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Abstract

We analyze industrial espionage in the context of entry deterrence. We consider a monopoly incumbent, who may expand capacity to deter entry, and a potential entrant who owns an inaccurate Intelligence System. The Intelligence System generates a noisy signal on incumbent's actions and the potential entrant decides whether to enter based on this signal. If the precision of the Intelligence System is commonly known, the incumbent will signal-jam to manipulate the distribution of likely signals and hence the entrant's decisions. Therefore, the incumbent will benefit from his rival's espionage. In contrast, the spying firm (the entrant) will typically gain if the espionage accuracy is sufficiently high and privately known by her. In this setting, the market will be more competitive under espionage.

JEL Classification: C72; D82; L10; L12

Keywords: Espionage; Entry; Asymmetric information; Signal-Jamming.

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1. Introduction.

An important part of firm information is relative to other firms and it may be about production processes and techniques, costs, recipes and formulas, costumer datasets, actions, decisions, plans and strategies, etc[1]. But firms do not always get information ethically and legally. The illegal and unethical process of getting information about other firms is called *industrial espionage*[2]. Industrial espionage has a large history and during the last few years, the more competitive environment based on knowledge and the advances in communication and information technologies have increased firms' incentive to exceed the limits of competitive intelligence activities. As a result, industrial espionage has become an important, even worrying, business practice. For instance, according to 1997 US State Department and Canadian Security and Intelligence Service Reports, industrial espionage costs US business over 8.16 billion dollar annually. Moreover, 43% of American firms have had at least six incidents of industrial espionage[3], embracing various activities in order to achieve cost advantages, to maintain market leadership, and the like. The issue is becoming so important that, one of the leaders of a recent *The Economist* (21st of February), analyzes China's cybercrime under the title "China's cyber-hacking. Getting ugly," where it is said that some criminal tribes operate inside the target multinational firm and misappropriate its resources, while others use purloined property and know-how to start rival businesses after (or even before) leaving the firm.

We wish to analyze the impact of industrial espionage on the strategic behavior of firms in the context of entry deterrence. It is assumed that the entrant spies on the incumbent's actions through some spying technology. The technology is not perfectly accurate and hence the incumbent's actions generate noisy signals. When the signal

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[1] As *Business Week* reported in 2002, most of the large companies have competitive intelligence. staff, many large US firms spend more than a million dollar a year on competitive intelligence issues, and multinational firms like Kodak, General Motors and British Petroleum have their own competitive intelligence units. See Billand et al (2009), page 2.

[2] Nasheri (2005).

[3] See Solan and Yariv (2004), page 174, footnote 1.

precision is common knowledge, only the incumbent will benefit from his rival's espionage activities. He rather uses his first mover advantage to signal-jam, or to strategically choose his actions, to manipulate the distribution of likely signals and hence the likely inferences drawn by the entrant. By correlating his actions with the precision of the spying technology, the incumbent is able to influence on the entrant's decision. In contrast, when only the entrant has private information of the signal precision, she uses both her private knowledge and her second mover advantage to correlate her action with that of the incumbent and benefit from espionage. The incumbent will signal-jam again using the expectation of the precision as a proxy for its true value. However, the entrant cannot be manipulated as before and, for some values of the precision, she makes equilibrium entry decisions independently of the signal received.

Although entry deterrence has been extensively studied in the literature[4] , the effects of espionage on this context have not yet been analyzed. Market entry is one of the most fundamental decisions a firm has to make and so is the incumbent's reaction before the threat of entry[5]. One of the possible incumbent's responses to deter entry is to invest in capacity expansion. Examples of strategic capacity expansion can be the famous one of the titanium dioxide industry (see Ghemawat, 1984 and Hall, 1990) and the "sleeping patents" of the bio-pharmaceutical industries and/or Airline companies (see Sull, 1999) among others.

The classical and stylized model of entry deterrence by capacity expansion assumes the existence of a monopoly incumbent and a potential entrant to the market. Under perfect information and sequential moves the entrant stays out if the incumbent's capacity is expanded and enters otherwise. However, capacity expansion requires an investment and in the real world the entrant does not observe ex-ante the incumbent's decision of whether to invest in capacity. Hence, the entrant enters only if she believes that with high probability the capacity was not expanded.

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[4] For a survey of this literature see Wilson (1992).

[5] See Milgrom and Roberts (1982), page 282.

To analyze industrial espionage in this context, we extend the entry game to include spying actions. This sort of activity is typically done by a market research firm. For example, the case study of Mezzanine Group (2010) deals with an entrant in an energy market that asked a consulting company (*The Mezzanine Group*) to evaluate the competitive landscape of Ontario market, and where the incumbent's strategies were part of the information the entrant obtained.

However, when the spy is a decision maker who can act strategically then double crossing may appear (see Ho, 2008). To avoid these strategic effects it is assumed that the entrant operates a costless Intelligence System (IS) which is set to detect the incumbent's action. This could be the case if a firm had already a spying technology before it encounters a new rival, for instance, the potential entrant could have the ability to introduce a Trojan horse in the computer system of the monopoly incumbent and obtain information about the action he plans to take. Today, the use of Trojan horse computer viruses for industrial espionage is a real practice. For instance, in 2005 three top-tier Israeli firms were suspected to use them in Israel to monitor competition in the cable industry, communications, office-equipment, photocopy, cars and trucks[6].

The IS sends out one of two signals. One signal, labeled *i*, indicating that the incumbent invests in new capacity and another signal, labeled *ni,* indicating the opposite. The IS has a precision, this meaning that the signal sent by the IS will be correct with a probability equal to the IS precision. Based on the signal received, the entrant decides whether or not (or with what probability) to enter the market.

Let us start with the benchmark case where the precision of the IS is commonly known. That is, when the incumbent knows his computer system is infected with a Trojan horse and how much information the potential entrant obtains through it[7]. Since the entrant only observes a signal from the IS and takes an action, this allows the incumbent to advantageously signal-jam or choose his capacity expansion probability, to influence on the conditional probability that the entrant enters, given the signal

[6] See Singer-Heruti (2005).

[7] However, this is not a very unrealistic assumption since the incumbent can realize his computer system is infected by a Trojan horse using antivirus software and know the last date of access to his computer files. With this information he can deduce which documents could have been accessed by the potential entrant.

received. Consider[8] that the investment cost is low enough such that the incumbent would prefer to invest if he knew that the entrant would enter. If, for instance, the precision of the IS is relatively high, the incumbent, will know that if he does not expand capacity, the entrant will detect this with high probability and she will likely enter. Hence, the incumbent will expand his capacity with high probability, and then the signal ni will be less likely to occur. Consequently, when the entrant observes the signal ni, she will no longer rely on its accuracy and she will rather stay out with positive probability, while if she observes signal *i* will stay out with probability one. As the IS precision increases, the probability of the signal ni and the conditional probability that the entrant enters given ni decreases. Therefore, the incumbent signal-jams by expanding capacity with a positive probability that is increasing in the IS precision. Alternatively, if the IS precision is less accurate, the incumbent will expands capacity with smaller probability, knowing that there will be a good chance that his action will not be detected. Furthermore, he will expand capacity with a positive probability that is decreasing in the IS precision, in order to decrease the unconditional probability that the entrant enters. The incumbent will benefit from the IS more than its owner, the entrant, if the IS is relatively accurate.

Next we analyze the asymmetric information case where the IS precision is private information to the entrant. The incumbent only knows the distribution of this precision and believes with positive probability that the entrant is operating an IS[9]. He will signal-jam at the (Bayesian) equilibrium by following the expectation of the precision as a proxy for its real value. However, the entrant cannot be as easily fooled as before because she knows the true value of the precision and compares it with its expectation. She plays pure strategies and, for some values of the precision, takes an entry decision independently of the signal received. Namely, if the expected precision of the IS is not too high, the incumbent will believe that the true precision is low and with high

[8] We leave aside the case where the investment cost is sufficiently high so that the incumbent would prefer not to invest even if he knew that the entrant would enter.

