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Theoretical Models of Industrial Espionage

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Contents

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Resumen: Objetivos, metodología y contenido

La información es un recurso muy importante para una empresa, tanto como lo puedan ser los recursos financieros, materiales y humanos, pues el éxito o fracaso de la misma puede depender de la información de la que dispone. Una parte importante de esta información es la relativa a otras empresas (competidores, empresas que operan en un mercado en el que se desea entrar, etc.), y puede referirse a los procesos y técnicas de producción, costes, recetas y fórmulas, clientes, acciones, planes y estrategias, etc.

La *inteligencia competitiva* es el proceso legal y ético por el que una empresa obtiene, analiza y utiliza información de valor estratégico sobre la industria y los competidores. Este proceso puede incluir la revisión de la prensa, publicaciones corporativas, páginas web, solicitudes de patentes, bases de datos especializadas, entre otras muchas actividades[1]. La importancia de este proceso queda reflejada, por ejemplo, en que en 2002 *Business Week* informaba que el 90% de las grandes empresas tienen empleados que se dedican a temas de inteligencia competitiva y que muchas de las grandes empresas estadounidenses gastan más de un millón de dólares anuales en temas de inteligencia competitiva. Además, algunas de las mayores multinacionales, como General Motors, Kodak y British Petroleum, disponen de unidades propias de inteligencia competitiva[2].

Sin embargo las empresas no siempre obtienen esta información de una forma ética y legal. Es a este proceso ilegal y no ético al que se denomina *espionaje industrial*[3].

Durante los últimos años han aumentado los incentivos de las empresas a sobrepasar los límites de la inteligencia competitiva, debido a que se enfrentan a entornos cada vez más competitivos basados en el conocimiento y a los avances de las tecnologías de la comunicación y la información. En este sentido, el espionaje industrial se ha convertido en una práctica empresarial muy importante e, incluso, preocupante.

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[1] Nasheri (2005).

[2] Ver Billand et al (2009), página 2.

[3] A diferencia del espionaje industrial, el *espionaje económico* lo llevan a cabo los gobiernos. Ver Nasheri (2005).

A finales de 1980 y en la década de los noventa, Francia y Estados Unidos se vieron envueltos en varios casos de espionaje industrial[4]. Según los informes de 1997 del US State Department y del Canadian Security and Intelligence Service, el espionaje industrial cuesta a los negocios estadounidenses cerca de los 8,16 millones de dólares por año. Además, el 43% de las compañías estadounidenses han sufrido, al menos, seis casos de espionaje industrial[5]. También a finales de los noventa, más concretamente, en 1997, Volkswagen fue condenada por tratar de obtener secretos industriales de Opel contratando a su Jefe de Producción, José Ignacio López, y a siete ejecutivos más[6].

Más recientemente, en 2009, la compañía hotelera estadounidense Starwood acusó a su competidor, Hilton, de espionaje industrial al contratar a varios de sus ejecutivos, que se llevaron con ellos una gran cantidad de secretos comerciales de la empresa y que Hilton usó en su propio beneficio[7]. Y en enero de 2011, tres directivos de Renault fueron acusados de vender información, posiblemente a la competencia, sobre el coche eléctrico en el que estaba trabajando la empresa[8].

Sin embargo muchas veces, en la práctica, resulta difícil discernir la legalidad y eticidad de los métodos usados. En este sentido, Crane (2005) realiza un estudio muy interesante sobre tres casos en que la inteligencia competitiva se convierte en espionaje industrial. Puede que el caso más curioso sea el de Procter & Gamble, que en 2001 se supo que trataba de obtener información sobre Unilever buscando en los contenedores de basura de la empresa.

Pero nuestro objetivo no es estudiar cuál es el límite que separa la inteligencia competitiva del espionaje industrial. Con estos ejemplos (que sólo son una parte de todos los que pueden encontrarse) simplemente queremos hacer notar que es muy importante para las empresas obtener información sobre sus competidores, sin entrar en el tema de la legalidad o eticidad de los métodos que usan para ello.

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[4] New York Times (1991), Jehl (1993) y Nolan (2000).
[5] Ver Solan y Yariv (2004), página 174, nota al pie 1.
[6] Reuters (1996) y Meredith (1997).
[7] Clark (2009).
[8] Jolly (2011).

Objetivos y metodología.

Dada la importancia de este tema, el objetivo de la presente tesis es analizar teóricamente el comportamiento de las empresas a la hora de obtener información de sus competidores (práctica a la que, por simplicidad, llamaremos espionaje industrial, independientemente de la legalidad o eticidad de los métodos, por lo que en este concepto se está incluyendo también a la inteligencia competitiva), para poder comprenderlo mejor y ver cuáles pueden ser sus consecuencias, ya que, aunque el espionaje industrial es una práctica muy extendida, pocos trabajos teóricos han tratado de analizarlo.

Más concretamente, nuestro objetivo es analizar teóricamente el impacto del espionaje industrial sobre el comportamiento estratégico de las empresas en un contexto de disuasión de la entrada usando las herramientas propias de la Teoría de Juegos.

Nos centramos en este contexto de entrada a un mercado, porque se trata de una de esas situaciones en que la información de que dispone una empresa (en este caso, la empresa que pretende entrar al mercado) puede suponer el éxito o el fracaso de la misma. El entrante tiene que tener muchos aspectos en cuenta, pero disponer de información al respecto, por ejemplo, de las estrategias y los costes de la empresa que opera en el mercado, puede ser de vital importancia a la hora de decidir si entrar o no al mercado. Un caso real que puede motivar los modelos teóricos de esta tesis podría ser el que se explica en Mezzanine Group (2010). Este estudio de caso muestra la importancia que tiene, para un entrante potencial a un mercado, la información sobre estrategias, posicionamientos y recursos de las empresas que operan en el mismo.

Además, aunque los juegos de disuasión de la entrada han sido ampliamente estudiados en la literatura[9] , los efectos del espionaje en estos juegos no han sido estudiados con anterioridad.

En los modelos de la presente tesis se considera la existencia de un monopolio (M) en un mercado y un entrante potencial (E) al mismo. Para tratar de impedir que E entre al mercado, M considera invertir en la expansión de su capacidad (Capítulos 2 y 3) o invertir en I+D para reducir su coste de producción (Capítulo 4). En el primer caso, E

[9] Ver Wilson (1992) para una revisión de esta literatura.

no observa las decisiones de inversión de M, y en el segundo E no sabe si la inversión para reducir costes fue exitosa. Por ello E utiliza un Sistema de Inteligencia (SI), que puede tener un coste o ser de libre acceso, para tratar de detectar la acción de M en el primer caso, y el resultado de la inversión en el segundo, y tiene en cuenta esta información que le proporciona el SI para decidir si entra o no al mercado.

El SI puede enviar dos señales con ruido sobre la decisión de M en el primer caso, y sobre el resultado de la inversión en el segundo. Sea α la precisión del SI, se supone sin pérdida de generalidad que $\frac{1}{2} \leq \alpha \leq 1$. Así pues, la señal enviada por el SI es correcta con probabilidad α. Por simplicidad se supone que la acción de M no influye en α. Si $\alpha = 1$, el SI es perfecto y E detecta perfectamente la acción de M en el primer caso, y el resultado de la inversión en el segundo. Si $\alpha = \frac{1}{2}$, la señal enviada por el SI no es informativa y es como si E no estuviera usando ningún sistema de inteligencia.

El SI que se considera es similar al que asumen Biran y Tauman (2009) y Solan y Yariv (2004). Por tanto, los modelos de esta tesis están relacionados con estos dos trabajos y, como ellos, con la literatura que estudia los juegos con comunicación[10]. Sin embargo, en estos juegos suele ser el jugador que dispone de información privada, quien envía una señal al otro jugador, mientras que en nuestros modelos la señal es generada por un sistema de inteligencia operado por el jugador que recibe la señal.

En esta tesis se supondrá que la precisión α del SI puede ser tanto exógena (Capítulos 2 y 4) como endógena (Capítulo 3). El primer caso sería aquel en que la empresa que espía dispone de un SI antes de encontrar a un nuevo rival (por ejemplo, una empresa que puede implantar un Caballo de Troya en el sistema informático de sus rivales). El segundo sería el de una empresa que contrata a directivos y trabajadores de otra para que le proporcionen información de la misma. El caso de Volkswagen en 1997 y el de Hilton en 2009, a los que nos hemos referido anteriormente, serían ejemplos de esta situación.

[10] Ver Solan y Yariv (2004), página 175.

Por último comentar que, como dicen Biran y Tauman (2009), este tipo de SI no es un jugador que actúa estratégicamente como en Perea y Swinkels (1999) y en Ho (2007, 2008)[11].

Estructura y contenido.

La tesis está estructurada en cinco capítulos. El primer capítulo es una introducción general. En los tres capítulos siguientes se desarrollan tres modelos teóricos en los que se analizan el espionaje industrial en un contexto de disuasión de la entrada. En el quinto capítulo se resumen los resultados obtenidos en la tesis y se comentan algunas líneas de investigación futura.

A continuación resumimos los capítulos 2, 3 y 4, sus principales resultados y posibles líneas de investigación futura.

En el segundo capítulo, *Entrada bajo una señal con ruido* (*Entry with a Noisy Signal*), un monopolio (M) pretende disuadir la entrada al mercado de un entrante potencial (E) a través de una expansión de su capacidad. Bajo información perfecta, E no entraría al mercado si M expandiera su capacidad, y sí que lo haría si M no la expandiera. Sin embargo, la información no es perfecta. Por consiguiente, E no observa las decisiones de inversiones en capacidad de M.

El entrante potencial E usa un Sistema de Inteligencia (SI), sin coste, para tratar de detectar la acción de M. El SI puede enviar solo dos señales, la señal i, que indica quee M está invirtiendo en capacidad, y la señal ni, que indica lo contrario. Denotemos por α a la precisión del SI, donde $1/2 \leq \alpha \leq 1$. Es decir, que la señal enviada por el SI es correcta con probabilidad α. En base a la señal recibida, E decide si entrar o no (o con qué probabilidad) al mercado. En este primer capítulo la precisión α del SI es exógena. Hay cuatro resultados posibles, (NI, NE), (NI, E), (I, NE), (I, E), donde I significa "invertir" y NI "no invertir". La interpretación de E y NE es similarmente "entrar" y "no entrar". Para hacer el análisis interesante se supone que los beneficios de M son

[11] Para el tema del valor de la información en conflictos estratégicos ver también Kamien, Tauman y Zamir (1990).

tales que su mejor resultado es el status quo (NI, NE). Su segundo mejor resultado es (I, NE). M prefiere (I, NE) a (I, E), y si el coste de la inversión no es muy alto, M prefiere (I, E) a (NI, E). De manera similar, los beneficios de E son tales que su mejor resultado es (NI, E), el cual es mejor que (I, NE) o (NI, NE), pues en ambos casos obtiene cero. El peor resultado para E es (I, E).

Este modelo se interpreta como un juego en el que los dos jugadores M y E eligen sus acciones simultáneamente, y que será de información simétrica o asimétrica según M conozca la precisión α o no, respectivamente. Por tanto, los conceptos de solución empleados serán el de equilibrio de Nash y el de equilibrio Bayesiano de Nash.

Antes de analizar el caso más realista en el que la precisión α es información privada de E, se estudia el caso de referencia bajo el que α es conocido por ambas empresas. Si el coste de la inversión es relativamente alto, de tal forma que M prefiere no invertir incluso sabiendo que E va a entrar al mercado, el equilibrio de Nash es simple, no invertir es la estrategia dominante de M y E entrará al mercado.

Si por el contrario el coste de la inversión es tal que M prefiere invertir si sabe que E va a entrar al mercado, la solución de equilibrio dependerá de la señal del SI. Supóngase primero que E recibe la señal ni. Si el SI no es muy preciso (α es menor que cierto umbral, $\bar{\alpha}$), entonces en el equilibrio E entra al mercado con probabilidad 1, creyendo que M no ha expandido su capacidad. Sin embargo, si el SI es relativamente preciso (α es mayor que $\bar{\alpha}$), sorprendentemente, en el equilibrio E "duda" entre entrar y no entrar al mercado, y asigna una probabilidad significativa a no entrar. Supóngase ahora que E recibe la señal i. Si el SI no es muy preciso (α es menor que $\bar{\alpha}$), en equilibrio E duda y asigna una probabilidad positiva (menor que 1) a entrar al mercado, teniendo en cuenta el posible error del SI. Si el SI es más preciso, E no entra al mercado con probabilidad 1.

