An Inspection Espionage Game

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Abstract

The economic losses of industrial espionage in the U.S. are estimated to be around 100bn - 250bn. Due to the high cost and frequency of attacks, corporate espionage is being analyzed not only by entrepreneurs but also by governments. This paper incorporates industrial espionage games in the framework of inspection games. The analysis is made under a Cournot competition duopoly in which we allow the intervention of an Inspector whose task is to maximize the probability of detecting espionage between the firms. Three cases are analyzed: a no espionage case, an exogenous inspection situation, and an endogenous probability of inspection game.

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1 Introduction

The development of technology and the increase in worldwide competition have increased people and institutions’ need for tools that allow them to successfully compete in the market. Spying is used in combat, in international affairs, and since a few decades ago in industrial competition [Provan, 2008].

According to Nasheri [2005], the new trend in businesses focuses on openness to communication and trade with potential customers, making it easier for adversaries to make attempts to look into their strategies. In 2003, only 16% of the companies in the U.S. avoided downtime from attacks. Firms, specially small ones, had made attempts to fight against these attacks by increasing the number of firewalls, antivirus tools, recruiting people devoted to the company’s security, etc. These kinds of efforts to avoid industrial theft or similar illegal actions between companies represent a high cost for the overall economy.

This study contributes to the limited literature on espionage by presenting an economic model which is able to identify the effects of an Inspector interventions over entrepreneurs’ behaviors. The Inspector is introduced in the espionage game as a detector with capability of giving penalties to those caught spying. In this sense the objective of this paper is to present:

1. A theoretical model based on the work of Solan and Yariv [2004] with the additional inclusion of an Inspector as a detector of illegal actions.

2. An espionage game with probability of detection. In this second approach, we study a Cournot competition in which Firm B’s production is based on one of its two possible expected demand levels (high or low). Later, we discuss how the equilibrium will change when the possibility of being detected by the Inspector is introduced in the analysis.
This paper begins with a literature review analyzing the first studies about strategic games and the most recent contributions in espionage games. Section 3 presents the inspection espionage model while Section 4 analyzes the corresponding espionage game. In Section 5, I present an analysis of the Espionage Inspection Equilibrium when the inspection probability is exogenous and endogenous. Finally, I discuss the conclusions and future work in this topic.

2 Literature Review

Strategic games combined with information, were first studied in Aumann [1974]. This study makes the first approach to mix strategies with subjective random devices. The use of these informational devices combined with subjectivity yields new Nash equilibriums. In an n-person game with \( n \geq 3 \), these new equilibriums lead to higher payoffs than the ones gotten by objective mixed strategies. Aumann [1974] also shows that correlated strategies can achieve equilibrium points outside the convex set of mixed strategies payoff vectors. In this sense, equilibriums can be self-enforcing agreements.

Industrial Espionage is indeed a branch of Aumann’s studies. However, since the early work of Matsui [1989] little has been done in the field of strategic information usage. Matsui considers a two-players infinite super-game with probability of information leakage. In a one-shot game, it is usually the case that the strategies chosen do not lead to the better possible outcome for the players (e.g. the Prisoner’s Dilemma). While in repeated games, the players make their decisions knowing that if they do not cooperate they may be punished by their opponent’s non-cooperative decision in the next round. He proved that if information leakage is possible and there is a small

\[ 1 \text{ People might disagree on the outcomes } \]
probability that the players will revise their strategies at some point of the game, they will be better off behaving cooperatively. Therefore, outcomes determined in one-shot games are not Pareto optimal in the repeated leakage game.

Using some numerical examples, Solan and Yariv [2004] studied one-shot normal form games in which two players decide on their strategies before the game starts and one of them has the opportunity to invest on a spying mechanism. This device is costly and may or may not give the player the correct information about the opponent’s action. If the player decides to behave illegally, he receives a signal which influences his choices. The authors proved that the equilibria achieved with pure strategies remain the same in the extended game with espionage. However, the mixed strategy equilibria change due to the cost of investing in the spying device. They concluded that the cost of the spying device only influences the decision of the player on whether or not to spy, and that in a Stackelberg game, when the follower is the spy, espionage is only used if it changes the perfect equilibrium payoff.