[9] For instance, the incumbent correctly believes that the entrant introduced a Trojan horse in his computer system, but he is not sure of how much information the potential entrant obtained through it.

probability he will not expand capacity believing that the entrant will not likely detect him. Then the entrant, following the more likely signal, ni, will enter the market irrespective of the actual precision. On the other hand, if the expected precision of the IS is high enough, the incumbent will believe now that the true precision is relatively high and the entrant will likely detect his action. Hence, the incumbent expands his capacity with relatively high probability, and the entrant, following the less likely signal, ni, will enter the market if the actual precision is relatively high and will not enter otherwise. If the signal is *i*, the entrant does not enter irrespectively of the IS precision. The entrant obtains positive payoff if the IS precision is sufficiently large and this payoff is increasing in this precision while the incumbent will be better off when the IS is not relatively accurate.

Therefore when espionage activities are undertaken with noise, the spied upon incumbent always practice signal-jamming, and he will be more successful in manipulating the entrant signals the more knowledge he has of the spying technology accuracy. When, instead, the IS accuracy is only the entrant's private information and the information is very asymmetric, market competition is increased because the entrant enters most of the times. Furthermore, the incumbent invest less in capacity making the market more efficient.

1.1 Related Literature

The paper is related to several research strands. The first strand is concerned with papers on industrial espionage. Solan and Yariv (2004) study espionage games, where the precision is costly and it is a choice strategic variable. Provan (2008) has a closer structure to us but it is more computational-based approach, using linear programming solutions for two-person-zero-sum games. Matsui (1989) considers a two person repeated game where every player has a small probability of perfectly detecting the other player's action and revise his strategy accordingly. The espionage double crossing phenomenon is the focus of Ho (2008). Espionage is used there to learn the rival's private information. Unlike Ho (2008), espionage in our paper, as well as in Solan and Yariv (2004) and Matsui (1989), is used to obtain information about the rival's action. Whitney and Gaisford (1999) study a duopoly competition between two companies (Airbus and Boeing) where one company spies in an attempt to learn its technology and as a result to be able to lower its own marginal cost. The intelligence system can result with either a pure success or a pure failure and it does not generate any noise. The outcome of the IS is assumed to be common knowledge. In a recent paper, Billand, Bravard, Chakrabarti and Sarangi (2009) study espionage in a Cournot model of several firms with differentiated goods. Their model is of symmetric information where firms observe the full espionage activity before choosing their quantity levels. Finally, our paper is similar in spirit to Biran and Tauman (2009), who deals with the role of intelligence in nuclear deterrence.

The second strand is the signal-jamming literature in oligopolistic models (Riordan 1985); Aghion, Espinosa and Jullien ,1993; Mirman, Samuelson and Urbano, 1993; Caminal and Vives 1996; Alepuz and Urbano, 2005, among others), where firms internalize how their output decisions affect price and influence the inferences of other firms, and hence their subsequent actions.

A third limit pricing/signaling strand develops two period models of entry deterrence where firms have private information about demand or cost and take actions (limit pricing) that influence the inference of other firms. In the limit pricing models of Harrington (1986, 1987), Caminal (1990), and Mailath (1989), etc., an incumbent's price duopoly or duopoly prices signal information about the costs of an entrant.

Finally, the paper is related with the sharing information in oligopoly markets as in Vives (1984), Raith (1996), and Gal-Or (1985, 1986, 1988), among others, where the equilibrium outcomes can be solved for conditional on the information revealed.

The next section sets out the basic model. In section 3 we analyze the Nash equilibrium of the entry game with espionage when the IS precision is commonly known. Section 4 is devoted to find the Bayesian Nash equilibrium strategies when the IS precision is the entrant's private information. Section 5 concludes the paper

2. The basic model.

There are two firms, M and E. The Incumbent Firm, M, is a monopolist and E is a potential entrant[10]. In an attempt to deter E from entering M considers whether to invest or not to invest in a new capacity. E has an Intelligence System (IS) that monitors the action of M. The IS sends a noisy signal, one of the two signals i or ni. The signal i indicates that M invests and the signal ni indicates that M does not invest. The IS sends the right signal with probability α and the wrong signal with probability $1-\alpha$. For simplicity we assume that the precision, α, of the IS is independent of the action of M. It is assumed w.l.o.g that $\frac{1}{2} \leq \alpha \leq 1$. If $\alpha = \frac{1}{2}$, the IS is of no relevance and if $\alpha = 1$, the IS is perfect. The following tree summarizes the above:

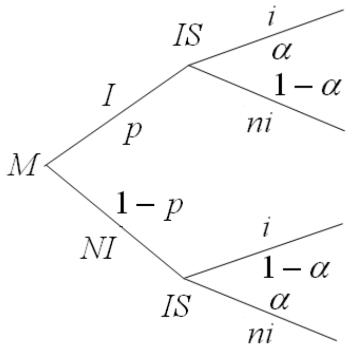

Figure 1

Based on the signal received E decides whether or not to enter the market.

The following table describes the payoffs of the two firms based on their possible actions:

M \ E	E	NE
I	b, -1	c, 0
NI	0, 1	1, 0

Figure 2

[10] With an abuse of notation, the letter E is used to denote the entrant, the action "enter" and also for expectations later on. However, no confusion should arise.

Where $0 < b < c < 1$ (AS1)[11]

3. The benchmark case: α commonly known.

We first focus on the case where α is common knowledge. In particular, M knows that E spies on him with an IS of precision α. Let us start with the two extreme cases where $\alpha = \frac{1}{2}$ and $\alpha = 1$.

If $\alpha = \frac{1}{2}$, then it will be basically as if E does not operate an IS on M, and the strategic game between M and E is described in Figure 2. This game has a unique Nash equilibrium in which: M invests with probability $\frac{1}{2}$ and E enters the market with probability $\frac{1-c}{1-c+b}$, which is decreasing in both b and c. Namely, the higher is the payoff of M from expanding capacity the lower is the probability that E enters.

The payoff of E is zero (E is indifferent between entering and not entering), and the payoff of M is $\frac{b}{1-c+b}$ (which increases in b and c).

The second case is $\alpha = 1$ and M's action is perfectly detected by E. In this case, E chooses her action based on M's action. This game can be described by the following tree:

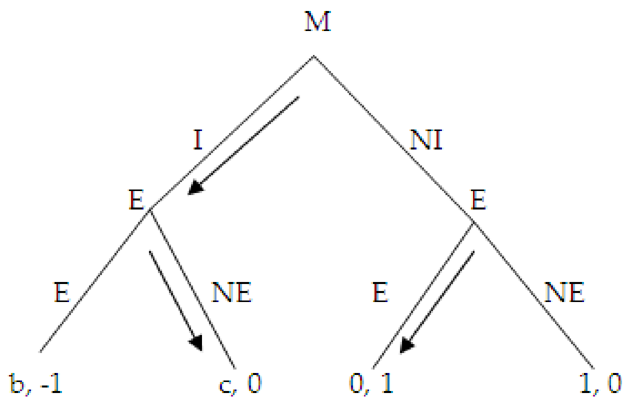

Figure 3

[11] The case where $b < 0$ is trivial as I is strictly dominated by NI.

A perfect signal allows the Incumbent take advantages as a leader in a sequential game and the backward induction is the unique Nash equilibrium. M expands his capacity and E does not enter the market. This outcome yields a higher payoff for M than the equilibrium outcome for $\alpha = \frac{1}{2}$. The payoff of E is zero in both two cases. Hence, only M benefits from a perfect IS. The entrant, who spies on M and who is able to perfectly monitor M's action (before taking her action) does not benefit at all from using it. This result follows by the assumption that α is commonly known.

The general case: $\frac{1}{2} < \alpha < 1$.

The entrant has four pure strategies. A pure strategy of E is a pair (x, y) where both x and y are in $\{E, NE\}$, x is the action of E if she observes the signal ni and y is her action if she observes the signal i. The following figure describes the game, G_α, between M and E in strategic form (see Figure 1 and Figure 2):

M \ E	(E, E)	(E, NE)	(NE, E)	(NE, NE)
I	$b, -1$	$\alpha c + (1-\alpha) b, -1+\alpha$	$\alpha b + (1-\alpha) c,\ -\alpha$	$c, 0$
NI	$0, 1$	$1-\alpha, \alpha$	$\alpha, 1-\alpha$	$1, 0$

Figure 4

For instance, the strategy (E, NE) of E is to enter the market if the signal is ni and not to enter if the signal is i. The strategy (E, E) is to enter the market irrespective of the signal.

