II to accept one request but reject two requests. Hence for both conditions to be satisfied simultaneously, it requires $Q_{BC}^1 \leq 0$ or $Q_{CB}^2 \leq 0$ or $[u_2(GB,Y) - u_2(BB,Y)] \leq Q_{BB}^1 + Q_{BB}^2$. In other words, firm I's total reward will be $\pi 2X + (1 - \pi)(R^H)$ and there will be *no* further requirement on R^H . This reward will be cheaper than the reward in the single PI case (equivalent to the reward when all requests are rejected in two PIs case), which is $\pi 2X + (1 - \pi)(R^H)$ with R^H required to be *at least* $u_2(GB,Y) - u_2(BB,Y)$. □

Notice that in this equilibrium, only S_4 is out of the equilibrium path, but since firm II is indifferent between accepting and rejecting, this equilibrium satisfies the criterion by Cho and Kreps (1987). Another query about this equilibrium might be that, on the equilibrium path, why should firm II attempt to buy the silence of one agent if it knows that the other agent will inform firm I anyway? The answer lies in the proof above; namely, in order to have consistent beliefs, it requires that $Q_{BC}^1 = 0$ or $Q_{CB}^2 = 0$. That is, although firm II takes the request by one of the agent, the equilibrium ransom is actually zero.

5. Concluding remarks

In this paper, we have addressed two very old issues in human society: *espionage* and *double crossing*. Espionage is considered one of the most direct and often used methods to grasp information from the opponents,

and it has become a well-organized profession as there have been many PI schools or even distance learning programmes in recent years.¹⁸

Despite its prevalence in various areas, espionage has received little attention by the theoretical literature. For the lack of contributions on this topic, there can be two possible reasons: either because espionage and covert actions are usually treated as immoral so they are not worth discussing, or because human behaviors present no difference in espionage from other activities. This paper does not intend to challenge the first argument, but rather we have tried to, given its existence and prevalence, characterize and understand economic agents' decisions in an espionage contract, just as the literature has been discussing various issues concerning collusion, despite the fact that it is illegal under antitrust laws (see, Daughety and Reinganum 2005). To the second argument, we have raised the problem of double crossing as a counter example. The double crossing problem is often connected with espionage activities, probably because of the image from the 007 film series. In fact, the double crossing problem we have addressed can occur in many other situations. For example, employees from high-tech companies can be recruited by rival firms and take away the information about a newly developed technology. An accountant can be recruited by the opponent companies, revealing secrets about the former client firm. The two mechanisms we proposed in this paper can help solve the employees' loyalty problems in these examples.

Appendix

Proof of Lemma 2: To see if it is worthy to engage in investigation, we need to compare firm I's ex-ante payoff after investigation (i.e., $U_1(c^*)$) and the payoff before investigation denoted by $U_1(\pi)$, provided that the result can be reported truthfully. As discussed, there can be three cases: $\hat{\pi}(e) \leq \pi \leq \pi^*$, $\pi^* \leq \hat{\pi}(e) \leq \pi$ and $\hat{\pi}(e) < \pi^* < \pi$.

- (i) For the case $\hat{\pi}(e) \leq \pi \leq \pi^*$, firm I's payoff before investigation is $U_1(\pi) = \pi u_1(GB, Y) + (1 - \pi)u_1(GG, N)$, and $U_1(c^*)$ is

¹⁸ See the website: www.findprivatedetectives.co.uk/categories/eye/private_investigator_school.html

$$\begin{aligned} & \pi p(e|Y)[u_1(BB, Y) - R(Y)] + [\pi(1 - p(e|Y)) + (1 - \pi)] \\ & \times [\hat{\pi}(e)u_1(GB, Y) + (1 - \hat{\pi}(e))u_1(GG, N) - R(N)]. \end{aligned}$$

After manipulation, $U_1(c^*)$ can be written as $\pi [p(e|Y)u_1(BB, Y) + (1 - p(e|Y))u_1(GB, Y)] + (1 - \pi)u_1(GG, N) - \phi(e)$. The difference $U_1(c^*) - U_1(\pi)$ is then $\pi p(e|Y)[u_1(BB, Y) - u_1(GB, Y)] - \phi(e)$.