Un resultado sorprendente bajo información simétrica es que M se beneficia del SI más que su dueño, E, si el SI es relativamente preciso. Cuando α excede el umbral $\bar{\alpha}$, el pago de E es cero y es indiferente entre espiar o no a M. La precisión óptima del SI para E es el umbral $\bar{\alpha}$, mientras que lo óptimo para M es que el SI sea perfecto (es decir, $\alpha = 1$). Esto se debe a que la probabilidad de que E entre al mercado es decreciente en la precisión, α, del SI, e implica que M debería subvencionar a E para que desarrollara el SI perfecto, aunque eso signifique que E sea capaz de observar perfectamente su acción.

En el caso en el que la precisión α es información privada de E (caso de información asimétrica), M conoce la distribución de α, pero no su valor real. En particular, este caso incluye la situación en que E no opera ningún SI ($\alpha = \frac{1}{2}$), pero M cree que E está operando un SI de precisión $\alpha > \frac{1}{2}$. En este caso, las estrategias de equilibrio son cualitativamente consistentes con las del caso anterior, pero los pagos de M y E se comportan de una forma menos sorprendente. Al contrario del caso de información completa, E obtiene un pago positivo si SI es relativamente preciso (es decir, si α es relativamente alto) y este pago es creciente en la precisión α. Además, si M cree que el valor esperado de α es menor que el umbral $\bar{\alpha}$, el pago de E es positivo para todos los valores de α. Respecto a M, y contrariamente al caso de información completa, M está mejor cuando E no le espía.

Este modelo está muy relacionado con el de Biran y Tauman (2009), pero su contexto es diferente, ya que estos autores analizan el papel del espionaje en la disuasión de la fabricación de bombas nucleares. Las preferencias de los jugadores, y por tanto los resultados del modelo, son diferentes. El trabajo de Solan y Yariv (2004) también está muy relacionado, pero considera que la precisión del SI es endógena, es decir, es elegida estratégicamente por el jugador que espía (analizamos este caso en tercer capítulo de la tesis). Otros trabajos en los que el objetivo del espionaje es la estrategia del oponente son Matsui (1989) y Provan (2008), pero tratan otro tipo de juegos.

La contribución de este primer capítulo es el análisis del espionaje industrial en un contexto de disuasión de la entrada. El resultado más sorprendente es que, cuando la precisión del SI es conocimiento público, el monopolista está interesado en el uso del mismo por el entrante.

En el tercer capítulo, *Elección estratégica del Sistema de Inteligencia* (*Strategic Choice of the Intelligence System*), se extiende el modelo analizado en el segundo suponiendo que el

SI y su precisión α son elegidos estratégicamente por E (es decir, la elección de α es endógena y además tiene un coste).

Mientras en el Capítulo 2 la precisión α es exógena (y puede ser conocida por ambas empresas o ser información privada de E), en el tercer capítulo se supone que el valor de α es conocido por ambas empresas y es elegido estratégicamente por E. En este caso M puede observar o no esta elección de E.

Este modelo es un juego dinámico de cuatro etapas. En la primera etapa E elige la precisión α del SI. En la segunda etapa, M puede observar o no (consideramos ambos casos) la elección de M y decide si invertir o no invertir en expandir su capacidad. En la tercera etapa el SI envía la señal i o ni. Y en la cuarta y última etapa, E decide si entrar o no entrar al mercado basándose en la señal enviada por el SI. El concepto de solución que se usa es el de equilibrio perfecto en subjuegos.

Se considera primero el caso en que α es elegido estratégicamente por E y su elección es perfectamente observada por M. Supóngase que el coste de un SI de precisión α es creciente y convexo en α. Como el equilibrio tiene que ser perfecto en subjuegos, hay dos errores que M podría cometer ex-post. El primer tipo de error consiste en que M (innecesariamente) invierte en expandir su capacidad y E decide no entrar al mercado. El segundo tipo de error consiste en que M no invierte y E entra al mercado. Los equilibrios de este modelo dependen de cuál de estos dos errores supone un mayor coste para M.

Si el coste del segundo tipo de error es menor para M, la elección óptima de E es desarrollar un SI de precisión, como máximo, $\bar{\alpha}$. Dependiendo del coste del SI, cualquier α entre $1/2$ y $\bar{\alpha}$ puede ser la elección óptima de E. Sin embargo, si el coste del primer tipo de error es menor para M, la elección óptima de E es no desarrollar ningún SI, independientemente de lo bajo que sea su coste, que siempre es positivo. Este es el peor resultado para M ya que, dado que α es conocido por ambas empresas, M se beneficia más cuanto mayor es α.

El caso en que M no observa la elección de E es más difícil de analizar. Si desarrollar un SI no tiene ningún coste, entonces el único equilibrio es que E desarrolla un SI perfecto

($\alpha = 1$) y M elige invertir en la expansión de capacidad. En este caso E no entra al mercado y obtiene un pago igual a cero. No obstante, dado que M invierte, E no entrará al mercado independientemente del valor de la precisión α y no puede beneficiarse de una reducción de la misma. Supóngase ahora que el coste del SI es lineal. Si el coste marginal es relativamente alto, E no espía a M. El caso complicado es cuando el coste marginal es relativamente bajo, pero positivo. Puede demostrarse que en este caso el equilibrio de Nash perfecto en subjuegos existe y es en estrategias mixtas, sin embargo no se ha podido encontrar la distribución de probabilidad de equilibrio sobre α. Además, cuando el coste del SI es constante (es decir, no depende de α), se obtienen resultados similares.

Encontrar esta distribución de probabilidad de equilibrio sobre α sería un tema interesante a investigar en el futuro, aunque sería más interesante analizar en general el caso en que M no observa la elección de E.

Solan y Yariv (2004) es un trabajo muy relacionado con este capítulo, pero se centra en el caso en que el jugador espiado observa la elección del jugador que le espía. En un contexto diferente, Provan (2008) también considera que el espionaje trata de obtener información sobre la estrategia del oponente y el jugador que espía tiene que elegir el sistema de inteligencia. En Gaisford y Whitney (1999) el objetivo del espionaje no es la estrategia del oponente, sino su tecnología, pero también se considera que la precisión del sistema de inteligencia es elegida estratégicamente por el jugador que espía.

La contribución de este capítulo es extender el segundo capítulo al caso en que la precisión del sistema de inteligencia es elección estratégica de su dueño, E, y hacer explícito el caso en que el jugador espiado (M en este caso) no observa la precisión elegida por dueño del sistema de inteligencia, escasamente considerado en la literatura.

En el cuarto capítulo, *Entrada bajo dos señales correlacionadas* (*Entry with Two Correlated Signals*), un monopolio (M) invierte en I+D para tratar de reducir su coste de producción y disuadir a un entrante potencial (E) de entrar al mercado. El resultado de este proyecto de I+D es información privada de M y E asigna cierta probabilidad a que M fracasa en reducir sus costes (M es de tipo H) y a que M consigue reducir sus costes

(M es de tipo L). Si el proyecto fracasa y E entra al mercado, E obtiene beneficios. Sin embargo, si el proyecto tiene éxito y E entra, E no es capaz de cubrir el coste de entrada y tiene perdidas.

El entrante E dispone de un Sistema de Inteligencia (SI) que le permite obtener información (con ruido) sobre la estructura de costes de M. El SI puede enviar dos señales, la señal h, que indica que el proyecto no tuvo éxito, y la señal l, que indica lo contrario. Al igual que anteriormente, la precisión del SI es α, $1/2 \leq \alpha \leq 1$. Es decir, que la señal enviada por el SI es correcta con probabilidad α. En este capítulo se supone que α es exógeno y conocido por ambas empresas.

El entrante E decide si entrar o no al mercado en base a dos señales: el precio p que M establece para su producto y la señal s (h o l) enviada por el SI. Si E entra al mercado, compite con M, sea en cantidades, en precios u otro tipo de competencia.

El caso en que $\alpha = 1/2$, es decir, cuando la señal enviada por el SI no es informativa y puede ser ignorada, es exactamente el modelo de Milgrom y Roberts (1982) (MR a partir de ahora). Por tanto, este capítulo es una extensión del modelo de MR en la que el entrante E dispone de un SI de precisión $1/2 < \alpha < 1$.

Este modelo es un juego de información asimétrica en el que la interacción entre E y M se describe como un juego en tres etapas. En la primera etapa, M, que conoce el resultado del proyecto de I+D, establece un precio para su producto y el SI envía la señal h o l. En la segunda etapa, E, basándose en el precio establecido por M y la señal enviada por el SI, decide entrar o no al mercado. Si E decide entrar, en la tercera etapa E y M compiten en el mercado. El concepto de equilibrio que se usa es el de equilibrio secuencial.

Se distinguen dos tipos de equilibrio. El primero es el equilibrio separador (separating equilibrium), en el que los dos tipos de M establecen precios diferentes p_H y p_L, $p_H \neq p_L$. El segundo es el equilibrio agrupador (pooling equilibrium), en el que $p_H = p_L$.

En este capítulo se demuestra que los equilibrios separadores del modelo coinciden con los de MR y que el SI no supone ninguna diferencia ni para E ni para M. Esto no es muy sorprendente dado que en un equilibrio separador E identifica perfectamente el tipo de M con o sin el SI. Este mismo resultado se obtiene para los equilibrios agrupadores si la precisión α del SI es suficientemente baja (cercana a $1/2$) para influir en la decisión de E de no entrar al mercado. En el otro extremo, si α es bastante alto (cercano a 1), entonces, a diferencia del modelo de MR, no existe ningún equilibrio agrupador. En este caso, E identifica el tipo de M con probabilidad alta y entrará al mercado si recibe la señal h y no entrará si recibe la señal l. El monopolista de tipo H, que sabe que su tipo es detectado con probabilidad elevada, tiene incentivos a desviarse a su precio de monopolio y, por tanto, a eliminar el equilibrio agrupador. En los casos intermedios en que α es relativamente mayor que $1/2$ y menor que 1, se demuestra que el conjunto de equilibrios agrupadores existe y el precio de monopolio del monopolista de tipo L es el máximo precio de equilibrio agrupador posible. La decisión de E continúa siendo entrar al mercado si recibe la señal h y no entrar si recibe la señal l. Mientras en el modelo de MR el entrante E nunca entra al mercado en un equilibrio agrupador, en el modelo desarrollado en este capítulo E entra al mercado para valores intermedios de α y cuando recibe la señal h, y esto es así incluso cuando el equilibrio agrupador no existe en el modelo de MR. Por tanto, desde este punto de vista, espiar a monopolistas puede aumentar la competencia con probabilidad alta.

Este capítulo está relacionado con Perea y Swinkels (1999) y con Ho (2007, 2008) dado que estos trabajos también consideran el espionaje en un contexto de información asimétrica. Sin embargo, en el modelo desarrollado en este capítulo el SI no es un jugador que actúa estratégicamente como en Perea y Swinkels (1999) y en Ho (2007, 2008). El capítulo también está relacionado con Sakai (1985) dado que este trabajo estudia el caso de dos empresas en el que uno de los objetivos de la actividad de obtención de información es, como en este capítulo de la tesis, la estructura de costes del oponente. Sin embargo, este trabajo considera que ambas empresas desconocen tanto los costes de su oponente como los suyos propios.

Otro trabajo relacionado es Bagwell y Ramey (1988). Este trabajo extiende el modelo de MR considerando que el monopolista puede señalizar su estructura de costes tanto con el precio que establece para su producto como con el gasto en publicidad. Por tanto, mientras que en este trabajo ambas señales son enviadas por el monopolista, en el modelo desarrollado en este cuarto capítulo de la tesis, la única señal enviada por el monopolista es el precio, la otra señal es generada por el sistema de inteligencia desarrollado por el entrante. Bagwell (2007) extiende Bagwell y Ramey (1988) y considera un juego más general en el que el monopolista tiene dos dimensiones de información privada, sus costes y su nivel de paciencia.
La contribución de este capítulo es extender el modelo de Milgrom y Roberts (1982) para el caso en que el entrante potencial dispone un sistema de inteligencia que le permite obtener información con ruido sobre la estructura de costes del monopolista. Suponiendo que la precisión del sistema de inteligencia es conocimiento público, se demuestra que el espionaje sobre monopolistas puede aumentar la competencia con probabilidad alta. En este sentido, sería muy interesante analizar este modelo para el caso más realista en que M no observa la precisión del sistema de inteligencia.