Note that the strategy (NE, E) of E is strictly dominated by her strategy (E, NE), since $\alpha > \frac{1}{2}$. Therefore the strategy (NE, E) can be removed, and the resulting game is:

	M \ E	(E, E)	(E, NE)	(NE, NE)
p	I	$b,-1$	$b+(c-b)\alpha,\ -1+\alpha$	$c,0$
1-p	NI	0,1	$1-\alpha, \alpha$	1, 0

Figure 5

Let $\bar{\alpha} = \max\left[\frac{1}{2}, \frac{1-b}{1-b+c}\right]$. This parameter plays a central role in our analysis[12]. The following Proposition states the equilibrium signal-jamming of the incumbent and the entrant's equilibrium entry decision. From now on all the proofs are in the Appendix.

Proposition 1. Suppose that $\alpha \neq \bar{\alpha}$. Then G_α has a unique Nash equilibrium.

(1) The Incumbent randomizes between expanding and not expanding its capacity. The probability that M expands capacity is decreasing in α for $1/2 < \alpha < \bar{\alpha}$ and it is increasing in α for $\bar{\alpha} < \alpha < 1$.

(2) If the Entrant observes the signal ni, she will enter the market with probability 1 if $\alpha < \bar{\alpha}$ and she will randomize her two actions if $\alpha > \bar{\alpha}$. If she observes the signal i she will randomize her two actions if $\alpha < \bar{\alpha}$ and will stay out with probability 1 if $\alpha > \bar{\alpha}$.

(3) Suppose now that $\alpha = \bar{\alpha}$. Then, the Entrant will enter the market with certainty if she observes the signal ni and she will stay out with certainty if she observes the signal i. The Incumbent has a continuum of best reply strategies.

The intuition is as follows. When $1-c \leq b$ (see Figure 2), the cost of making a mistake for M is larger when E enters than when E does not enter. Note that in this case

[12] Note that when E chooses her strategy (E, NE) and $\alpha = \frac{1-b}{1-b+c}$, M is indifferent between investing and not investing.

$\bar{\alpha} = \frac{1}{2}$ and, hence, $\alpha > \bar{\alpha}$ for all $\alpha \in \left(\frac{1}{2}, 1\right)$. Since $b \geq 1-c$ the penalty of M for not expanding capacity if E enters is relatively high. Thus M invests in capacity expansion with relatively high probability. Actually, this probability is shown to be equal to the precision α of the IS and since $\alpha > \frac{1}{2}$ E expects to observe signal i with higher probability than signal ni. As a result, E will stay out for sure if she observes the signal i and E will hesitate if she observes the less expected signal ni. In the latter case E will mix her two pure actions. The higher is the precision α of the IS the higher is the probability that M invests and the higher is the probability that E stays out.

When, on the contrary, $1-c > b$, then $\bar{\alpha} > \frac{1}{2}$ and the equilibrium outcome depends on whether $\alpha < \bar{\alpha}$ or $\alpha > \bar{\alpha}$. If the precision α of the IS is sufficiently large ($\alpha > \bar{\alpha}$), M knows that his action will be correctly detected with high probability. Therefore he expects that if he did not expand capacity, E would likely enter. Hence, M expands his capacity with high probability, in fact with probability α. Consequently, the signal ni is not likely to occur. If E observed this signal, she would not trust and would update her belief about M's action. As a result, she would not enter with positive probability. On the other hand, E expects the signal i and when she observes it, she trusts its accuracy and does not enter with probability 1.

If the precision of the IS is not too accurate ($\frac{1}{2} < \alpha < \bar{\alpha}$), M assigns significant probability that his action will not be accurately detected. Therefore, in an attempt to conceal his action, M mixes his two strategies I and NI, both with significant probabilities ($1-\alpha$ and α respectively). Thus both signals i and ni have reasonable likelihood to occur. However the signal ni is more likely than the signal i since $\alpha > 1-\alpha$. As a result E will enter with probability 1 if the signal is ni and will randomize her actions if the signal is i.

An increase in the quality α of the IS increases the reliability of the signal generated. Hence, when E observes the signal i she enters the market with lower probability and M is better off. Less intuitive is the fact that as α increases M invests with lower probability and reduces the probability of the signal i. However, we argue that this decreases the probability that E enters, as we show in the next proposition.

<u>Proposition 2.</u> Consider the equilibrium of G_α. Then, the probability that E enters the market is positive and decreasing in α for all $\alpha \in \left(\frac{1}{2},1\right)$.

If the precision of the IS is not too accurate ($\frac{1}{2} < \alpha < \bar{\alpha}$), M expands capacity with probability decreasing in α. This behavior of M implies that the increase of α has two opposite effects on the unconditional probability that E enters. The positive effect is the increase of the probability of the signal ni, which contributes to the increase of the probability that E enters (E enters with probability 1 when she observes the signal ni). On the other hand, it decreases the conditional probability that E enters given i, which contributes to the decrease of the probability that E enters. It turns out that the latter effect outweighs the positive effect and as a result the unconditional probability that E enters decreases in α. Similarly, If the precision of the IS is relatively accurate ($\bar{\alpha} < \alpha < 1$), M will expand capacity with probability increasing in α. Hence, as α increases, the probability of the signal ni and the conditional probability that E enters given ni decrease. This implies that the unconditional probability that E is decreasing in α.

<u>Proposition 3.</u> Consider the equilibrium of G_α. Then, the expected payoff of the Incumbent is increasing in α, for all α, and the expected payoff of the Entrant is increasing in α for $\frac{1}{2} < \alpha < \bar{\alpha}$ and it is zero for all α, $\bar{\alpha} < \alpha < 1$.

The proposition implies that E is better off the higher is the precision of the IS as long as it is smaller than $\bar{\alpha}$ (see Figure 6). Let Π_E be the equilibrium expected payoff of E.

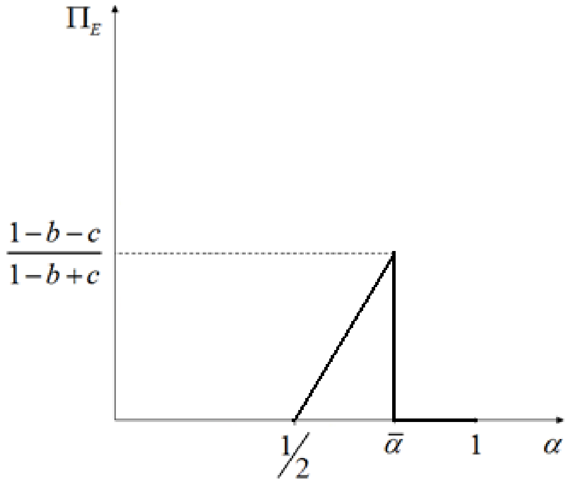

Figure 6

Which is the explanation of figure 6? By Proposition 1, if $\frac{1}{2} < \alpha < \bar{\alpha}$, then E will randomize between (E,E) and (E,NE). Moreover, in equilibrium the Entrant will enter the market with probability 1 if the signal is ni, and with some probability (see the Appendix) if the signal is i. Furthermore, by Proposition 1, at this interval, the Incumbent will randomize between expanding and not expanding its capacity with probability decreasing in α. The effect is the increase of the probability of the signal ni, which contributes to the increase of the Entrant's expected payoff from playing (E,E). Since she plays a mixed strategy, her expected payoffs from playing (E,E) are the same than those from playing (E,NE), and the former are clearly increasing in α. Therefore even though the probability that E enters the market is decreasing in α, the entrant' expected payoffs are increasing in α, for the interval $\frac{1}{2} < \alpha < \bar{\alpha}$,

Note that that for $\bar{\alpha} < \alpha < 1$, by Propositions 1 and 2, even if the IS is cost free, E has no incentive to use it since her payoff is zero irrespective of the quality α. The expected payoff of the Incumbent is increasing in α, for all α, since the probability that E enters the market is decreasing in α. Hence, M is best off with a perfect IS, even thought that means perfect monitoring of his actions.