In relation to general espionage, Provan [2008] studies computational intensive zero-sum games in which information is used by each of the players in different scenarios. The players can make use of probes to spy. Also, in some cases the players can defend themselves from espionage by using defense devices. It is proved that spying mechanisms increase the player’s expected gain in those scenarios. Even though the author studied a restricted-strategy game and not the penalty-version one, his work suggests that informational probes can be also used in models that include penalties on illegal actions (as in our case).

\footnote{Information devices capable of identifying the hidden action of the opponent}
Urbano et al. extended the study of Solan and Yariv [2004] on a different scenario, looking at the effect of espionage in an incumbent-entrant game. They consider an entrant who does not know which strategy will the incumbent take, and so decides whether to use an imprecise Intelligence System to spy on his opponent or not. One will expect that the entrant would benefit more from a precise device but the authors proved that if the Intelligence System has a high precision, the incumbent can signal-jam. Therefore, the entrant will be better off with a non-high precision device.

*Inspection Games* are another branch in the literature of strategic games that we consider in this paper. An “inspection game” is a mathematical representation of a situation where one party, called the *Inspector*, verifies if the other party, called the *Inspectee*, has strategically executed an illegal action [Avenhaus et al., 2002]. A vast application of inspection games has been applied to arms control and disarmament [Dresher, 1962], auditing, and environmental regulations; but to our knowledge, inspection games have not been thoroughly studied in the case of industrial espionage.

In the inspection game, the *Inspector* decides strategically if he should hold an inspection procedure for detecting illegal actions or not. Also, he decides on the penalties for the violators. Legal action and no alarm is the norm, in this case *Inspector* and *Inspectee* get a payoff 0. When there exists violations and no alarm, the payoff is positive for the *Inspectee* and negative for the *Inspector*. The majority of the literature follows the leadership principle [Von Stackelberg, 1934] which suggests that the *Inspector* should not announce his strategy. However, Maschler [1966] considered the scenario in which the *Inspector* announces his strategy in advance. In this paper, we consider the case in which

\[\text{In a competitive situation, it can be advantageous to be the first player to take an action and stay with it [Von Stackelberg, 1934].}\]
the strategy of the Inspector is unknown to the players.

3 The Inspection Espionage Model

In this section, we present a model based on the work of [Solan and Yariv 2004] that we extend by incorporating the participation of an espionage detector, called the Inspector. The game is played by two rational firms in competition (A and B). Both produce homogeneous goods and are quality setting firms.

Let’s also assume that there is a fixed demand $\bar{D}$ for the good produced by both firms and that espionage from A to B, is possible.

The goal of this model is to analyze the equilibrium espionage. And for that, we will analyze two approaches: the no espionage case (which simply refers to a Cournot game with incomplete information) and the espionage case. For the latter case, we analyze how the equilibrium changes when an Inspector with the ability to set false inspection alarms is included in the game. A sequential game with probability to spy and the presence of an Inspector is left for future discussions.

This model starts with the following main assumptions:

1. Demand disturbances are negatively correlated.

2. The products of firms A and B are substitutes.

3. There exists a signal that forecasts the demand that Firm B will have. For example, if the signal predicts that the demand for the product of Firm B will be high, this means that the demand of Firm A will be
low and therefore, Firm A will be better off producing low.

Based on all the above assumptions, the Espionage Model consists of:

1. Two firms, A and B, that compete against each other in a Cournot competition.
2. A set of actions $I = (1, ..., n)$ and $J = (1, ..., n)$, taken by A and B respectively.
3. Two payoff matrices, $A = (a_{ij})$ and $B = (b_{ij})$, for each firm.
4. The probability $s$ that Firm A will chose to spy.
5. The probability that the Inspector will send an inspection alarm $0 < u < 1$. 
4 The Inspection Espionage Game

4.1 No Espionage Equilibrium

Figure 1 shows the possible responses of Firm A to the expected production decision of Firm B. Given that Firm B produced H, if Firm A decides to produce “high”, there will be an over supply situation (represented here as negative $a$ for Firm B and negative $b$ for Firm A). On the contrary, if Firm A produces “low”, neither firm will lose anything. The other case occurs when Firm B receives a signal forecasting a “low” demand and therefore it produces “Low”. In this situation, if Firm A produces “high”, there is no loss. However, if it produces “low” then it will lose the possibility of having fulfilled the demand (negative $b$).