Por último, comentar que otra línea de investigación futura podría ser ampliar los modelos de esta tesis suponiendo que el monopolista lleva a cabo actividades de contraespionaje.

Chapter 1. Introduction

1.1. Motivation.

Information is an important resource for a firm, as much as material, financial and human resources are, since information can make the difference between success and failure. An important part of this information is relative to other firms (competitors, incumbents firms, etc.), and it may be about production processes and techniques, costs, recipes and formulas, costumer datasets, actions, decisions, plans and strategies, etc.

Competitive intelligence is the ethical and legal process of collecting, analyzing and managing information of strategic value about the industry and competitors. This activity may include review of newspapers, corporate publications and websites, patent filings and specialized databases, among others[12]. 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[13].

But firms do not always get this information ethically and legally. This illegal and unethical process of getting information about other firms is called *industrial espionage*[14].

Industrial espionage has a large history. An early case of industrial espionage could be the letter by Jesuit Father Francois Xavier d'Entrecolles revealing to Europe the manufacturing methods of Chinese porcelain in 1712[15]. In the same century, the Vezzi brothers, in Venice, were involved in several incidents of industrial espionage that helped to reveal the secret of manufacturing Meissen (Germany) porcelain[16]. Also in

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[12] Nasheri (2005).

[13] See Billand et al (2009), page 2.

[14] Unlike industrial espionage, economic espionage is conducted by governments. See Nasheri (2005).

[15] Brook and Rowe (2009).

[16] Wikipedia, *Industrial Espionage*.

the 18th century there were cases of industrial espionage between Britain and France involving technology transfer between both countries, as stated by Harris (1998).

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[17].

In late 1980 and in the nineties, France and the USA were involved in several cases of industrial espionage[18]. Also at the end of the nineties, more precisely, in 1997, Volkswagen was sentenced for attempting to obtain industrial secrets from Opel, the German division of General Motors, by hiring eight managers from General Motors, who took secret documents with them[19]. In 2009, the US based hospitality company Starwood accused its rival Hilton of a "massive" case of industrial espionage when the latter employed 10 managers and executives from the former, who took many commercial secrets with them that Hilton used to its advantage[20]. And more recently, in January 2011, three executives of Renault were sentenced for selling information, possibly to competitors, about the electric vehicle project the company was working on[21].

However, often it is hard to discern the legality and ethicality of the methods employed by firms to obtain information about competitors. Crane (2005) is an interesting study of three cases where competitive intelligence becomes industrial espionage. Maybe, the most curious case is Procter & Gamble trying to get more information about Unilever by hunting through their garbage bins.

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

[18] New York Times (1991), Jehl (1993) and Nolan (2000).

[19] Reuters (1996) and Meredith (1997).

[20] Clark (2009).

[21] Jolly (2011).

But our objective is not to study the limit between competitive intelligence and industrial espionage. With all these examples (these are only a few and much more can be found) we just wanted to note that it is very important for firms to obtain information about their competitors, and hence the importance of competitive intelligence and industrial espionage as topics of study.

Given the importance of this topic, the objective of this thesis is to analyze theoretically the behavior of firms in obtaining information about their competitors, to better understand it and the possible consequences it may imply. Note that in this thesis we call *industrial espionage* to every process by which a firm tries to get information about another one, regardless of the legality or ethicality of the methods used. Hence, in this thesis, the concept *industrial espionage* includes *competitive intelligence*.

1.2. Literature Review.

Espionage is a widespread practice in many areas of society, not only in industrial or economic field[22]. As Ho (2008) says[23], espionage has become a well-organized profession and there are many private investigators who offer their services to investigate infidelity, fraud, and more. On the other hand, the importance of espionage in military and national security affairs is undeniable.

Despite the importance of espionage, little theoretical work has been done to analyze it. This could be related to the veil of secrecy surrounding espionage. However, several theoretical papers analyze situations closely related to espionage where an agent has incentive to violate certain rules, and an inspector has to verify that the former adheres to them. This is the literature on *inspection games* and analyzes situations such that arm control and disarmament, auditing and accounting, etc[24].

Sakai (1985), Gaisford and Whitney (1999), Billand et al (2009) and Grossman (2005), like us in this thesis, analyze theoretically espionage in an economic and industrial context.

[22] Bishop (2012) is a very interesting article on espionage in the Olympic Games.

[23] See Ho (2008), page 55.

[24] An extensive survey of this literature is Avenhaus, Von Stengel y Zamir (2002).

Sakai (1985) considers a duopoly market model in which both firms know neither their own costs nor the costs of their opponent. Both firms can pay a market research agency to obtain information about these facts. When one firm hires this agency to obtain information about the cost structure of the other one, it would be a case of competitive intelligence. The paper assumes that this agency is not a strategic player in the game and the information it provides is correct.

Sakai (1985) shows that any improvement in information structure from the case where both firms have no information, tends to be beneficial to both firms and consumers. However, when the existing information structure is not the null information structure, improvements in information are more complex to evaluate.

Gaisford and Whitney (1999) study economic espionage between two countries (France and the USA as an example). Assuming that there is a single firm in each country (Airbus and Boeing in the example) and both firms compete *à la* Cournot, this paper analyzes the case where one or both countries spy on the other in an attempt to learn the technology and as a result to be able to lower the marginal cost of its own firm. When only one country is spying, the paper also considers the case where the spied country conducts counterespionage activities[25].

Assume that Boeing possesses a secret technology and France engages in economic espionage trying to obtain that technology for Airbus. Gaisford and Whitney (1999) show that espionage always benefits France and it is harmful to the US. Although the US can reduce this damage by conducting counterespionage activities, France would still benefit from spying. When both countries engage in spying on each other, both may be better off because of the technology transfer implicit in espionage[26]. Espionage is generally beneficial to consumers because the expected output rises and the expected price falls. However, as Gaisford and Whitney (1999) point out, all these results highly

[25] Gaisford and Whitney (1999) say that this "analysis could easily be adapted to allow for spying by the firms themselves" (page 104). This would be an industrial espionage case.

[26] This result would be related to Harris' (1998) historical research, according to which espionage helped the technology transfer between Britain and France in the eighteenth century (see Ho (2008), page 35, footnote 3).

depend on the type of competition. For instance, if firms compete *à la* Bertrand, espionage will also be harmful to France.

In a recent paper, Billand et al (2009) analyze industrial espionage in a Cournot model of several firms with differentiated goods. Firms compete on two interrelated markets and there are diseconomies of scope across them. Before competing on the markets, firms can spy each other trying to obtain information about other products that help to improve the quality of their own product. In this first version, it is assumed that spying is always successful.

The paper focuses first on the case where firms engage in espionage in one market only and, depending on the espionage costs, characterizes all the possible espionage configurations. The paper also shows that, in some situations, firms have no incentive to spy even if the costs are very low. Another interesting result is that, in some situations, firms may wish to be spied upon and, hence, they have no incentive to conduct counterespionage activities. Moreover, even though espionage implies improvements in product quality, there exist situations where it is detrimental to consumers as well as social welfare.

In case of economies of scope, firms spy on each other provided that the espionage costs are low enough. On the other hand, when firms engage in espionage in both markets, the number of equilibrium configurations increases without altering the above results.

Grossman (2005) considers a model where agents can pirate creative ideas created by others and these ideas can be protected from pirating. Pirating is defined as the appropriation of valuable ideas and, hence, it may include, among other activities, industrial (or economic) espionage. Consequently, guarding ideas from pirating may include counterespionage activities[27]. For instance, this would be the case of a firm that reduced its production cost or differentiated its product after investing in research and development, and another firm tries to appropriate the results of this research to reduce its own cost or differentiate its own product.

[27] Other ways of guarding ideas considered by Grossman (2005) include filing patents and copyrights. Hence, in this model, pirating activities also include the violation of them.

Note that the last two situations are, more or less, the ones considered by Gaisford and Whitney (1999) and Billand et al (2009) respectively, but the approach of Grossman (2005) is quite different and uses the structure of the models of producers, predators and guarding against predators summarized in Grossman (1998)[28]. More precisely, the paper analyses a model where, for a exogenously given environment for pirating ideas and distribution of talent, both creative activity and the security of the intellectual property rights depend on the decisions made by potential creative agents either to engage in creative activity (becoming inventors) or to be pirates of the creative ideas created by others and on the decisions made by inventors to allocate time and effort to guarding ideas from pirating[29].

Grossman (2005) first analyzes a simple version of the model in which all potentially creative agents are equally talented, but the most interesting case is when some potentially creative agents, the geniuses, are more talented than ordinary creative agents. The paper shows that the existence of geniuses may result in the fraction of potentially creative agents that chooses to be pirates, the fraction of time and effort that inventors allocate to guarding their ideas and the value of ideas created being larger than in the previous simple version of the model. However, in this case, the intellectual property rights are less secure and inventors are allocating a larger fraction of their time and effort to guarding their ideas than the fraction that would maximize the value of the ideas created[30].

Matsui (1989) considers a two-person repeated game in which one or both of the players have a small probability of perfectly detecting the other player action and

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[28] Usher (1987) developed a seminal model in which people decide whether to be producers or predators and in which producers also decide how much time and effort allocate to guarding against predators.

[29] Cozzi (2001) also considers the choice to be an inventor or to spy, but the paper does not consider the efforts of inventors to guard against espionage and focuses on the implications of espionage for growth. Cozzi and Spinesi (2006) also analyze the implications of espionage for growth.

[30] Grossman (2005) recognizes that the paper does not attempt a complete welfare analysis in which pirating can result in consumers paying lower prices for ideas (something like the welfare analysis of espionage in Gaisford and Whitney (1999) and Billand et al (2009)), and even, by diffusing ideas, can stimulate the creation of more ideas (see page 272, footnote 6).

revise his strategy accordingly. A central assumption of this model is that there is a certain cost in revising strategies.

The basic model focuses on the case where only one player spies on the other one, his preferences are lexicographical and the revision cost is infinitesimal. Matsui (1989) shows that, in this case, any subgame perfect equilibrium payoff is Pareto efficient for any positive probability of espionage.

A similar result is obtained when the preferences are not lexicographical and the revision cost is not infinitesimal. However, when both players spy on each other, this result is true only for sufficiently small probability of espionage.

Solan and Yariv (2004) also analyze espionage in two-person games in which espionage tries to obtain information about the opponent's strategy. But they consider normal form games where players decide on their strategies before the game starts and one of the players can purchase noisy information about his opponent's decision.

The paper provides a sort of a "folk theorem". Namely, for every espionage game it provides a characterization of the set of distributions over the entries of the payoff matrix that for some set of information devices and some cost structure can arise from espionage equilibria. It also describes their welfare and Pareto properties.

Solan and Yariv (2004) conclude that, while pure equilibria of the base game remain in the game with espionage, the set of mixed equilibria may change when the costs of the information devices are sufficiently low. Moreover, there may be additional (perfect Bayesian) equilibria when on player can spy on his opponent's strategy. In general, the set of true equilibria of the games with espionage coincides with the set of non-degenerate semi-correlated equilibrium distributions. On the other hand, while espionage sometimes leads to a strict Pareto improvement, espionage does not necessarily imply efficiency.

Provan (2008) focuses on two-person-zero-sum games in which one or both players can spy trying to obtain information about his opponent's strategy and the spied player can conduct counterespionage activities to mislead the spying player. This paper is more computational-based approach and it uses linear programming solutions.

Unlike the previous papers, Perea and Swinkels (1999) and Ho (2008) analyze espionage in the context of asymmetric information that is not related to the player's actions.

Perea and Swinkels (1999) study a model of extensive form games in which, at every information set, players can purchase an information device from a monopolistic seller who sets prices for the devices. They consider different scenarios and analyze the value of information, the way it can be computed and how the way the information seller sets the price (in advance or to negotiate at every information set) influences the game.