To sum up, when the Incumbent knows the value of α (namely, it is common knowledge), he signal-jams using the IS precision as a correlation device and benefits from his rival's espionage. This signal-jamming activity is inefficient for the market, since it may imply an excess of capacity. Therefore, an important question is whether espionage activities enhance market efficiency, as compared with no espionage, when the IS precision is common knowledge. The answer is affirmative only if the IS precision is small enough ($1/2 < \alpha < \bar{\alpha}$). In this interval, the incumbent signal-jamming strategy forces him to invest less in capacity to decrease the unconditional probability that the Entrant enters. This behavior increases the probability of the signal *ni* and hence the Entrant´s profits. As a consequence, both firms are better off which is Pareto improving and the capacity of the market is more efficient that under no espionage.

4. Asymmetric information about the precision of the IS.

In this section we assume that the precision α of the IS is the private information of its owner, E. The Incumbent, who doesn't know α, assigns a continuous density probability $f(\alpha) > 0$ to every α, $\frac{1}{2} \le \alpha \le 1$ and $\int_{\frac{1}{2}}^{1} f(\alpha)\, d\alpha = 1$. In other words, E knows the game G_α which is actually being played while M doesn't know what game is being played. But M knows that α is chosen according to $f(\alpha)$, and this is commonly known. Denote by Γ this game.

Let u_M and u_E be the utilities of the two firms from the various outcomes. As in the previous section (see Figure 2), it is assumed that

$$\begin{array}{ll} u_M(I, E) = b & u_E(I, E) = -1 \\ u_M(I, NE) = c & u_E(I, NE) = 0 \\ u_M(NI, E) = 0 & u_E(NI, E) = 1 \\ u_M(NI, NE) = 1 & u_E(NI, NE) = 0 \end{array}$$

Let $E(\alpha) = \int_{\frac{1}{2}}^{1} \alpha\, f(\alpha)\, d\,\alpha$ be the expected value of α. Namely $E(\alpha)$ is the expected quality of the IS from the perspective of the uninformed M.

The next proposition shows that at the (Bayesian equilibrium) the incumbent signal-jams again, using the expectation of the precision, and that the Entrant follows a pure strategy.

Proposition 4. Suppose that $E(\alpha) \neq \overline{\alpha}$. Then Γ has a unique perfect Bayesian equilibrium.

(1) If $E(\alpha) > \overline{\alpha}$, there exists $\overline{p}_1$, $\frac{1}{2} < \overline{p}_1 < 1$ such that M will expand capacity with probability $\overline{p}_1$. If the signal is ni, E will not enter the market if $\alpha < \overline{p}_1$ and she will enter if $\alpha > \overline{p}_1$. If the signal is i, E will not enter irrespective of the precision α of the IS.

(2) If $E(\alpha) < \overline{\alpha}$, there exists $\overline{p}_2$, $0 < \overline{p}_2 < \frac{1}{2}$, such that M will expand capacity with probability $\overline{p}_2$. If the signal is ni, E will enter the market irrespective of the precision α of the IS. If the signal is i, E will not enter if $\alpha > 1 - \overline{p}_2$ and she will do it if $\alpha < 1 - \overline{p}_2$.

The next two figures illustrate the results of Proposition 4:

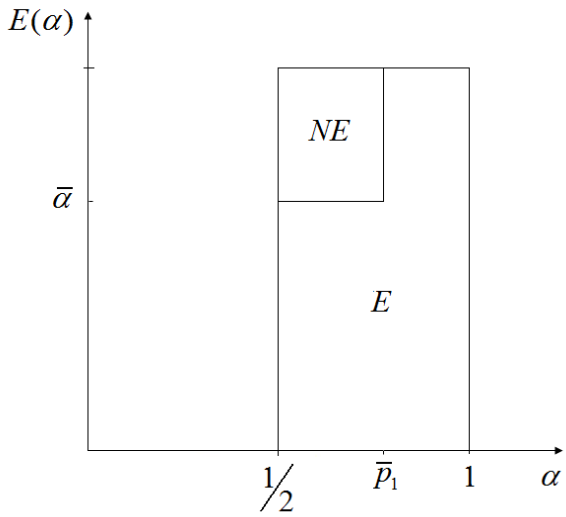

Figure 7: The decision of E when the signal is ni

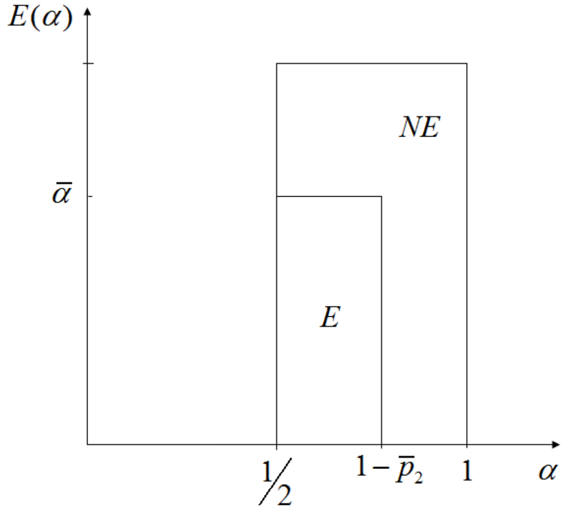

Figure 8: The decision of E when the signal is i

Notice that unlike the case where α is commonly known, the equilibrium strategy of E of type α is a pure action (enter or not enter the market with probability 1). However, M mixes his two pure actions to signal-jam, similarly to the common knowledge case.

The action of E depends on both the expected and the actual precision of the IS. If the expected precision of IS does not exceed $\bar{\alpha}$, M will believe that the true IS precision is low and with high probability he will not expand capacity believing that E will not likely detect him. Then E, following the more likely signal ni, will enter the market irrespective of the actual precision. Furthermore, E will enter the market even if she receives the signal i and if the actual precision α is relatively small ($\alpha < 1 - \bar{p}_2$), otherwise she will not enter. If on the other hand, the expected precision of the IS exceeds $\bar{\alpha}$, M will believe that the true precision is relatively high and E will likely detect his action. Hence, M will expand his capacity with relatively high probability, and E, following the less likely signal ni, will enter the market if the actual precision is relatively high ($\alpha > \bar{p}_1$) and will not enter otherwise. If the signal is *i*, the entrant will not enter irrespectively of the IS precision.

Next we analyze the expected payoff of the entrant. Let $\pi_E(\alpha)$ be the equilibrium expected payoff of E when the precision of the IS is α. The next proposition provides a significant change from the symmetric information case.

Proposition 5. Consider the equilibrium of Γ. Then,

(1) Suppose that $E(\alpha) > \overline{\alpha}$. Then for all α in the interval $\left(\frac{1}{2}, \overline{p}_1\right)$ E does not enter the market, irrespective of the signal received, and $\pi_E(\alpha)$ is zero in this interval. For all α in $(\overline{p}_1, 1)$, $\pi_E(\alpha)$ is strictly increasing.

(2) Suppose that $E(\alpha) < \overline{\alpha}$. Then for all α in the interval $\left(\frac{1}{2}, 1-\overline{p}_2\right)$ E enters the market, irrespective of the signal sent by the IS, and $\pi_E(\alpha)$ is a positive constant in this interval. On the other hand, for all α in $(1-\overline{p}_2, 1)$, $\pi_E(\alpha)$ is strictly increasing.