Let’s now analyze the perfect and imperfect information games in normal form. In Figure 2 we assign probabilities to each outcome. We assume that Firm A assigns probability $\beta$ that Firm B will choose “high” and Firm B assigns probability $\alpha$ that its opponent will choose “high”. The game represented in Figure 2 shows that the two Nash equilibria are those that
set the aggregate supply equal to the amount of the aggregate demand, i.e: \((l, H)\) and \((h, L)\). These constitute a perfect Nash equilibrium in both cases, under perfect or imperfect information.

\[
\begin{array}{c|cc}
\alpha & B & H \\
\hline
A & (\beta) & (1-\beta) \\
\hline
h & (-a, -e) & (0, 0) \\
(1-\alpha) & (0, 0) & (0, -b)
\end{array}
\]

Figure 2: No espionage game

Considering the Nash equilibrium of this game, the optimal choices for \(\alpha\) and \(\beta\) are

\[
\alpha^* = 1, \text{ if } \beta^* = 0,
\]
\[
\alpha^* = 0, \text{ if } \beta^* = 1
\]

The presented equilibrium can be applied to the maximization problem of both firms. The problem of Firm B with respect to \(q_L\) is given by

\[
\pi^B_L = q_L[(1 - \alpha)(a - q_L - q(l) - c_L)] + (\alpha)(a - q_L - q(h) - c_L)]
\]

(1)

and the maximization problem of Firm B with respect to \(q_H\) is

\[
\pi^B_H = q_H[(1 - \alpha)(a - q_H - q(l) - c_H)] + \alpha[a - q_H - q(h) - c_H]]
\]

(2)

By solving both maximization problems and applying the Nash equilibrium \(\alpha^*\) and \(\beta^*\), we get the optimal choices of Firm B.
If $\alpha^* = 1$, and $\beta^* = 0$,

$$ q^*_L = \frac{a - q(h) - c_L}{2} \quad (3) $$

If $\alpha^* = 0$, and $\beta^* = 1$,

$$ q^*_H = \frac{a - q(l) - c_H}{2} \quad (4) $$

The maximization problem of Firm A is characterized by

$$\max \ (\pi_A) \text{ over } q(l) \text{ and } q(h), \text{ where}$$

$$\pi_A = \text{Prob}(l)[\text{Prob}(L|l) \ast q(l)(a - q(l) - q_L - c_l) + \text{Prob}(H|l) \ast q(l)(a - q(l) - q_H - c_l)] + \text{Prob}(h)[\text{Prob}(L|h) \ast q(h)(a - q(h) - q_L - c_h) + \text{Prob}(H|h) \ast q(h)(a - q(h) - q_H - c_h)]$$

which represented in terms of $\alpha$ and $\beta$ is equal to

$$\pi_A = (1 - \alpha)[(1 - \beta)(1 - \alpha) \ast q(l)(a - q(l) - q_L - c_l) + \beta(1 - \alpha) \ast q(l)(a - q(l) - q_H - c_l)] + \beta(1 - \beta)\alpha \ast q(h)(a - q(h) - q_L - c_h) + \alpha[(1 - \beta)\alpha \ast q(h)(a - q(h) - q_L - c_h) + \beta\alpha \ast q(h)(a - q(h) - q_H - c_h)] \quad (5)$$

The maximizing argument of Firm A if $\alpha^* = 0$, and $\beta^* = 1$ is

$$ q^*(l) = \frac{a - q_H - c(l)}{2} \quad (6) $$

otherwise,

$$ q^*(h) = \frac{a - q_L - c(h)}{2} \quad (7) $$
5 The Espionage Inspection Equilibrium

Following the literature on Inspection Games [Avenhaus et al., 2002], now we let an Inspector participate in the game. Its objective is to detect illegal espionage. First, we study the case in which the probability of receiving an alarm of inspection is exogenous, randomly distributed by nature and unknown to the firms. And finally, we develop the case in which the probability of inspection is endogenous.