Ho (2008) focuses on a two-person game in which an uninformed player can hire at least one private investigator (PI) to try to obtain this information. The PI is another player in the game, with his own interests. In this environment there are two possible loyalty problems. First, PI might not put full effort to obtain the information, and this is the moral hazard problem. Second, if the value of the information is really high, the spied side might pay PI to not give the information or even to transmit false information. This is the double crossing problem.

Ho (2008) focuses on these PI's loyalty problems and analyzes, applying contract theory, if there exists a mechanism to ensure PI's loyalty and extract information. The paper concludes that, in the case without a double crossing problem, direct mechanism, in which the uninformed player hire only one PI, can solve the moral hazard problem and espionage is most beneficial when the uninformed side has only a small suspicion. When there may be double crossing problems, direct mechanism is costly and the reward can be too high for a PI to be hired. This is because in the direct mechanism the PI has larger bargaining power by double crossing. The controlling side's bargaining power would increase by introducing some competition to the PI side. In this sense, Ho (2008) shows that a competitive mechanism, where the controlling side hires two PIs and introduces a relative performance regime, can extract information and mitigate the over rewarding problem in the direct mechanism.

Let us briefly mention only a few theoretical papers on military intelligence.

Ho (2007) is similar in spirit to Ho (2008). In this case there are two countries and asymmetric information about the possession of a new weapon by one of the countries.

In this context, Ho (2007) uses contract theory to analyze when the uninformed country will hire a spy to obtain this information, why a spy will defect and how the enemy can use a double agent to fight back.

Biran and Tauman (2009) deal with the role of intelligence in nuclear deterrence and, unlike Ho (2007), espionage aims to obtain information on the rival's strategy. In this game there are two rival countries. One of them wishes to develop some weapons and the other one wants to frustrate this, even if it requires attacking the country. But before attacking, he spies his enemy to make sure with high probability she is indeed developing the weapons. The purpose of the paper is to analyze the impact the spying activity has on the strategic behavior of the two rivals and on the equilibrium outcome of this conflict.

Biran and Tauman (2009) is closely related to Solan and Yariv (2004), but in the latter the spying device is the strategic choice of the player who spies on his opponent. Biran and Tauman (2009), on the other hand, assume that the owner of the device owns it before the game starts, and its quality is either common knowledge or it is his private information.

Finally, the purpose of Pecht and Tishler (2011a,b) is to determine the optimal expenditures on military intelligence, subject to the assumption that the government's objective is to maximize national welfare.

1.3. Objectives and Methodology.

The objective of this thesis is to analyze theoretically the impact of industrial espionage on the strategic behavior of the firms in the context of entry deterrence using the tools provided by Game Theory.

We focus on market entry because it is one of the situations where, as we said above, information can make the difference between success and failure of a firm. Market entry is one of the most fundamental decisions a firm has to make. The entrant firm has to consider many things[31], but for instance, information about the incumbent's actions or production costs may be very important ones. A real case that can motivate the

[31] Basov, Smirnov and Wait (2007).

theoretical models of this thesis could be the one explained in Mezzanine Group (2010). This is a case study that shows the importance for a potential entrant to obtain information about the incumbent(s) firm(s). More precisely, it deals with the case of an energy market entrant that asked a consulting company (*The Mezzanine Group*) to evaluate the competitive landscape of Ontario market. Similarly as we consider in the models of this thesis, competitor positions, strategies and resources were part of the information the entrant obtained.

Moreover, although entry deterrence games have been extensively studied in the literature[32] , the effects of espionage on these games have not been studied before.

In the models of this thesis we consider the existence of a monopoly incumbent (M) and a potential entrant (E) to the market. M wishes to deter E from entering the market. For this purpose, M can consider an investment in capacity expansion (Chapters 2 and 3) or to invest in R&D in an attempt to reduce his production cost (Chapter 4). In the first case E does not observe M's decision of whether or not to invest in capacity, and in the second one E does not observe if the investment was successful or not. For this reason, E operates an Intelligence System (IS) which set to detect M's action in the first case, and the result of the investment in the second one. E takes into account the information provided by the IS to decide whether or not to enter the market.

The precision of the IS is α and it is assumed w.l.o.g that $1/2 \leq \alpha \leq 1$. The IS can send one out of two noisy signals about M's decision in the first case, or about the success of the investment in the second one. The signal sent by the IS is correct with probability α. For simplicity we assume that the precision, α, of the IS is independent of the action of M. If $\alpha = 1$, the IS is a perfect device and E can perfectly detect the action of M in the first case, and the success of the investment in the second one. If $\alpha = 1/2$, it is the case where E is not using any intelligence system.

This IS is exactly the same to that considered by Biran and Tauman (2009) and to the information devices in Solan and Yariv (2004). Hence the models in this thesis are closely related to both papers and, like them, to games with communication where the

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

noisy signals are determined via free messages that players send according to an exogenously specified communication protocol and precede the players' decisions[33]. Nonetheless, it is worth nothing that Crawford and Sobel (1982) consider a signaling game of one sender, S, and one receiver, R. The sender has private information and based on his information he sends a noisy signal to the receiver. The receiver then chooses an action that affects the utilities of both players based on the signal she observes. We can think of M in our models as the sender of the signal since his action or the success or failure of his investment automatically induces a noisy signal by the IS. The entrant, E, is the receiver of the signal and takes it into account to decide whether or not to enter the market.

In this thesis we consider that the precision α of the IS may be both exogenously given (Chapters 2 and 4) and endogenous (Chapter 3). The first one is the case if a firm has already a spying technology before it encounters a new rival (e.g., a firm that has the ability to plant a Trojan Horse in the computer system of her rivals). The second one would be the case of a firm hiring managers and workers from another one trying to obtain industrial secrets from them. For instance, the Volkswagen case in 1997 and the Hilton case in 2009 we refer in the motivation section of this chapter, would be real examples of this situation.

Finally, as Biran and Tauman (2009) say, this kind of IS is not a decision maker who can act strategically as in Perea and Swinkels (1999) and Ho (2007, 2008). For the value of information in strategic conflicts see also Kamien, Tauman and Zamir (1990).

1.4. Structure and Contents.

The remainder of the thesis is structured in four chapters.

Chapters two, three and four analyze theoretically industrial espionage in the context of entry deterrence. In what follows, we summarize each chapter and point out the important results.

In the second chapter, *Entry with a Noisy Signal*, a monopoly incumbent (M) wishes to deter a potential entrant (E) from entering the market considering a capacity

[33] Solan and Yariv (2004), page 175.

expansion. Under perfect information E stays out if the capacity of M is expanded and enters if M did not expand capacity. Capacity expansion requires investment and E does not observe M's decision of whether or not to invest in capacity. Hence, E enters only if she believes that with high probability the capacity was not expanded.

The entrant E operates an Intelligence System (IS) which set to detect M's action. The IS can send one out of two signals. The signal i indicating that M invests in new capacity and the signal ni indicating the opposite. The precision of the IS is α, $1/2 \leq \alpha \leq 1$. Namely, the signal sent by the IS is correct with probability α. Based on the signal received, E decides whether or not (or with what probability) to enter the market. In this chapter the precision α of the IS is exogenously given.

There are four possible outcomes: (NI, NE), (NI, E), (I, NE), (I, E), where I stands for "invest" and NI stands for "not invest". The interpretation of E and NE is similar. The best outcome for M is the status quo outcome (NI, NE). His second best outcome is (I, NE). M prefers the outcome (I, NE) on (I, E), and if the investment cost not too high, then M prefers the outcome (I, E) on (NI, E). As for E, her best outcome is (NI, E) and it is better for her than either (I, NE) or (NI, NE) (in both cases E obtains zero). The worst outcome for E is (I, E).

This model is a game in which M and E choose their actions simultaneously. The information is symmetric or asymmetric depending on whether or not M knows the precision α of the IS. Hence, the solution concepts employed in this chapter are Nash equilibrium and perfect Bayesian equilibrium.

A more realistic scenario is the case where α is a private information of E. But before analyzing this case, we study the benchmark case where the value of α is commonly known. If the investment cost is sufficiently high so that M prefers not to invest even if he knows that E enters, the result is straightforward. It is a dominant strategy for M not to invest and E will enter the market.

Suppose next that the investment cost is such that M prefers to invest if he knows that E enters. Suppose first that E obtains the signal ni. If the IS is not very accurate (α falls below a certain threshold, $\bar{\alpha}$) then with probability 1 E enters (believing with high probability that M did not expand his capacity). However, if the IS is sufficiently accurate (above $\bar{\alpha}$) then, quite surprisingly, E "hesitates" and stays out with a significant probability. Suppose next that E obtains the signal i. If the IS is not very accurate (below $\bar{\alpha}$), E hesitates and enters with a positive probability (less than 1), taking into account the possible mistake of the IS. If the IS is more accurate, E stays out with probability 1.

Regarding the benefits of the two players, M benefits from the IS more than its owner, E, if the IS is relatively accurate. Whenever α exceeds the threshold, $\bar{\alpha}$, E ends up with zero payoff and she is indifferent between spying on M or not. The optimal accuracy of the IS for E is the threshold value $\bar{\alpha}$ while M is best off with a perfect IS (namely $\alpha = 1$). The implication is that M should subsidize E for building a perfect IS, even though this means that E will be able to perfectly monitor him.

Next we analyze the asymmetric information case where the precision, α, of the IS is the private information of E. The incumbent M knows the distribution of α but does not know the actual realization of α. In particular it covers the case where E does not use an IS ($\alpha = \frac{1}{2}$) but M believes with positive probability that E does operate an IS of a precision $\alpha > \frac{1}{2}$. We find out that while the equilibrium strategies are qualitatively consistent with the common knowledge case, the payoffs of M and E behave in a more intuitive way. Contrary to the complete information case, E obtains positive payoff if α is sufficiently large and this payoff is increasing in α. Furthermore, if M believes that the expected value of α is below the threshold $\bar{\alpha}$, then E obtains positive payoff for all values of α. As for M and contrary to the complete information case, M is best off when E does not spy on him.

The closest related paper to this chapter is Biran and Tauman (2009). Actually, our model is similar in spirit to them, but their context is different and deals with the role of intelligence in nuclear deterrence. The preferences of the players are different and so are the results. Solan and Yariv (2004) are also closely related to this chapter, but they consider that the precision of the intelligence system is the strategic choice of the spying player. Another papers where the objective of the espionage activities is the opponent's strategy are Matsui (1989) and Provan (2008), but their set-up is different from ours.

The contribution of this chapter is the analysis of industrial espionage in the context of entry deterrence. The most interesting result is that when the precision α of the IS is common knowledge, M benefits from the IS more than its owner, E.

In the third chapter, *Strategic Choice of the Intelligence System*, we extend the model in Chapter 2 by assuming that the Intelligent System and its precision α are a costly choice of E.

While in Chapter 2 α is exogenously given (and it can either be commonly known or a private information of its owner E), in the third chapter we assume that the value of α is common knowledge to both firms and it is a strategic choice of E. In this case M can either observe or not this choice of E.

This model is a four-stage game in which E chooses first the precision α of the IS. In the second stage M can observe or nor α (we consider both cases) and chooses whether to invest or not to invest. In the third stage the IS sends a signal "i" or "ni", and in the last stage, based on the signal observed, E chooses whether or not to enter. The solution concept employed is the subgame perfect equilibrium (s.g.p.e.).

Consider first the case where α is a strategic choice of E and her choice is perfectly observed by M. Suppose that the cost of an IS of precision α is increasing and convex in α. Ex-post M could make two possible mistakes. The first type mistake is that M (unnecessarily) expands his capacity and E decides to stay out. The second type mistake is when M does not invest and E enters. Our results depend on whether the penalty of M from the first type mistake is smaller or larger than that of the second type mistake.

If the penalty is smaller for the second type mistake, the optimal choice of E is to build an IS of a precision of at most $\bar{\alpha}$. Depending on the cost structure, any α in between $1/2$ and $\bar{\alpha}$ can be the optimal choice of E. If however the penalty of M from committing the first type mistake is smaller, the optimal choice of E is not to build any IS, irrespective of how small is the cost to build it (provided that it is positive). Sadly for M, this is the worst case scenario. M benefits the higher is the precision of the IS, provided that the value of α is common knowledge to both firms.