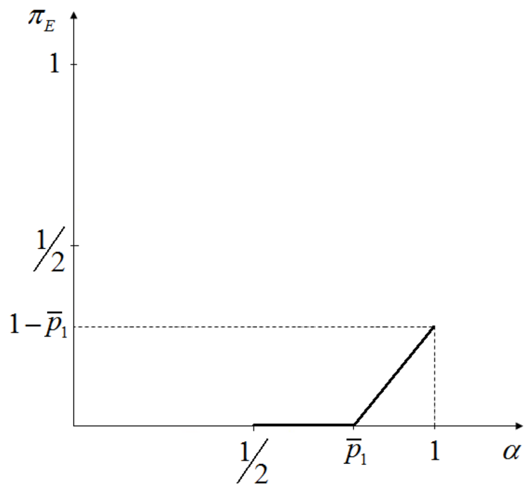

Figure 9: The expected payoff of E when $E(\alpha) > \overline{\alpha}$

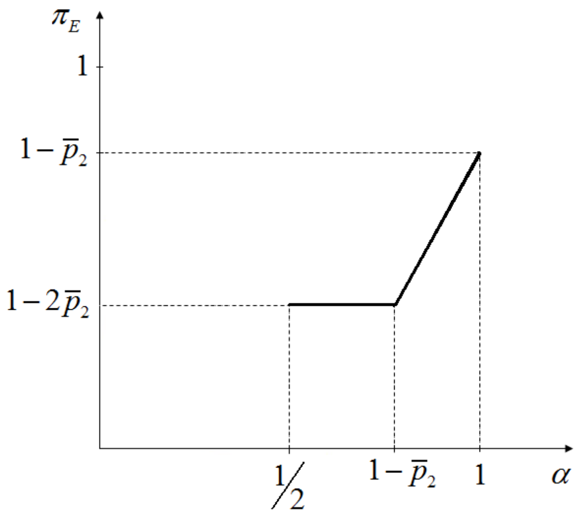

Figure 10: The expected payoff of E when $E(\alpha) < \overline{\alpha}$

In contrast to the common knowledge case, Proposition 5 shows that in the asymmetric case E is always best off with a perfect IS. The payoff of E as function of α is constant up to a certain α since her equilibrium strategy does not depend on the signal generated by the IS: she will not enter and, hence, her equilibrium expected payoff will be zero if $E(\alpha)>\bar{\alpha}$ and she will do it if $E(\alpha)<\bar{\alpha}$. Thereafter, the equilibrium expected payoff of E is strictly increasing because she can detect M's action with a relatively accurate precision and choose her strategy accordingly. The expected equilibrium payoff of E when $E(\alpha)<\bar{\alpha}$ is greater than when $E(\alpha)>\bar{\alpha}$ because in the former M invest with low probability believing that E is not likely to detect him.

The next proposition describes the equilibrium payoff of M.

<u>Proposition 6.</u> Consider the equilibrium of Γ. Then,

(1) If $E(\alpha)>\bar{\alpha}$, $\pi_M(\alpha)$ is constant for $\frac{1}{2}<\alpha<\bar{p}_1$. For $\bar{p}_1<\alpha<1$, $\pi_M(\alpha)$ is strictly decreasing if $\frac{1}{2}<\bar{p}_1<\frac{1}{1-b+c}$, and it is strictly increasing if $\frac{1}{1-b+c}<\bar{p}_1<1$.

(2) If $E(\alpha)<\bar{\alpha}$, $\pi_M(\alpha)$ is constant for $\frac{1}{2}<\alpha<1-\bar{p}_2$ and is strictly decreasing for $1-\bar{p}_2<\alpha<1$.

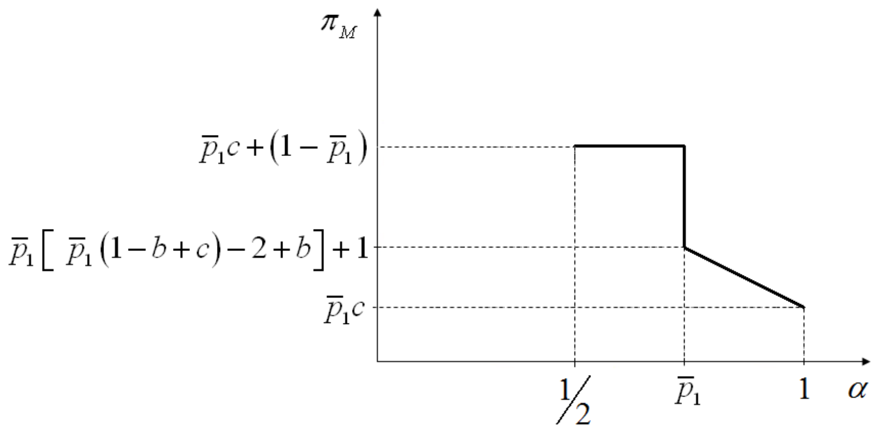

Figure 11: The expected payoff of M when $E(\alpha)>\bar{\alpha}$ and $\frac{1}{2}<\bar{p}_1<\frac{1}{1-b+c}$

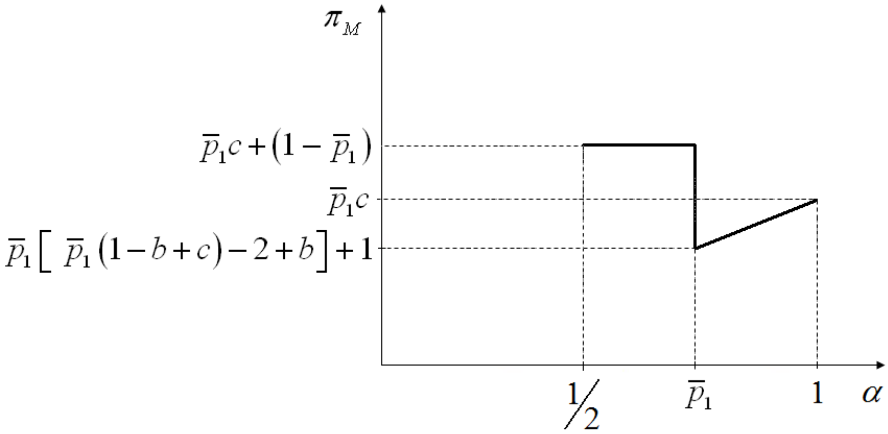

Figure 12: The expected payoff of M when $E(\alpha) > \bar{\alpha}$ **and** $\frac{1}{1-b+c} < \bar{p}_1 < 1$

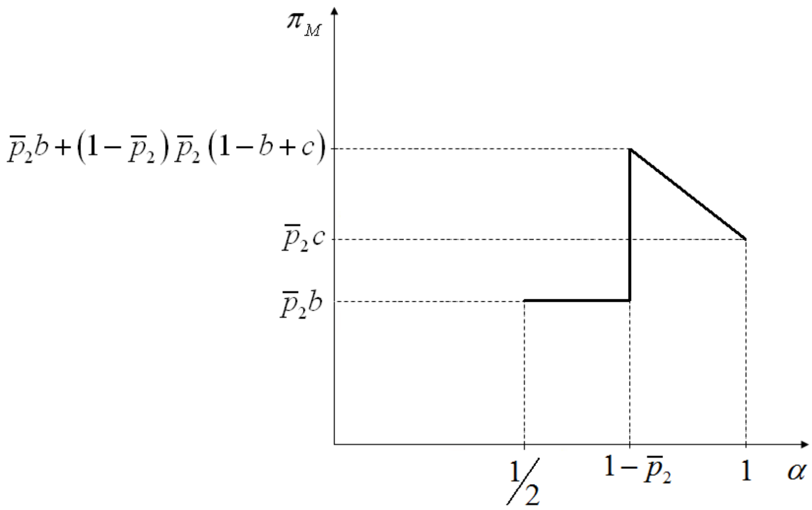

Figure 13: The expected payoff of M when $E(\alpha) < \bar{\alpha}$

In the common knowledge case M is always best off when E perfectly detects his action. Under asymmetric information results are different. Up to a certain value of α the ex-post expected payoff of M is constant because, as already mentioned, the equilibrium strategy of E does not depend on the signal she receives. Thereafter, the payoff of M is increasing or decreasing.

If the expected precision of the IS is relatively high and M invests with high probability ($\frac{1}{1-b+c} < \bar{p}_1 < 1$), his payoff will be increasing because the more accurate the IS is the more likely is that the IS generates signal i, inducing E to stay out. But, if he invests with relatively low probability ($\frac{1}{2} < \overline{p}_1 < \frac{1}{1-b+c}$), it will not be likely that the IS generates signal i and his payoff will decrease. However, even when M invests with high probability, his expected equilibrium payoff is greater when $\frac{1}{2} < \alpha < \overline{p}_1$ than when $\overline{p}_1 < \alpha < 1$ because in the former case E stays out for sure while in the latter there exists a chance that she enters the market. Hence, M will be best off when E does not spy on him or when the IS has a low accuracy.