5.1 Exogenous inspection probability

As shown in Figure 3, we assume that the probability of an inspection alarm (\(u\)) is given by nature. Therefore, we have a game in which Firm A has to decide whether to spy on its opponent’s action or not. Also, it is assumed

As shown in Figure 3, we assume that the probability of an inspection alarm (\(u\)) is given by nature. Therefore, we have a game in which Firm A has to decide whether to spy on its opponent’s action or not. Also, it is assumed
that the loss of being caught spying is greater than any possible loss of a potential bad choice. For example, if Firm A decides not to spy and choses to produce “high” when Firm B is also producing “High” it will lose, \(-b\); if Firm A produces “low” when its opponent goes “Low” it also losses \(-b\) (given that \(e \geq b\)).

Therefore, the expected utilities of Firm B are the following

\[
E_B[\text{Espionage}] = -\mu e,
\]
\[
E_B[\text{Produce high}] = -\beta b,
\]
\[
E_B[\text{Produce low}] = -(1 - \beta)b.
\]

As such, we know that Firm B will be indifferent between spying and producing high if \(\mu^* = \frac{\beta b}{e}\), it will be indifferent between spying and producing low if \(\mu^* = \frac{(1-\beta)b}{e}\), and indifferent between all three options if \(\beta^* = \mu^* = \frac{1}{3}\) and \(e = b\).

### 5.2 Endogeneity of the inspection probability

In this section, I analyze the equilibrium in the case of endogeneity of the inspection probability. For this, let’s assume that the Inspector uses a random device which gives him a signal about possible espionage going on in the market of Firm A and Firm B. Depending on the signal he receives he will choose to send an inspection alarm or not. Also, let’s assume that Firm A uses an espionage device \(\theta\) which gives it a set of signals about its opponent’s action.

This section is divided into two parts. In the first one, I study the case of a simple Nash Equilibrium of a game where the players (Inspector and Inspectee) do not integrate the available devices in their payoff functions.
This means that Firm A does not use any espionage device and the Inspector does not use any signal to detect illegal actions. The second approach follows the literature on *Inspection Games* in which the players include the use of the mentioned devices in their maximization problem.

### 5.2.1 No-devices equilibria

![Figure 4: Endogeneity of the inspection probability.](image)

Figure 4: Endogeneity of the inspection probability. The action of Firm B is exogenous to the model. The first term of the payoffs correspond to Firm A and the second row to the *Inspector*. Where \( \beta \) is given by nature, \( 1 > e \geq b \), and \( 1 > h > a \).

Figure shows the payoffs of the espionage inspection game for the *Inspectee* and the *Inspector*. It is assumed that if Firm A decides to spy with probability \( s \) and the *Inspector* sends an alarm, the spy will be caught and will receive a fine \(-e\). If it is not caught, it gets 0 penalty. In case Firm B goes *High*, if Firm A behaves legally and chooses *high* it losses \(-b\) and if it chooses *low* it losses 0, whether the *Inspector* sends an alarm or not. If Firm B goes *Low*, when Firm A chooses *high* it losses 0 and when it chooses *low* it gets \(-b\).
An Inspection Espionage Game

The second element of the payoffs presented in Figure 4 refers to the Inspector’s outcome. The payoff \(-a\) represents the cost for the Inspector to send an alarm. In the case he doesn’t send an alarm and Firm A decides to \\textit{spy}, the Inspector losses \(-1\). Also, the cost for the Inspector of sending a false alarm, this is an alarm in the case where Firm A has decided not to spy, is equal to \(-h\).

Firm A will be indifferent between choosing whether to spy or not if \(\mu^* = \beta^* = (1 - \beta^*) = \frac{1}{3}\) and if \(e = b\). This happens if the penalty of being caught spying is the same as the loss it will face if it chooses a bad action.