The case where M does not observe the choice α of E is more difficult to analyze. If building an IS of precision α is cost free, then the only equilibrium is that E chooses to build a perfect IS ($\alpha = 1$) and M chooses to invest. In this case E stays out and obtains zero. Nevertheless, given that M invests, E will not enter no matter what is α and she cannot benefit from reducing α. Suppose next that the cost of building an IS is linear and the marginal cost of α is constant. If the marginal cost is relatively high, E does not spy on M. The difficult part is when the marginal cost is relatively low, but positive. It can be shown that there is no equilibrium where E selects a certain α with probability 1. While it is shown that equilibrium exists, we could not find the equilibrium probability distribution over α. Similar results are obtained when the cost of building an IS is constant, i.e, it does not depend on the precision α.

The closest related paper to this chapter is Solan and Yariv (2004), but they focus on the case where the spied player observes the precision of the device chosen by the spying player. In a different set-up, Provan (2008) also considers that the objective of the espionage is to obtain information about the opponent's strategy and analyzes the situation where the player has to choose which informational probe he will employ, but the opponent does not know which one he will be using. In Gaisford and Whitney (1999) the objective of the spying activities is not the opponent's strategy, but they also consider that the precision of the intelligence system is the strategic choice of its owner. The contribution of this chapter is to extend the model in Chapter 2 assuming that the precision of the IS is a strategic choice of its owner, E. In this chapter we consider the case where the spied player (M, in this case) does not observe the choice of E (the spying player), scarcely considered in the literature.

In the fourth chapter, *Entry with Two Correlated Signals*, a monopoly, M, is engaged in R&D to reduce his cost of production and deter a portential entrant, E, from entering the market. The outcome of this R&D project is a private information of M and E assigns a certain probability that M fails to reduce his cost. If the project fails and E enters, she obtains positive profit. Otherwise, if the project succeeds and E enters, she will not be able to cover her entry cost and she will end up with negative profit.

The entrant has an access to an Intelligence System (IS) that allows her to collect (noisy) information about the cost structure of M. The IS sends one out of two signals. The signal h, which indicates that the investment was not successful (M is of type H), and the signal l, which indicates that the investment was successful (M is of type L). As usually, the precision of the IS is α, $1/2 \leq \alpha \leq 1$. That is, the signal sent by the IS is correct with probability α. It is assumed that α is exogenous and common knowledge.

The entrant decides whether or not to enter the market based on a pair of signals: the price, p, that M charges for his product and the signal s (h or l) sent by the IS. If E enters the market, she competes with M (whether it is a Cournot or Bertrand competition, or any other mode of competition).

The case where $\alpha = 1/2$, namely, where the IS has no value (and, therefore, can be ignored), is exactly the limit pricing model of Milgrom and Roberts (1982) (hereafter MR). Therefore, our model is an extension of the MR model where the entrant has an access to an intelligence system and it is only for $1/2 < \alpha < 1$.

This model is a game with asymmetric information and the interaction between E and M is described as a three-stage game. In the first stage M sets a price and the IS sends a signal, h or l. In the second stage, E who observes both the price set by M and the signal sent by the IS, decides whether or not to enter the market. Finally, in the third stage, if E enters, M and E compete in the market. The solution concept employed is sequential equilibrium.

We distinguish two cases: the first one is the separating equilibrium where the two types of M charge different prices p_H and p_L, $p_H \neq p_L$; the second one is the pooling equilibrium case where $p_H = p_L$.

We show that the separating equilibria of our model coincide with that of MR and the IS makes no difference for either E or M. This is not very surprising since in a separating equilibrium E identifies the type of M with or without the use of the IS. The same result is obtained for pooling equilibria if the precision α of the IS is sufficiently low (close to $\frac{1}{2}$) to affect the decision of E of staying out. For the other extreme, if α is very accurate (close to 1), then contrary to the MR model, pooling equilibrium does not exist. In this case, E identifies with high probability the type of M and she will enter the market if the signal is h and she will stay out if the signal is l. The H type monopolist, who knows that his type is detected with high probability, has an incentive to deviate to his monopoly price, upsetting a pooling equilibrium. For the intermediate case, where α is bounded away from $\frac{1}{2}$ and 1, we show that the set of pooling equilibria is non-empty and the monopoly price of the L-type monopoly is the highest pooling equilibrium price. The decision of E is still entering if the signal is h and staying out if the signal is l. Note that in the MR model the entrant never enters in a pooling equilibrium. Hence, the use of the IS with high probability increases competition in pooling equilibrium. The entrant enters the market for intermediate levels of α if the signal is h. This is true even when pooling equilibrium does not exist in the MR model. From this point of view, spying on incumbent firms increases competition with high probability.

This chapter is related to Perea and Swinkels (1999) and Ho (2007, 2008) since they also consider espionage in the context of asymmetric information. However, in the present model the IS is not a decision maker who can act strategically as in Perea and Swinkels (1999) and Ho (2007, 2008). The chapter is also related to Sakai (1985) since he considers two firms and one objective of the information gathering activity is, like in our model, the cost structure of the opponent firm. However, unlike us, the paper considers that both firms know neither the costs of their opponent nor their own costs.

Another related paper is Bagwell and Ramey (1988). They extend the MR model by allowing the incumbent to signal his costs with both price and advertisements. Hence, while in this paper both signals are sent by the incumbent, in our model he only signals his costs by the price, the other signal is generated by the IS operated by the entrant. Bagwell (2007) extends Bagwell and Ramey (1988) and considers a more general game in which the incumbent has two dimensions of private information, his costs and his level of patience.

The contribution of this chapter is to extend the MR model to the case where the potential entrant has an access to an intelligence system to better detect the cost structure of the cost structure of the monopolist. Assuming that the precision α of the IS is common knowledge, we show that spying on incumbent firms increases competition with high probability.

Finally, the fifth chapter summarizes the results of this thesis and presents some guidelines for future research.

Chapter 2. Entry with a Noisy Signal

2.1. Introduction.

Information about the reaction of an incumbent firm to a new firm entering the market is very important for a firm considering market entry. Since incumbent's strategy may be determined in meetings and filed in reports, it may leak to the potential entrant firm by means of industrial espionage[34].

In this chapter we analyze the role of industrial espionage when a monopoly incumbent (M) wishes to deter a potential entrant (E) from entering the market considering a capacity expansion. Under perfect information E stays out if the capacity of M is expanded and enters if M did not expand capacity. Capacity expansion requires investment and E does not observe M's decision of whether or not to invest in capacity. Hence, E enters only if she believes that with high probability the capacity was not expanded.

The entrant E operates an Intelligence System (IS) which set to detect M's action. The IS can send one out of two signals. The signal i indicating that M invests in new capacity and the signal ni indicating the opposite. The precision of the IS is α, $1/2 \leq \alpha \leq 1$. Namely, the signal sent by the IS is correct (it sends the signal i when M invests and sends the signal ni, otherwise) with probability α. If $\alpha = 1$ the IS is a perfect device and E can perfectly detect the action of M. The case $\alpha = 1/2$ is equivalent to not using any intelligence system. Based on the signal received, E decides whether or not (or with what probability) to enter the market.

In this model the precision α of the IS is exogenously given. This would be the case if the entrant firm has already a spying technology before she considers entering the market where the incumbent firm is operating (e.g. she has the ability to plant a Trojan Horse in the computer system of the incumbent firm).

[34] Matsui (1989).

There are four possible outcomes: (NI, NE), (NI, E), (I, NE), (I, E), where I stands for "invest" and NI stands for "not invest". The interpretation of E and NE is similar. The best outcome for M is the status quo outcome (NI, NE). His second best outcome is (I, NE). M prefers the outcome (I, NE) on (I, E), and if the investment cost not too high, then M prefers the outcome (I, E) on (NI, E). As for E, her best outcome is (NI, E) and it is better for her than either (I, NE) or (NI, NE) (in both cases E obtains zero). The worst outcome for E is (I, E).

A more realistic scenario is the case where α is a private information of E. But before analyzing this case, we study the benchmark case where the value of α is commonly known. If the investment cost is sufficiently high so that M prefers not to invest even if he knows that E enters, the result is straightforward. It is a dominant strategy for M not to invest and E will enter the market.

Suppose next that the investment cost is such that M prefers to invest if he knows that E enters. Suppose first that E obtains the signal ni. If the IS is not very accurate (α falls below a certain threshold, $\bar{\alpha}$) then with probability 1 E enters (believing with high probability that M did not expand his capacity). However, if the IS is sufficiently accurate (above $\bar{\alpha}$) then, quite surprisingly, E "hesitates" and stays out with a significant probability. Suppose next that E obtains the signal i. If the IS is not very accurate (below $\bar{\alpha}$), E hesitates and enters with a positive probability (less than 1), taking into account the possible mistake of the IS. If the IS is more accurate, E stays out with probability 1.

Let us provide some intuition for these results. If the precision of the IS is relatively high, M who knows α knows that if he does not expand his capacity, E will detect this with high probability and she is likely to enter the market. Hence, M expands capacity with high probability, and the signal ni is less likely to occur. Consequently, when E observes the signal ni, she can no longer rely on its accuracy and she decides to stay out with positive probability. If the precision of the IS is less accurate, M expands capacity with smaller probability, knowing that there is a good chance that his action will not be detected. The signal ni is now more likely to be sent and when E observes it, she enters the market with probability 1.

In equilibrium the unconditional probability that E enters the market decreases, the higher is the precision of IS. Hence, M benefits from a better precision of IS.

Regarding the benefits of the two players, M benefits from the IS more than its owner, E, if the IS is relatively accurate. Whenever α exceeds the threshold, $\bar{\alpha}$, E ends up with zero payoff and she is indifferent between spying on M or not. The optimal accuracy of the IS for E is the threshold value $\bar{\alpha}$ while M is best off with a perfect IS (namely $\alpha = 1$). The implication is that M should subsidize E for building a perfect IS, even though this means that E will be able to perfectly monitor him.

Next we analyze the asymmetric information case where the precision, α, of the IS is the private information of E. The incumbent M knows the distribution of α but does not know the actual realization of α. In particular it covers the case where E does not use an IS ($\alpha = \frac{1}{2}$) but M believes with positive probability that E does operate an IS of a precision $\alpha > \frac{1}{2}$. We find out that while the equilibrium strategies are qualitatively consistent with the common knowledge case, the payoffs of M and E behave in a more intuitive way. Contrary to the complete information case, E obtains positive payoff if α is sufficiently large and this payoff is increasing in α. Furthermore, if M believes that the expected value of α is below the threshold $\bar{\alpha}$, then E obtains positive payoff for all values of α. As for M and contrary to the complete information case, M is best off when E does not spy on him.

The closest related paper to this chapter is Biran and Tauman (2009). Actually, our model is similar in spirit to them, but their context is different and deals with the role of intelligence in nuclear deterrence. The preferences of the players are different and so are the results. Solan and Yariv (2004) are also closely related to this chapter, but they consider that the precision of the intelligence system is the strategic choice of the spying player[35]. Another papers where the objective of the espionage activities is the opponent's strategy are Matsui (1989) and Provan (2008), but their set-up is different from ours[36].

[35] We consider this situation in Chapter 3.

[36] For more details about all these papers see the literature review in Chapter 1.

The contribution of this chapter is the analysis of industrial espionage in the context of entry deterrence. The most interesting result is that when the precision α of the IS is common knowledge, M benefits from the IS more than its owner, E.

The reminder of the paper is organized as follows. The next section sets out the basic model. In Section 2.3 we analyze the equilibrium when the precision α of the IS is commonly known. Section 2.4 analyzes the equilibrium when α is the private information of E. And Section 2.5 gives a conclusion of the chapter. The proofs of all the results are given in the Appendix of this chapter.

2.2. The Basic Model.

There are two firms, M and E. The Incumbent Firm, M, is a monopolist and E is a potential entrant. 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 $1-\alpha$. If $\alpha = 1/2$, the IS is of no relevance and if $\alpha = 1$, the IS is perfect.

The following tree summarizes the above:

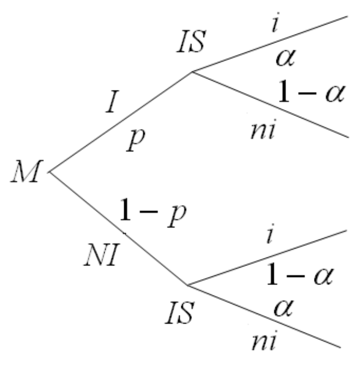

Figure 1

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	a, 1	1, 0

Figure 2

It is assumed that $\max(a,b) < c < 1$ and $\min(a,b) \geq 0$.