If, on the contrary, the IS expected precision is low but the IS is quite accurate ($1 - \overline{p}_2 < \alpha < 1$), the equilibrium payoff of M will be decreasing in α because in this case with high probability M will not expand capacity believing that E will not likely detect him, and then, as α becomes larger E will more likely detect M's action and will enter. But, even though the payoff of M is decreasing in this region, it is greater when the IS is less accurate ($\frac{1}{2} < \alpha < 1 - \overline{p}_2$) than when it is more accurate, because in the latter E enters for sure while in the former there exists a chance that she stays out. Hence, M prefers E to spy on him, but with an IS which is not perfect. Actually, the closer α is to $1 - \overline{p}_2$ (from above) the better is M, because with this precision is more likely that the IS generates the (less likely) signal i, inducing E to stay out.

What the market has gained from espionage under asymmetric information? Obviously it depends on how asymmetric is the information. When information is very asymmetric, that meaning that the IS precision is high but the Incumbent beliefs are wrong (the IS expected precision is lower than some threshold), market competition is increased because the Entrant enters most of the times. Furthermore, the Incumbent invest less in capacity making the market more efficient. On the contrary, when the IS precision is high and the Incumbent beliefs are aligned (the IS expected precision is high enough), the Entrant will enter with smaller probability and the Incumbent will expand capacity with higher probability than in the previous case. The higher the IS precision the better is the Entrant because she can detect M's action with a relatively accurate precision and choose her strategy accordingly.

5. Concluding remarks.

In spite of the importance for a potential entrant to obtain information about the incumbent(s) firm(s), the effects of espionage on entry deterrence models have not been studied before in the literature. Our paper makes a first step in this direction, but more research needs to be done.

In this paper we have considered a model where a potential entrant uses an inaccurate Intelligence System (IS), of a given precision, to spy upon a monopoly incumbent and detect his decision of whether to expand capacity. Taking into account this information, the entrant takes entry decisions.

It could be expected that more precise information would always benefit the entrant, but we have showed that, if the precision of the spying technology is commonly known to both firms, then only the incumbent will benefit from a perfect IS while the entrant will prefer a less accurate one. However, when the IS precision is the Entrant's private information, she can avoid being completely manipulated by the incumbent's signal-jamming, and, in fact, for some values of the precision, she will make equilibrium entry decisions independently of the signal.

The Incumbent's signal-jamming behavior under both information structures is similar to the one on oligopoly games of Riordan (1985), Aghion, Espinosa and Jullien (1993), Mirman, Samuelson and Urbano (1993), Caminal and Vives (1996), Alepuz and Urbano (2005), among others. Also, the incumbent's manipulation of information is related to results of Vives (1984) Raith (1996), Gal-Or (1985, 1986, 1988), about sharing information in oligopoly markets, where letting the rivals acquire a better knowledge of their profits functions leads to a higher correlation of strategies.

Industrial espionage has become an increasing business practice. While espionage is considered an illegal and unethical activity it has the potential to yield desirable strategic effects and/or profits-shifting effects in markets with entry barriers.

Do espionage activities enhance market competition? The answer depends on the asymmetry of the information about the accuracy of the spying activity. If the IS precision is common knowledge, there will be small room for spying activities. Only if this precision is small enough, the Incumbent's probability of expanding capacity will be lower than in the case of not spying, making the market more efficient. When, instead, the IS accuracy is high enough and the Entrant's private information, and the information is very asymmetric, market competition is increased because the Entrant enters most of the times. Spying will also be beneficial to consumers because typically the expected market output will rise, the expected price will fall and the expected consumer surplus will be enlarged.

Which are the main policy implications? Should espionage be completely banned? From the above results it can only be said that whether espionage is a virtue or a vice (Whitney and Gaisford, 1999) is still an open question which needs much more research.

6. Appendix

Proof of Proposition 1. It is easy to verify that the unique Nash equilibrium strategy of M is to invest with probability p, s.t.

$$p(\alpha)=\begin{cases}1-\alpha, & \frac{1}{2}<\alpha<\bar{\alpha}\\ \alpha, & \bar{\alpha}<\alpha<1\end{cases}$$

As for E, if $\frac{1}{2}<\alpha<\bar{\alpha}$, she will play (E,E) with probability q^*, where

$$q^*=\frac{1-b-\alpha(1+c-b)}{1-\alpha(1+c-b)} \quad \text{(A1)}$$

and (E,NE) with probability $1-q^*$. If $\bar{\alpha}<\alpha<1$, E will play (E,NE) with probability $\hat{q}$, where

$$\hat{q}=\frac{1-c}{\alpha(1-b+c)+b-c} \quad \text{(A2)}$$

and (NE,NE) with probability $1-\hat{q}$.

If $\alpha=\bar{\alpha}$, the game will have multiple equilibrium points: M will invest with probability $\tilde{p}$ where $\frac{c}{1-b+c}\leq\tilde{p}\leq\frac{1-b}{1-b+c}$, and E will play (E,NE) purely.

∎

<u>Proof of Proposition 2.</u> Consider first the case $\frac{1}{2} < \alpha < \bar{\alpha}$. In equilibrium the Entrant will enter with probability 1 if the signal is ni, and with probability q^* if the signal is i. Hence

$$Prob(E) = Prob(ni) + q^* Prob(i)$$

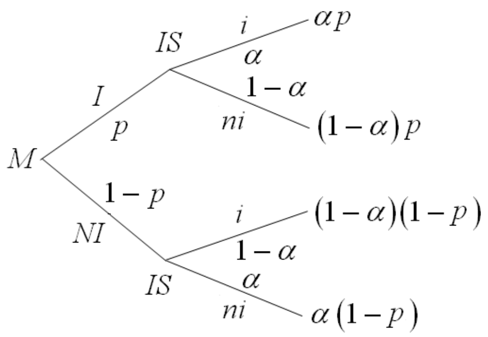

Figure 14

where $p = 1 - \alpha$. By Figure 14,

$$Prob(ni) = p(1-\alpha) + (1-p)\alpha = (1-\alpha)^2 + \alpha^2$$

and

$$Prob(i) = p\alpha + (1-p)(1-\alpha) = 2(1-\alpha)\alpha$$

By (A1)

$$Prob(E) = \frac{1 + 2b\alpha^2 - \alpha(1+c+b)}{1 - \alpha(1+c-b)}$$

Since $\left[2-(1+c-b)\alpha\right]\alpha - 1 = -(\alpha-1)^2 + (b-c)\alpha^2 < 0$,

$$\frac{\partial Prob(E)}{\partial \alpha} = \frac{2b\left[\left[2-(1+c-b)\alpha\right]\alpha - 1\right]}{\left[1-\alpha(1+c-b)\right]^2} < 0$$

Next assume that $\bar{\alpha} < \alpha < 1$. In equilibrium the Entrant will not enter if the signal is i, and she will enter with probability $\hat{q}$ if the signal is ni. Hence

$$Prob(E) = \hat{q} Prob(ni) + 0 Prob(i)$$

Using Figure 14 (but now $p = \alpha$) we have

$$Prob(ni) = p(1-\alpha) + (1-p)\alpha = 2(1-\alpha)\alpha$$

By (A2)

$$Prob(E) = \frac{2(1-c)(1-\alpha)\alpha}{\alpha(1-b+c)+b-c}$$

and it is decreasing in α since

$$\frac{\partial Prob(E)}{\partial \alpha} = \frac{-2(1-c)\left[(\alpha-1)^2(c-b)+\alpha^2\right]}{\left[\alpha(1-b+c)+b-c\right]^2} < 0$$

■

<u>Proof of Proposition 3.</u> It can be easily verified that

$$\Pi_M = \begin{cases} \frac{(1-\alpha)b}{1-\alpha(1+c-b)}, & 1/2 < \alpha < \bar{\alpha} \\ \frac{\alpha(2c-b)+b-c}{\alpha(1-b+c)+b-c}, & \bar{\alpha} < \alpha < 1 \end{cases}$$

and

$$\Pi_E = \begin{cases} 2\alpha - 1, & 1/2 < \alpha < \bar{\alpha} \\ 0, & \bar{\alpha} < \alpha < 1 \end{cases}$$

and the proof follows immediately.