- (ii) For the case $\pi^* \leq \hat{\pi}(e) \leq \pi$, firm I's payoff before investigation is $U_1(\pi) = \pi u_1(BB, Y) + (1 - \pi)u_1(BG, N)$, and $U_1(c^*)$ is

$$\begin{aligned} & \pi p(e|Y)[u_1(BB, Y) - R(Y)] + [\pi(1 - p(e|Y)) + (1 - \pi)] \\ & \times [\hat{\pi}(e)u_1(BB, Y) + (1 - \hat{\pi}(e))u_1(BG, N) - R(N)] \end{aligned}$$

After manipulation, $U_1(c^*)$ can be written as $\pi [p(e|Y)u_1(BB, Y) + (1 - p(e|Y))u_1(BB, Y)] + (1 - \pi)u_1(BG, N) - \phi(e)$. The difference $U_1(c^*) - U_1(\pi)$ is then $-\phi(e) < 0$. It is not profitable to hire a PI.

- (iii) For the case $\hat{\pi}(e) < \pi^* < \pi$, firm I's payoff before investigation is $U_1(\pi) = \pi u_1(BB, Y) + (1 - \pi)u_1(BG, N)$, and $U_1(c^*)$ is

$$\begin{aligned} & \pi p(e|Y)[u_1(BB, Y) - R(Y)] + [\pi(1 - p(e|Y)) + (1 - \pi)] \\ & \times [\hat{\pi}(e)u_1(GB, Y) + (1 - \hat{\pi}(e))u_1(GG, N) - R(N)]. \end{aligned}$$

After manipulation, $U_1(c^*)$ can be written as $\pi [p(e|Y)u_1(BB, Y) + (1 - p(e|Y))u_1(GB, Y)] + (1 - \pi)u_1(GG, N) - \phi(e)$. The difference $U_1(c^*) - U_1(\pi)$ is then $\pi [u_1(GB, Y) - u_1(BB, Y)] + \pi p(e|Y)[u_1(BB, Y) - u_1(GB, Y)] + (1 - \pi)[u_1(GG, N) - u_1(BG, N)] - \phi(e)$.

We next argue that the value of $U_1(c^*) - U_1(\pi)$ is greater in case (i) than in case (iii). First, compare the values of $U_1(c^*) - U_1(\pi)$ in two cases. Since the differentiation of $U_1(c^*) - U_1(\pi)$ with respect to e is the same for both cases, the optimal effort levels remain the same for both cases. Moreover, the difference between case (i) and case (iii)'s payoff difference is $\pi [u_1(GB, Y) - u_1(BB, Y)] + (1 - \pi)[u_1(GG, N) - u_1(BG, N)]$, which is negative, as when $\pi > \pi^*$, $\pi [u_1(GB, Y) + (1 - \pi)[u_1(GG, N)] < \pi u_1(BB, Y) + (1 - \pi)u_1(BG, N)$. Hence, the benefit from espionage is the highest for $\hat{\pi}(e) \leq \pi \leq \pi^*$. \square

Proof of Lemma 3: The probability of successful double crossing is the probability where $\pi_N = \pi^*$. Firstly, rewrite the two conditions of successful double crossing as: $Z^1 \equiv \pi_N - \pi^*$ and $Z^2 \equiv Q - p(e|Y)[u_2(GB, Y) -$

$u_2(BB, Y)$. By applying the implicit function theorem, we have $\frac{\partial \text{prob}(II \text{ accept})}{\partial e} = -\frac{\frac{\partial Z^1}{\partial e}}{\frac{\partial Z^1}{\partial \text{prob}(II \text{ accept})}}$ and $\frac{\partial \text{prob}(II \text{ accept})}{\partial \pi} = -\frac{\frac{\partial Z^1}{\partial \pi}}{\frac{\partial Z^1}{\partial \text{prob}(II \text{ accept})}}$. Because $\frac{\partial Z^1}{\partial e} = \frac{\partial \pi_N}{\partial e} < 0$, $\frac{\partial Z^1}{\partial \text{prob}(II \text{ accept})} = \frac{\partial \pi_N}{\partial \text{prob}(II \text{ accept})} > 0$ and $\frac{\partial Z^1}{\partial \pi} = \frac{\partial \pi_N}{\partial \pi} > 0$, we can conclude that $\frac{\partial \text{prob}(II \text{ accept})}{\partial e} > 0$ and $\frac{\partial \text{prob}(II \text{ accept})}{\partial \pi} < 0$. \square

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