We consider two cases: (i) $a > b$ and (ii) $b > a$. The first case is when the investment cost is high and M prefers not to invest even if he knows that E enters. In this case NI is a strictly dominat strategy for M and E enters the market irrespective the signal received. The more difficult case is where the investment cost is not too high and M prefers to invest if he knows that E enters.

So from now on we assume that

$$0 \leq a < b < c < 1 \qquad \text{(AS1)}$$

Without loss of generality assume $a = 0$. Then, we replace the table in Figure 2 by

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

Figure 3

2.3. The Case where α is Commonly Known.

Suppose that (AS1) holds. 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.

2.3.1. Two Extreme Cases.

Let us start with the two extreme cases where $\alpha = 1/2$ and $\alpha = 1$.

The case $\alpha = 1/2$ is basically the case where E does not operate an IS on M, and the strategic game between M and E is described in Figure 3. 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 his 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:

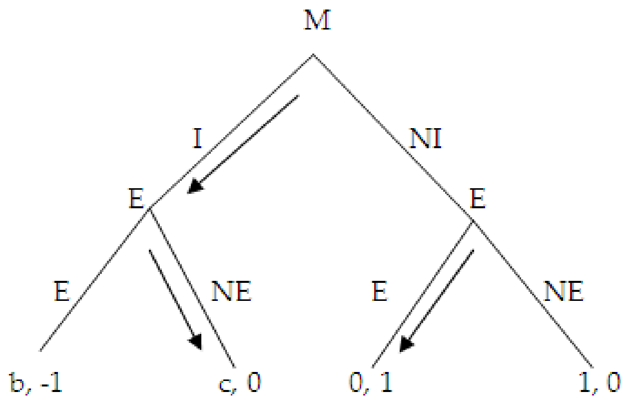

Figure 4

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 $\alpha = 1/2$. The payoff of E is zero in both there 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 is α commonly known.

2.3.2. 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 3):

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 5

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:

E \ M		(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 6

Let $\bar{\alpha} = \max\left[\frac{1}{2}, \frac{1-b}{1-b+c}\right]$. This parameter plays a central role in our analysis.

We first analyze the case where $1-c \le b$. Namely (see Figure 3), the cost of making a mistake for M is larger when E enters than when E does not enter. In this case $\bar{\alpha} = \frac{1}{2}$.

<u>Proposition 1.</u> Suppose that $1-c \le b$. Then the game has a unique Nash equilibrium. (1) The Entrant does not enter the market if the signal is i and randomizes between entering and not entering if the signal is ni. The Incumbent randomizes between expanding and not expanding its capacity. (2) The probability that the Incumbent expands his capacity is increasing in α. The probability that the Entrant enters the market is decreasing in α. (3) The expected payoff of the Incumbent increases in α. The expected payoff of the Entrant is zero.

<u>Proof.</u> See Appendix.

Since $b \ge 1-c$ 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 the signal i with higher probability than the signal ni. As a result, E stays out for sure if she observes the signal i and E hesitates if she observes the less expected signal ni. In the latter case E mixes 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. Hence, the expected payoff of M increases with α and the expected payoff of E is zero.

We conclude that for $1-c \le b$ even if the IS is cost free E has no incentive to use IS since her payoff is zero irrespective of the quality α.

We next deal with the case where $1-c>b$. In this case $\bar{\alpha}>\frac{1}{2}$ and the equilibrium outcome depends on whether $\alpha<\bar{\alpha}$ or $\alpha>\bar{\alpha}$.

<u>Proposition 2.</u> Suppose that $1-c>b$. If $\alpha\neq\bar{\alpha}$, the game has a unique Nash equilibrium. In equilibrium: (1) If E observes the signal ni she enters the market with probability 1 if $\alpha<\bar{\alpha}$ and she randomizes her two actions if $\alpha>\bar{\alpha}$. If E observes the signal i she randomizes her two actions if $\alpha<\bar{\alpha}$ and stays out with probability 1 if $\alpha>\bar{\alpha}$. (2) The probability that E enters the market is decreasing in α for all $\alpha\in\left(\frac{1}{2},1\right)$. (3) The probability that M expands capacity is decreasing in α for $\frac{1}{2}<\alpha<\bar{\alpha}$ and it is increasing in α for $\bar{\alpha}<\alpha<1$. (4) The expected payoff of M is increasing in α, for all α, and the expected payoff of E is increasing in α for $\frac{1}{2}<\alpha<\bar{\alpha}$ and it is zero for all α, $\bar{\alpha}<\alpha<1$.

If $\alpha=\bar{\alpha}$, the game has a multiplicity of equilibria. In equilibrium E enters the market with certainty if she observes the signal ni and E stays out with certainty if she observes the signal i. M has a continuum of best reply strategies.

<u>Proof.</u> See Appendix.

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 7 below). The incumbent firm is best off with a perfect IS, even thought that means perfect monitoring of his actions. Let Π_E be the equilibrium expected payoff of E.

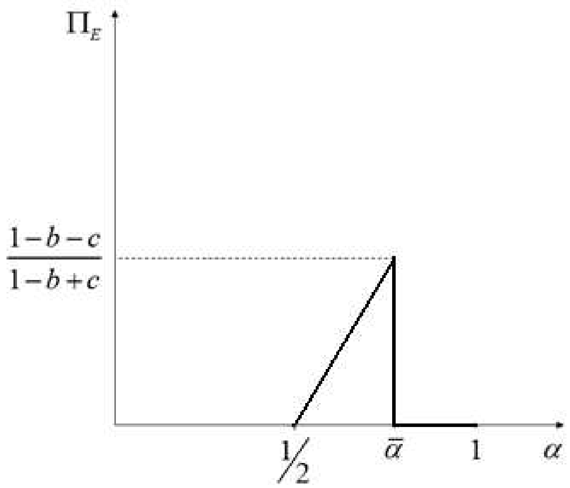

Figure 7

Let us provide intuition for these results. If the precision α of the IS is sufficiently large ($\alpha > \bar{\alpha}$), M who knows α knows that his action will be correctly detected with high probability. He therefore expects that if he does not expand his capacity, E is likely to enter. Hence, M expands his capacity with high probability which can be shown to be α. Consequently, the signal ni is not likely to occur. If E observes this signal, she should not trust its accuracy and should update her belief about M's action. As a result, she does 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 enters with probability 1 if the signal is ni and randomizes her action 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. This behavior of M has two opposite effects on M's payoff. The negative 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 outperforms the negative effect and as a result the unconditional probability that E enters decreases with α.

2.4. 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 $\alpha, \frac{1}{2} \leq \alpha \leq 1$ 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 3), it is assumed that

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

Suppose that M chooses I with probability p and NI with probability $1 - p$.

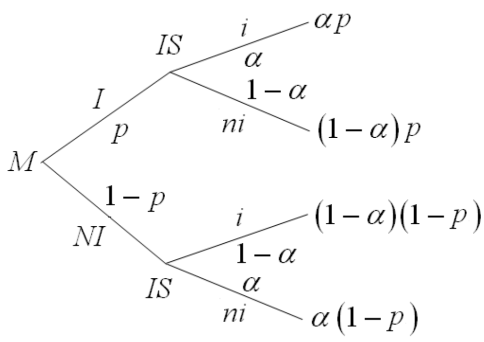

Figure 8

The probability that E assigns to the event that M expands his capacity after observing the signal i is

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

Similarly

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

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

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

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

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

Similarly

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

$$\Pi_E\left(NE\middle|\alpha,i\right)=0 \quad (2)$$

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

Given p, by (1) and (2), if E receives the signal i she prefers E on NE iff

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

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 $\alpha>1-p$. If $\alpha=1-p$, E is indifferent between entering and not entering the market.

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

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

or equivalently iff $\alpha>p$.

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

$$s_E\left(i\middle|\alpha, p\right)=\begin{cases} NE & p>\frac{1}{2},\quad \frac{1}{2}<\alpha\leq 1\\ E & p\leq\frac{1}{2},\quad \frac{1}{2}<\alpha<1-p\\ NE & p\leq\frac{1}{2},\quad 1-p<\alpha\leq 1\\ \text{any strategy} & p\leq\frac{1}{2},\quad \alpha=1-p\end{cases} \tag{3}$$

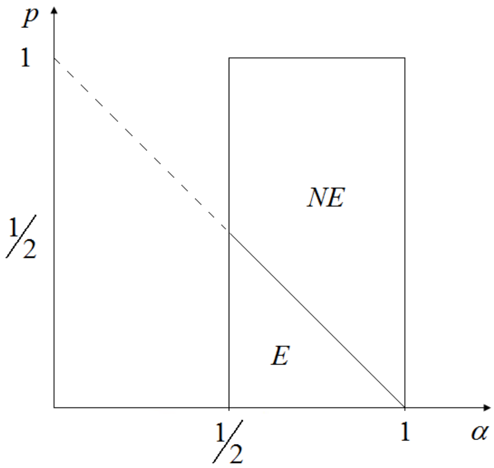

Figure 9: $s_E\left(i\,|\,\alpha,\,p\right)$

$$s_E\left(ni\,|\,\alpha,\,p\right)=\begin{cases} E & p<\frac{1}{2},\quad \frac{1}{2}<\alpha\le 1 \\ NE & p\ge\frac{1}{2},\quad \frac{1}{2}<\alpha<p \\ E & p\ge\frac{1}{2},\quad p<\alpha\le 1 \\ \text{any strategy} & p\ge\frac{1}{2},\quad \alpha=p \end{cases} \tag{4}$$

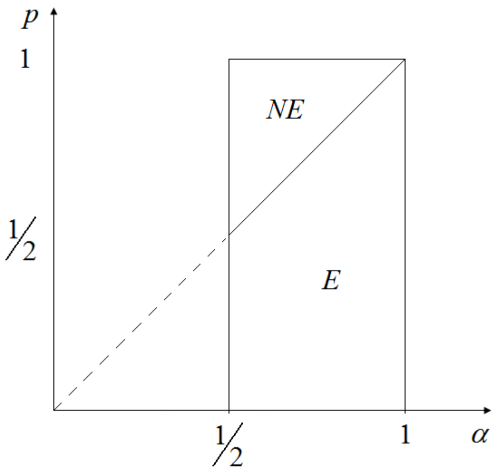

Figure 10: $s_E\left(ni\,|\,\alpha,\,p\right)$

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 the strategic behavior of the two players in the asymmetric information case is qualitatively similar to the case where the precision of the IS is common knowledge.

Proposition 3. Suppose that $E(\alpha)\neq\bar{\alpha}$. Then Γ has a unique perfect Bayesian equilibrium.

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

(2) If $E(\alpha)<\bar{\alpha}$, there exists $\bar{p}_2$, $0<\bar{p}_2<\frac{1}{2}$, such M expands his capacity with probability $\bar{p}_2$. If the signal is ni, E enters the market irrespective of the precision α of the IS. If the signal is i, E does not enter the market if $\alpha>1-\bar{p}_2$ and she enters the market if $\alpha<1-\bar{p}_2$.

Proof. See Appendix.

The next two figures illustrate the results of Proposition 3.