If $\alpha = \bar{\alpha}$, $\tilde{\Pi}_M = \frac{c}{1-b+c}$ and $\tilde{\Pi}_E \in \left[0, \frac{1-b-c}{1-b+c}\right]$.

■

<u>Proof of Proposition 4.</u> Suppose that M chooses I with probability p and NI with probability $1-p$. Using Figure 14,

$$Prob_E\left(I \middle| \alpha, i\right) = \frac{\alpha\, p}{\alpha\, p + (1-\alpha)(1-p)}$$

$$Prob_E\left(NI \middle| \alpha, i\right) = \frac{(1-\alpha)(1-p)}{\alpha\, p + (1-\alpha)(1-p)}$$

$$Prob_E\left(I \middle| \alpha, ni\right) = \frac{(1-\alpha)\, p}{(1-\alpha)\, p + \alpha(1-p)}$$

$$Prob_E\left(NI \middle| \alpha, ni\right) = \frac{\alpha(1-p)}{(1-\alpha)\, p + \alpha(1-p)}$$

Let $\Pi_E\left(E\middle|\alpha,i\right)$ be the expected payoff of E if the signal is i and she enters the market. Then,

$$\Pi_E\left(E\middle|\alpha,i\right)=Prob_E\left(I\middle|\alpha,i\right)u_E\left(I,E\right)+Prob_E\left(NI\middle|\alpha,i\right)u_E\left(NI,E\right)= \\ =\frac{1-p-\alpha}{\alpha\ p+\left(1-\alpha\right)\left(1-p\right)} \tag{A3}$$

Similarly

$$\Pi_E\left(E\middle|\alpha,ni\right)=\frac{\alpha-p}{\left(1-\alpha\right)\ p+\alpha\left(1-p\right)}$$

$$\Pi_E\left(NE\middle|\alpha,i\right)=0 \tag{A4}$$

$$\Pi_E\left(NE\middle|\alpha,ni\right)=0$$

Given p, by (A3) and (A4), if E receives the signal i she will prefer E on NE iff

$$\frac{1-p-\alpha}{\alpha\ p+\left(1-\alpha\right)\left(1-p\right)}>0$$

or equivalent iff $\alpha<1-p$.

That is, if E receives the signal i she will enter if $\alpha<1-p$ and she will not enter if $\alpha>1-p$. If $\alpha=1-p$ E will be indifferent between entering and not entering the market.

Similarly, if E receives the signal ni she will enters the market iff

$$\frac{\alpha-p}{\left(1-\alpha\right)\ p+\alpha\left(1-p\right)}>0$$

or equivalently iff $\alpha>p$.

We can write now the best reply strategy of E as a function of the signal she receives.

$$s_E\left(i\,|\,\alpha,\,p\right)=\begin{cases} NE & p>\dfrac{1}{2},\quad \dfrac{1}{2}<\alpha\le 1 \\ E & p\le\dfrac{1}{2},\quad \dfrac{1}{2}<\alpha<1-p \\ NE & p\le\dfrac{1}{2},\quad 1-p<\alpha\le 1 \\ \text{any strategy} & p\le\dfrac{1}{2},\quad \alpha=1-p \end{cases} \tag{A5}$$

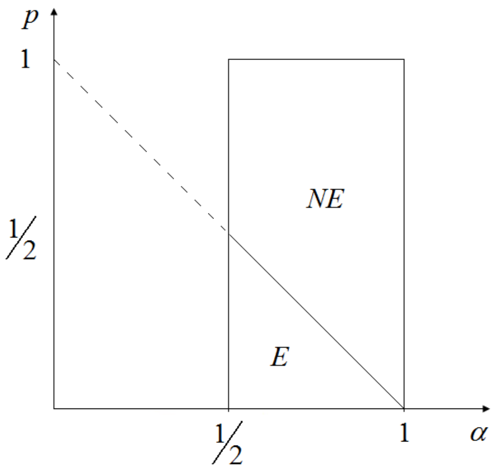

Figure 15: $s_E\left(i\,|\,\alpha,\,p\right)$

Next,

$$s_E\left(ni\,|\,\alpha,\,p\right)=\begin{cases} E & p<\dfrac{1}{2},\quad \dfrac{1}{2}<\alpha\le 1 \\ NE & p\ge\dfrac{1}{2},\quad \dfrac{1}{2}<\alpha<p \\ E & p\ge\dfrac{1}{2},\quad p<\alpha\le 1 \\ \text{any strategy} & p\ge\dfrac{1}{2},\quad \alpha=p \end{cases} \tag{A6}$$

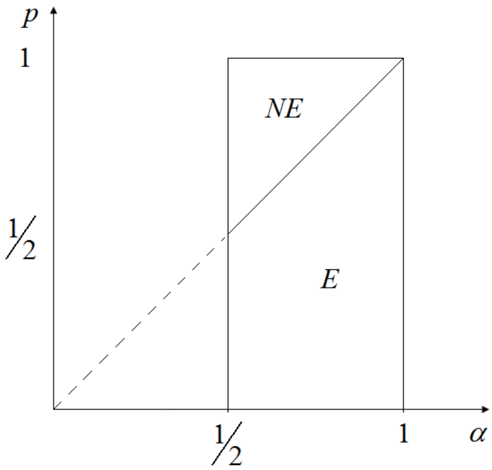

Figure 16: $s_E\left(ni \,|\, \alpha,\, p\right)$

(1) Suppose that $E\left(\alpha\right) > \bar{\alpha}$ where $\bar{\alpha} = \dfrac{1-b}{1-b+c}$. Consider first the case where M expands his capacity with probability $\dfrac{1}{2} < p < 1$. Let $E\Pi_M\left(p\right)$ be the expected payoff of M. By (A5) and (A6)

$$E\Pi_M\left(p\right) = p\left[\int_{\frac{1}{2}}^{1} \alpha\, u_M\left(I, NE\right) f\left(\alpha\right) d\,\alpha + \int_{\frac{1}{2}}^{p} (1-\alpha) u_M\left(I, NE\right) f\left(\alpha\right) d\alpha + \int_{p}^{1} (1-\alpha)\; u_M\left(I, E\right) f\left(\alpha\right) d\alpha\right] +$$

$$+\left(1-p\right)\left[\int_{\frac{1}{2}}^{p} \alpha\;\; u_M\left(NI, NE\right) f\left(\alpha\right) d\,\alpha + \int_{p}^{1} \alpha\;\; u_M\left(NI, E\right) f\left(\alpha\right) d\alpha + \int_{\frac{1}{2}}^{1} (1-\alpha) u_M\left(NI, NE\right) f\left(\alpha\right) d\alpha\right]$$

Since $u_M\left(I, E\right) = b,\;\; u_M\left(I, NE\right) = c,\;\; u_M\left(NI, E\right) = 0$ and $u_M\left(NI, NE\right) = 1$

$$E\Pi_M\left(p\right) = p\left[c\int_{\frac{1}{2}}^{1} \alpha\, f\left(\alpha\right) d\;\alpha \;+ c\int_{\frac{1}{2}}^{p} \left(1-\alpha\right) f\left(\alpha\right) d\alpha + b\int_{p}^{1} \left(1-\alpha\right) f\left(\alpha\right) d\alpha\right] +$$

$$+\left(1-p\right)\left[\int_{\frac{1}{2}}^{p} \alpha\, f\left(\alpha\right) d\;\alpha + \int_{\frac{1}{2}}^{1} \left(1-\alpha\right)\; f\left(\alpha\right) d\alpha\right]$$

Since $\int_{\frac{1}{2}}^{1} f\left(\alpha\right) d\alpha = 1$

$$E\Pi_M\left(p\right) = p\left[c + \left(b-c\right)\int_{p}^{1} (1-\alpha) f\left(\alpha\right) d\alpha\right] + \left(1-p\right)\left[1 - \int_{p}^{1} \alpha\;\, f\left(\alpha\right) d\alpha\right] \qquad \text{(A7)}$$