On the other hand, the Nash equilibrium of \(s\), the probability of spying, is given by,

\[
s^* = \frac{h}{1-a+h}, \text{ where } h \text{ is the cost of a false alarm and } a \text{ the cost of detection efforts.}
\]

5.2.2 Devices equilibria

Following Avenhaus et al. [2002] now we assume that the payoff functions of the players depend on the devices available in the game.

\textit{Definition 1.} \(Z\) is a variable describing the Inspectee’s actions available to the Inspector. Its distribution depends on the spying device used by Firm A.

\textit{Definition 2.} An endogenous inspection game with probability of detec-
An Inspection Espionage Game

tion in normal form is defined as

\[ G = ((A, B), I, J, \varsigma, z) \]

where,

- \((A, B)\) is the base game.
- Payoff matrices \(A = (a_{ij})\) and \(B = (b_{ij})\).
- Set of actions \(I = (1,\ldots,n)\) and \(J = (1,\ldots,n)\), taken by Firm A and Firm B respectively.
- \(\varsigma\) is the finite set of signals that the espionage device used by Firm A \((\theta)\) sends back to it. \(\varsigma: J \to \Delta(\theta)\).
- \(z\) is the Inspector’s observations of the random variable \(Z\).

The strategy of Firm A consists of \(s\), the probability of behaving illegally, and \(\theta\), the spying mechanism. Given the observations \(z\), the Inspector applies a statistical hypothesis test \(\delta\). This test \(\delta\) constitutes his strategy.

**Assumption.** The Inspector uses the observations \(z\) of the random variable \(Z\) to build a statistical hypothesis test \(\delta \in [0,1]\).

The Inspector maximizes his payoff,

\[ I(\delta, (s, \theta)) = (1 - s)(-e\gamma(\delta)) + s(-a - (1 - a)u(\delta, \theta)) \]

and Firm A maximizes its payoff represented as,

\[ A(\delta, (s, \theta)) = (1 - s)(-h\gamma(\delta)) + s(-b + (1 + b)u(\delta, \theta)) \]
Following Avenhaus et al. [2002], I integrated $\gamma(\delta)$ which represents the probability of a false alarm, where $\gamma$ is a convex function. As shown in Figure 4, the probability of not sending an alarm is equal to $(1-u)$. In this section we will call this probability $\xi$ for notation purposes. Therefore, the probability of non-detecting espionage is $\xi(\delta, \theta)$, where $\xi$ is also a convex continuous function.

In the non-detection case, the payoff for the Inspectee is $\xi(\delta, \theta) = 0$, where Firm A will maximize $\theta$ and the Inspector will try to minimize $\delta$.

$$\xi(\gamma) := \min_{\delta} \max_{\theta} \xi(\delta, \theta) \tag{8}$$

where

$$\delta \in [0, 1] \tag{9}$$

and

$$\xi(0) = 1, \quad \xi(1) = 0 \tag{10}$$

Therefore, spying or not is indifferent to Firm A if the false alarm probability equals the following,

$$-b\gamma(\delta^*)(1 - s) = -b$$

$$\gamma(\delta^*) = \frac{1}{1 - s} \tag{11}$$

And in equilibrium the probability of espionage $s$ is the same as in the former section,

$$s^* = \frac{h}{1 - a + h} \tag{12}$$

6 Conclusions

This paper joins the recent and scarce literature on industrial espionage games with the more studied theory of inspection games. We construct a
model which allows the intervention of an Inspector which maximizes the probability of detecting espionage. First, we studied a Cournot game with incomplete information in which Firm B can have a high or low expected demand and spying is not allowed. Second, we analyze the same game but we allow Firm A to choose between spying on its opponent or not and later, we incorporate an Inspector. The Espionage Inspection Equilibrium was found by incorporating the concepts describing the behavior of the Inspector presented by Avenhaus et al. [2002] in the Cournot competition game.

This work can serve as a basis for further studies on industrial espionage inspection. It would be interesting to perform a similar analysis in a Bertrand duopoly competition, in an oligopoly competition model, or in a sequential game.
References


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