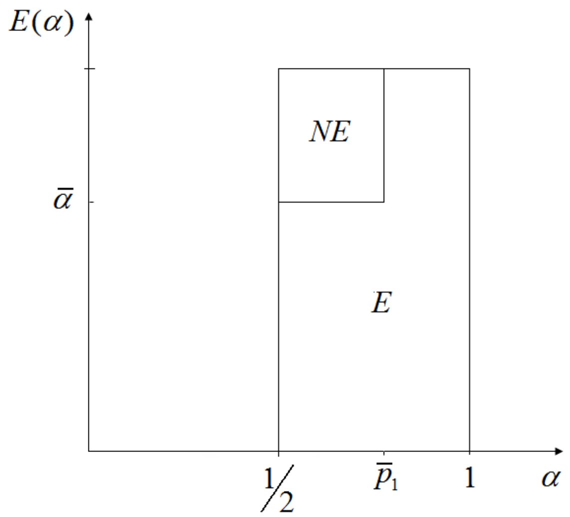

Figure 11: The decision of E when the signal is ni

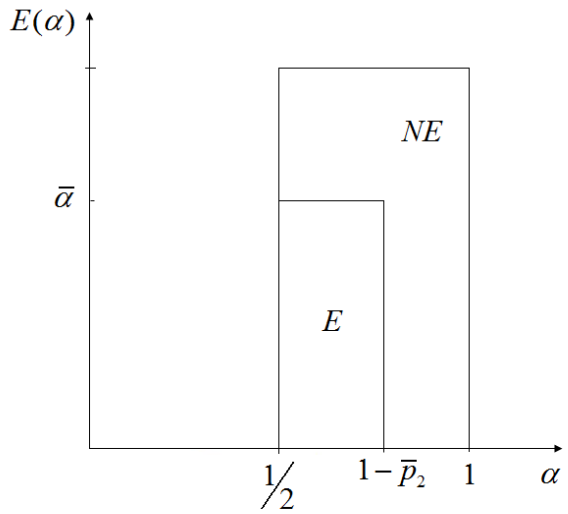

Figure 12: The decision of E when the signal is i

Unlike the case where α is commonly known, the equilibrium strategy of E as a function of α is a pure action (enter or not enter the market with probability 1). However, M mixes his two pure actions, 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 believes that the expected precision of the IS is low and with high probability he does not expand capacity believing that E is likely not to detect him. Then E, following the 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 the market. If on the other hand, the expected precision of the IS exceeds $\bar{\alpha}$, M believes that the expected precision of the IS is relatively high and in this case E is likely to detect his action. Hence, M expands his capacity with relatively high probability, and E, following the signal ni, will enter the market if the actual precision is relatively high ($\alpha > \bar{p}_1$) and will not enter the market otherwise.

This result is quite consistent with the case where α is commonly known. When α is commonly known, the actual precision and the expected precision are the same. If it does not exceed $\bar{\alpha}$, M invests with relatively low probability and E, following the signal ni, will enter the market with probability 1. If it exceeds $\bar{\alpha}$, M invests with relatively high probability and E, following ni, will randomize between entering and not entering. In the asymmetric information case the mixing is obtained by varying the pure action of E as a function of α. Namely, E of type α enters the market if $\alpha > \bar{p}_1$ and stays out if $\alpha < \bar{p}_1$.

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 4. Consider the equilibrium of Γ. Then,

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

(2) Suppose that $E(\alpha) < \bar{\alpha}$. Then for all α in the interval $\left(\frac{1}{2}, 1-\bar{p}_2\right)$ 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 $(1-\bar{p}_2, 1)$, $\pi_E(\alpha)$ is strictly increasing.

Proof. See Appendix.

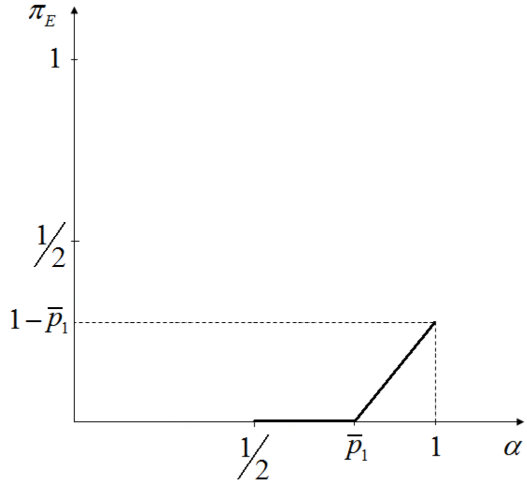

Figure 13: The expected payoff of E when $E(\alpha) > \bar{\alpha}$

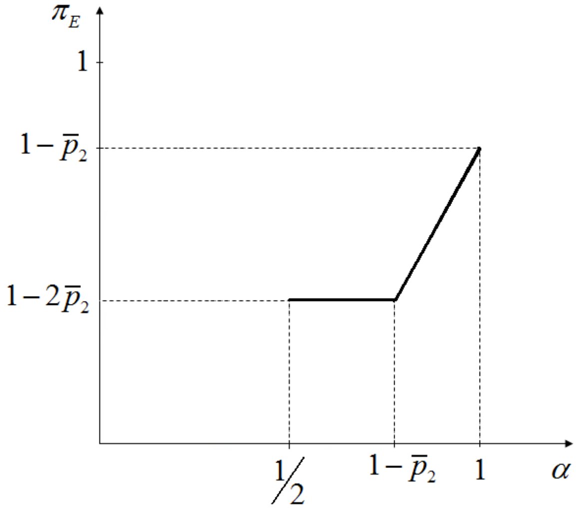

Figure 14: The expected payoff of E when $E(\alpha) < \bar{\alpha}$

In contrast to the common knowledge case, Proposition 4 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 (depending on whether or not $E(\alpha) > \bar{\alpha}$) since her equilibrium strategy does not depend on the signal generated by the IS, and there after it is strictly increasing because E can detect M's action with a relatively accurate precision and choose her strategy accordingly. When $E(\alpha) < \bar{\alpha}$, the expected equilibrium payoff of E is greater than when $E(\alpha) > \bar{\alpha}$ because in the first case M invest with low probability believing that E is not likely to detect him and, for large α, E can accurately detect that he is not investing and enter the market consequently, while in the second case, M invests with relatively high probability reducing the equilibrium expected payoff of E.

Let $\pi_M(\alpha)$ be the equilibrium expected payoff of M when the precision of the IS is α.

The next proposition describes the equilibrium payoff of M.

<u>Proposition 5.</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 $1-\bar{p}_2 < \alpha < 1$.

(3) Suppose that $E(\alpha) > \bar{\alpha}$, if c is sufficiently close to 1, then $\bar{p}_1 > \frac{1}{1-b+c}$ and $\pi_M(\alpha)$ is strictly increasing for $\bar{p}_1 < \alpha < 1$. If c is sufficiently small, $\bar{p}_1 < \frac{1}{1-b+c}$ and $\pi_M(\alpha)$ is strictly decreasing.

<u>Proof.</u> See Appendix.

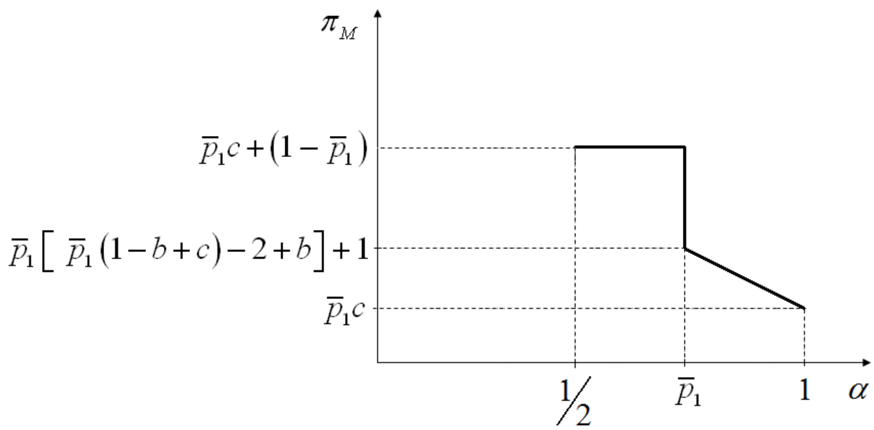

Figure 15: The expected payoff of M when $E(\alpha) > \bar{\alpha}$ and $\frac{1}{2} < \bar{p}_1 < \frac{1}{1-b+c}$

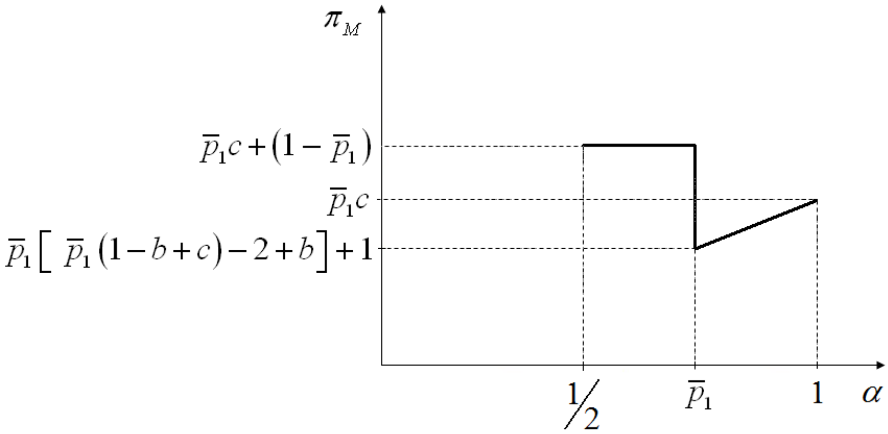

Figure 16: The expected payoff of M when $E(\alpha) > \overline{\alpha}$ **and** $\frac{1}{1-b+c} < \overline{p}_1 < 1$

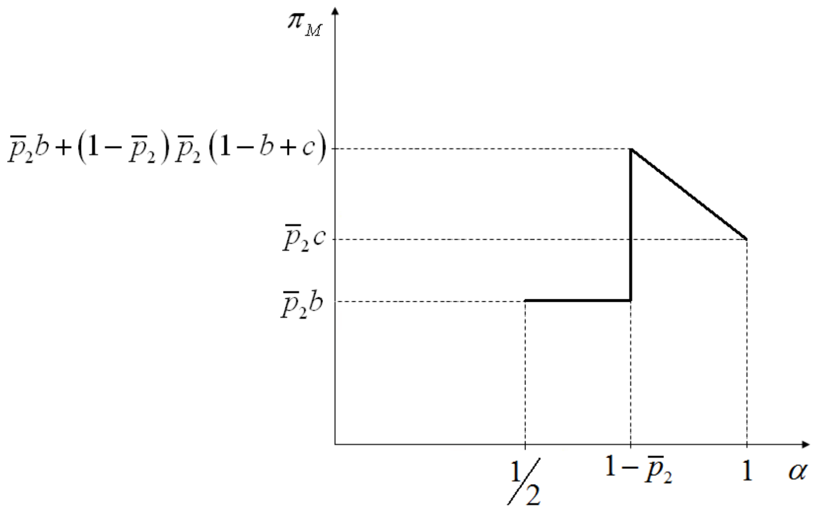

Figure 17: The expected payoff of M when $E(\alpha) < \overline{\alpha}$

In the common knowledge case M is always best off when E perfectly detects his action. The asymmetric case yields different results.

Up to a certain value of α the ex-post expected payoff of M is constant because the equilibrium strategy of E does not depend on the signal she receives.

If M believes that the expected precision of the IS is relatively high he is best off when E does not spy on him or if the IS has a low accuracy.

Note that in this case, when $\overline{p}_1 < \alpha < 1$, the equilibrium payoff of M may be increasing or decreasing in α. When the reward, c, from deterring E from entering the market when M expands capacity, is sufficiently close to 1, then (and only then) M benefits from large values of α. The reason is that when $E(\alpha) > \bar{\alpha}$ M believes that it is likely that E operates a highly accurate IS and in this case E is likely to detect his action. Hence, M expands his capacity with relatively high probability and for large α it is likely that the IS generates the signal i, which induces E to stay out. In this case M obtains c. Hence, the larger is c the larger is the probability that M expands capacity[37] (and if c is sufficiently close to 1, $\frac{1}{1-b+c} < \bar{p}_1 < 1$). Also the more accurate the IS is the higher is the probability that E stays out and the higher is the payoff of M.

When c is not sufficient close to 1, M expands his capacity with relatively high probability ($\bar{p}_1 > 1/2$) but it is not as large as when c is sufficient close to 1 (now $\frac{1}{2} < \bar{p}_1 < \frac{1}{1-b+c}$). Then, in this case, for large α it is more likely that the IS generates the signal ni than when c is sufficient close to 1, inducing E to enter the market and decreasing the expected equilibrium payoff of M.

However, even when c is sufficient close to 1, the expected equilibrium payoff of M is greater when $\frac{1}{2} < \alpha < \bar{p}_1$ than when $\bar{p}_1 < \alpha < 1$ because in the first case E stays out for sure while in the second one there exists a chance that she enters the market. That's why M prefers an IS with a low accuracy.