Note that E observes neither the mixed strategy played by M nor his actual action. She only observes the signal sent by the IS. Hence, if M unilaterally deviates from his mixed strategy $(p, 1-p)$ to any other strategy, the strategy of E (as a function of her type α and the signal observed) will not change, but the probabilities of the signals will do it. In equilibrium, M should be indifferent between playing $(p, 1-p)$ and playing either one of his pure strategies, since $0 < p < 1$. That is

$$E\Pi_M(0) = E\Pi_M(1) \tag{A8}$$

By (A7) and (A8)

$$c + (b-c)\int_p^1 (1-\alpha) f(\alpha)\, d\alpha = 1 - \int_p^1 \alpha\, f(\alpha)\, d\alpha \tag{A9}$$

Let

$$g(p) \equiv c - 1 + (b-c)\int_p^1 (1-\alpha) f(\alpha)\, d\alpha + \int_p^1 \alpha\, f(\alpha)\, d\alpha$$

be defined for all $\frac{1}{2} \le p \le 1$. Since $f(\alpha)$ is continuous in α, $g(p)$ is continuously differentiable in p. Also

$$g\left(\frac{1}{2}\right) = -1 + b + (1-b+c)\, E(\alpha)$$

By our assumption $E(\alpha) > \frac{1-b}{1-b+c}$, hence $g\left(\frac{1}{2}\right) > 0$. Since $g(1) = c - 1 < 0$ by the Mean Value Theorem there is a $\bar{p}_1$, $\frac{1}{2} < \bar{p}_1 < 1$, such that $g(\bar{p}_1) = 0$.

Next

$$\begin{aligned} g'(p) &= -(b-c)\, f(p) - (1-b+c)\, p\, f(p) = \\ &= \left[-(1-b+c)\, p - (b-c)\right] f(p) \end{aligned}$$

Since $f(p) > 0$

$$g'(p) > 0 \text{ iff } p < \frac{c-b}{1-b+c}$$

Since $\frac{c-b}{1-b+c}<\frac{1}{2}$, $g(p)$ is decreasing for $\frac{1}{2}\le p<1$. Since $g\left(\frac{1}{2}\right)>0$ and $g(1)<0$ then g crosses the p-axis only once. Therefore $\bar{p}_1$ is the unique solution of $g(p)=0$ and therefore of (A9).

Next observe that M has no equilibrium strategy $(\bar{p},1-\bar{p})$ such that $0<\bar{p}\le\frac{1}{2}$ and $E(\alpha)>\frac{1-b}{1-b+c}$. Otherwise (A9) should be replaced by

$$c+(b-c)\int_{\frac{1}{2}}^{1}(1-\alpha)f(\alpha)\,d\alpha=1-\int_{\frac{1}{2}}^{1}\alpha\, f(\alpha)\,d\alpha$$

This implies that

$$E(\alpha)=\frac{1-b}{1-b+c},$$

which is a contradiction. We conclude that whenever $E(\alpha)>\frac{1-b}{1-b+c}$ the game Γ has a unique equilibrium.

(2) Suppose next that $E(\alpha)<\frac{1-b}{1-b+c}$. Consider first the case where M expands his capacity with probability p, $0<p<\frac{1}{2}$. Similarly to the previous case

$$E\Pi_M(p)=p\left[\int_{\frac{1}{2}}^{1-p}\alpha\, u_M(I,E)\,f(\alpha)\,d\alpha+\int_{1-p}^{1}\alpha u_M(I,NE)\,f(\alpha)\,d\alpha+\int_{\frac{1}{2}}^{1}(1-\alpha)\,u_M(I,E)\,f(\alpha)\,d\alpha\right]+$$
$$+(1-p)\left[\int_{\frac{1}{2}}^{1}\alpha\, u_M(NI,E)\,f(\alpha)\,d\alpha+\int_{\frac{1}{2}}^{1-p}(1-\alpha)u_M(NI,E)\,f(\alpha)\,d\alpha+\int_{1-p}^{1}(1-\alpha)u_M(NI,NE)\,f(\alpha)\,d\alpha\right]$$

Since $u_M(I,E)=b$, $u_M(I,NE)=c$, $u_M(NI,E)=0$ and $u_M(NI,NE)=1$

$$E\Pi_M(p)=p\left[b+(c-b)\int_{1-p}^{1}\alpha f(\alpha)\,d\alpha\right]+(1-p)\left[\int_{1-p}^{1}(1-\alpha)\,f(\alpha)\,d\alpha\right] \tag{A10}$$

In equilibrium where $0<p<1$ we have

$$E\Pi_M(0)=E\Pi_M(1) \tag{A11}$$

By (A10) and (A11) we have

$$b+(c-b)\int_{1-p}^{1}\alpha f(\alpha)\,d\alpha=\int_{1-p}^{1}(1-\alpha)\,f(\alpha)\,d\alpha \tag{A12}$$

Let

$$m(x)\equiv b+(c-b)\int_{x}^{1}\alpha f(\alpha)\,d\alpha-\int_{x}^{1}(1-\alpha)\,f(\alpha)\,d\alpha$$

be defined for all $\frac{1}{2}\le x\le 1$. Clearly $m(x)$ is continuous and differentiable. Since $E(\alpha)<\frac{1-b}{1-b+c}$,

$$m\left(\frac{1}{2}\right)=(1-b+c)\,E(\alpha)+(b-1)<0$$

Also

$$m(1)=b>0$$

In addition

$$m'(x)=\left[1-(1-b+c)\,x\right]f(x)$$

Since $f(x)>0$

$$m'(x)>0 \text{ iff } x<\frac{1}{1-b+c}$$

Hence m increases for $\frac{1}{2}\le x<\frac{1}{1-b+c}$ and decreases for $\frac{1}{1-b+c}<x\le 1$. Since $m\left(\frac{1}{2}\right)<0$ and $m(1)>0$ then m intersects the x-axis only once. Namely, there is a unique $\bar{x}$ such that $m(\bar{x})=0$ and $\frac{1}{2}<\bar{x}<1$. Thus there exists a $\bar{p}_2, 0<\bar{p}_2<1$, such that $\bar{p}_2$ is the unique solution of (A12), and $\bar{p}_2<\frac{1}{2}$ which is consistent with our assumption.

Next it is easy to verify (similarly to the previous case) that there is no equilibrium where $p\ge\frac{1}{2}$ and $E(\alpha)<\frac{1-b}{1-b+c}$. We conclude that whenever $E(\alpha)<\frac{1-b}{1-b+c}$ the game Γ has a unique equilibrium.

It is also easy to verify that there is no equilibrium where M is playing a pure strategy.

■

Proof of Proposition 5. By (A5), (A6) and Proposition 4 it is easy to verify that

$$\pi_E(\alpha)=\begin{cases}1-2\bar{p}_2 & , \quad E(\alpha)<\bar{\alpha},\ \frac{1}{2}<\alpha<1-\bar{p}_2\\ \alpha-\bar{p}_2 & , \quad E(\alpha)<\bar{\alpha},\ 1-\bar{p}_2<\alpha<1\\ 0 & , \quad E(\alpha)>\bar{\alpha},\ \frac{1}{2}<\alpha<\bar{p}_1\\ \alpha-\bar{p}_1 & , \quad E(\alpha)>\bar{\alpha},\ \bar{p}_1<\alpha<1\end{cases}$$

and the proof follows immediately.

■

Proof of Proposition 6. By (A5), (A6) and Proposition 4 it is easy to verify that

$$\pi_M(\alpha)=\begin{cases}\bar{p}_2 b & , \quad E(\alpha)<\bar{\alpha},\ \frac{1}{2}<\alpha<1-\bar{p}_2\\ \left[\bar{p}_2(1-b+c)-1\right]\alpha+1-\bar{p}_2(1-b) & , \quad E(\alpha)<\bar{\alpha},\ 1-\bar{p}_2<\alpha<1\\ \bar{p}_1 c+(1-\bar{p}_1) & , \quad E(\alpha)>\bar{\alpha},\ \frac{1}{2}<\alpha<\bar{p}_1\\ \left[\bar{p}_1(1-b+c)-1\right]\alpha+1-\bar{p}_1(1-b) & , \quad E(\alpha)>\bar{\alpha},\ \bar{p}_1<\alpha<1\end{cases}$$

and the proof follows immediately.

■

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