If M believes that the expected precision of the IS is low, M prefers E to spy on him, but with an IS which is not perfect. Actually, the closer α is to $1-\bar{p}_2$ (from above) the better is M.

Note that in this case, when $1-\bar{p}_2 < \alpha < 1$, the equilibrium payoff of M is decreasing in α because in this case with high probability M does not expand capacity believing that E is likely not to detect him, and then, as α becomes larger E is more likely to detect M's action and she is likely to enter. But, even though the expected equilibrium payoff

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[37] $\bar{p}_1$ is also increasing in b, but it can be shown that $\frac{\partial \bar{p}_1}{\partial c} > \frac{\partial \bar{p}_1}{\partial b}$. See the proof of Proposition 3 in the Appendix.

of M is decreasing in α when the IS is quite accurate ($1-\bar{p}_2 < \alpha < 1$), it is greater than his expected equilibrium payoff when the IS is less accurate ($\frac{1}{2} < \alpha < 1-\bar{p}_2$) because in the last case E enters the market for sure while in the first one there exists a chance that she stays out. That's why M prefers a precision of the IS, α, as close as possible to $1-\bar{p}_2$ (from above), because with this precision is more likely that IS generates the (less likely) signal i, inducing E to stay out.

Finally consider the next two examples to illustrate these results.

Example 1: Consider the uniform distribution case where $f(\alpha)=2$ for $\frac{1}{2} \leq \alpha \leq 1$ and $f(\alpha)=0$ otherwise. Note that $E(\alpha)=\frac{3}{4}$ and $E(\alpha)>\bar{\alpha}$ implies that $b+3c>1$.

It can be shown that $\bar{p}_1 = \frac{(c-b)+\sqrt{c^2+b-bc}}{1-b+c}$ and the equilibrium ex-post expected payoff $\pi_M(\alpha)$ of M is increasing in α for $\bar{p}_1 < \alpha < 1$ iff $\frac{1}{2} < c < 1$ and $0 < b < \frac{-(1-c)+\sqrt{c^2+6c-3}}{2}$.

For every other values of b and c s.t. $0<b<c<1$ $\pi_M(\alpha)$ is strictly decreasing.

Example 2: Assume that $b=c-\frac{1}{2}$. Note that in this case it must be that $\frac{1}{2}<c<1$. Consider, like the example 1, the uniform distribution case where $f(\alpha)=2$ for $\frac{1}{2} \leq \alpha \leq 1$ and $f(\alpha)=0$ otherwise. $E(\alpha)=\frac{3}{4}$ and $E(\alpha)>\bar{\alpha}$ implies that $c>\frac{3}{8}$.

It can be shown that $\bar{p}_1 = \frac{1+\sqrt{6c-2}}{3}$ and the equilibrium ex-post expected payoff $\pi_M(\alpha)$ of M is increasing in α for $\bar{p}_1 < \alpha < 1$.

The proof of these examples appears in the Appendix.

2.5. Conclusion.

In this chapter we analyzed industrial espionage when a potential entrant (E) develops an Intelligence System (IS) of precision α to spy on a monopoly incumbent (M), trying to detect his decision of whether or not to invest in capacity expansion, and then decide whether or not to enter the market taking into account this information. We showed that, if α is commonly known to both firms, surprisingly, M is the one who benefits from a perfect IS and E who spies on M prefers a less accurate one. If, on the other hand, α is a private information of E, the opposite result is obtained. E is best off with a perfect IS and M with a less accurate one. However, the equilibrium strategies of both firms in the asymmetric information case are quite consistent with the case where α is common knowledge.

2.6. Appendix

Proof of Proposition 1.

Note that the game has no equilibrium in pure strategies (since $1/2 < \alpha < 1$, $0 < c < 1$ and $b > 0$). And since $\alpha > 1/2$ there is no equilibrium where the Entrant mixes its three pure strategies.

Consider first the case where the Entrant mixes its strategies (E, E) and (E, NE). Note that in this case the strategy NI of the Incumbent is strictly dominated by its strategy I. Hence the Incumbent will deviate from $(p, 1-p)$ to I.

When the Entrant mixes (E, E) and (NE, NE), $p = \frac{1}{2}$ and the Entrant obtains zero. But the Entrant will deviate to (E, NE) because $\alpha - \frac{1}{2} > 0$ since $\alpha > 1/2$.

If the Entrant mixes (E, NE) and (NE, NE), $p = \alpha$ and the Entrant obtains zero. If the Entrant deviates to (E, E), it obtains $1 - 2\alpha < 0$, since $\alpha > 1/2$. Hence, the Entrant will not deviate.

Note that in this case, if the Incumbent chooses the strategy I he obtains $\left[b + (c-b)\alpha\right]q + c(1-q)$, and if he chooses its strategy NI he obtains $(1-\alpha)q + (1-q)$. Hence, in equilibrium,

$$\left[b + (c-b)\alpha\right]q + c(1-q) = (1-\alpha)q + (1-q)$$

Solving for q we have

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

We can conclude that the game has the following equilibrium point: the M's equilibrium strategy is $(p, 1-p)$ and the E's strategy is $(0, q, 0, 1-q)$ where $p = \alpha$ is the probability that M invests and

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

The expected payoffs of the firms are

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

$$\Pi_E = 0$$

■

Proof of Proposition 2.

Consider five cases:

Case 1. The Entrant mixes only the two pure strategies (E, E) and (E, NE) and assigns zero probability to the pure strategy (NE, NE). The following figure shows the resulting game:

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

Figure 18

This case is relevant only if $\alpha < \bar{\alpha} = \frac{1-b}{1-b+c}$. If $\alpha > \bar{\alpha}$, the strategy NI of the Incumbent is strictly dominated by its strategy I, and M will choose I with probability 1, which contradicts the fact that the game has no equilibrium in pure strategies. Let $\alpha < \bar{\alpha}$ and suppose that the Incumbent chooses the mixed strategy $(p, 1-p)$ where $0 < p < 1$. If the Entrant chooses (E, E), she obtains an expected payoff of $-p+(1-p)$, while her expected payoff is $(-1+\alpha)p+\alpha(1-p)$ if she chooses (E, NE). Since the Entrant mixes two pure strategies it must be that $-p+(1-p)=(-1+\alpha)p+\alpha(1-p)$.

Solving for p we obtain $p^* = 1-\alpha$.

The payoff of the Entrant is $2\alpha - 1$ and she has no incentive to deviate to (NE, NE) because $2\alpha - 1 > 0$.

Suppose next that the Entrant mixes her two pure strategies (E, E) and (E, NE) with probabilities q and $1-q$ respectively, where $0 < q < 1$. If the Incumbent chooses the strategy I, he obtains $bq + \left[b+(c-b)\alpha\right](1-q)$; and if he chooses NI, he obtains $(1-\alpha)(1-q)$. Since $0 < p^* < 1$ it must be that

$$bq + \left[b+(c-b)\alpha\right](1-q) = (1-\alpha)(1-q)$$

Solvig for q we have

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

We summarize this first case in the following lemma:

Lemma 1. Suppose that $\frac{1}{2} < \alpha < \bar{\alpha}$. Then the game has the following equilibrium point: the Incumbent plays $\left(p^*, 1-p^*\right)$ and the Entrant plays $\left(q^*, 1-q^*, 0, 0\right)$ where

$$p^* = 1-\alpha$$

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

The expected payoffs are

$$\Pi^*_M = \frac{(1-\alpha)b}{1-\alpha(1+c-b)}$$

$$\Pi^*_E = 2\alpha - 1$$

also they both increase in α.

Case 2. The Entrant mixes only the two pure strategies (E,E) and (NE,NE) and assigns zero probability to (E,NE). The resulting game is

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

Figure 19

Suppose first that the Incumbent mixes his two strategies I and NI and plays $(p, 1-p)$. If the Entrant chooses (E,E), she obtains $-p+(1-p)$, and if she chooses (NE,NE), she obtains zero. Since the Entrant mixes these two strategies, $-p+(1-p)=0$.

Solving for p we obtain $\widehat{p} = \frac{1}{2}$.

The expected payoff of the Entrant is zero. If the Entrant deviates to (E,NE), she obtains $(-1+\alpha)\widehat{p} + \alpha(1-\widehat{p}) = \alpha - \frac{1}{2}$, which is positive.

Hence, the Entrant is better off deviating to (E, NE), and there is no equilibrium where the Entrant mixes only the two pure strategies (E, E) and (NE, NE).

<u>Case 3.</u> The Entrant mixes her two pure strategies (E, NE) and (NE, NE).

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

Figure 20

This case is relevant only if $\alpha > \bar{\alpha} = \dfrac{1-b}{1-b+c}$. If $\alpha < \bar{\alpha}$, the strategy I of M is strictly dominated by the strategy NI, and the Incumbent will play NI purely, contradicting the fact that the game has no pure strategy equilibrium. Assume therefore that $\alpha > \bar{\alpha}$. If E chooses (E, NE), she obtains $(-1+\alpha)p + \alpha(1-p)$; and if she chooses (NE, NE), she obtains zero. Hence in equilibrium, $(-1+\alpha)p + \alpha(1-p) = 0$.

Solving for p we obtain $\hat{p} = \alpha$, and E obtains zero. If E deviates to (E, E), she obtains $-\hat{p} + (1-\hat{p}) = 1-2\alpha$, which is negative. Hence, the Entrant has no incentive to deviate.

Suppose next that E mixes her two pure strategies (E, NE) and (NE, NE) with probabilities q and $1-q$ respectively. Note that if M chooses the strategy I he obtains $\left[b+(c-b)\alpha\right]q + c(1-q)$, and if he chooses his strategy NI it obtains $(1-\alpha)q + (1-q)$.

Hence, in equilibrium,

$$\left[b+(c-b)\alpha\right]q + c(1-q) = (1-\alpha)q + (1-q)$$

Solving for q we have

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

We summarize this case in the following lemma:

Lemma 2. Suppose that $\bar{\alpha} < \alpha < 1$. Then, the game has a unique equilibrium point: the Incumbent's strategy is $(\hat{p}, 1-\hat{p})$ and the Entrant's strategy is $(0, \hat{q}, 0, 1-\hat{q})$ where

$$\hat{p} = \alpha$$

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

The expected payoffs of the firms are

$$\hat{\Pi}_M = \frac{\alpha(2c-b)+b-c}{\alpha(1-b+c)+b-c}$$

$$\hat{\Pi}_E = 0$$

The expected payoff of M increases in α.

Case 4. The Entrant mixes the three strategies (E,E), (E,NE) and (NE,NE). By cases 1 and 3 we must have that $p^* = \hat{p}$. It can be easily shown that $p^* = \hat{p}$ iff $\alpha = 1/2$. Consequently, there is no equilibrium in this case as we assumed that $\alpha > 1/2$.

Case 5. The Entrant chooses (E,NE) purely. This case is relevant only if $\alpha = \bar{\alpha} = \frac{1-b}{1-b+c}$. If $\alpha \neq \bar{\alpha}$ by cases 1 and 3 we know that there is no equilibrium in which E chooses one strategy purely. Assume therefore that $\alpha = \bar{\alpha}$.

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

Figure 21

If E plays (E,NE) purely, M is indifferent between choosing I or NI and he plays $(\tilde{p},1-\tilde{p})$. In this case E obtains

$$-\frac{c}{1-b+c}\tilde{p}+\frac{1-b}{1-b+c}(1-\tilde{p})=\frac{1-b-\tilde{p}(1-b+c)}{1-b+c}$$

In order for E not to deviate from (E,NE) to (NE,NE),

$$\frac{1-b-\tilde{p}(1-b+c)}{1-b+c}\geq 0$$

or equivalently,

$$\tilde{p}\leq\frac{1-b}{1-b+c}$$

In order for E not to deviate from (E,NE) to (E,E),

$$\frac{1-b-\tilde{p}(1-b+c)}{1-b+c}\geq 1-2\tilde{p}$$

or equivalently,

$$\tilde{p}\geq\frac{c}{1-b+c}$$

Note that $\frac{1-b}{1-b+c}>\frac{1}{2}$ since we are assuming $1-c>b$. Then, $\frac{1-b}{1-b+c}>\frac{c}{1-b+c}$ and we can conclude that $\frac{c}{1-b+c}\leq\tilde{p}\leq\frac{1-b}{1-b+c}$.

We summarize this case in the following lemma:

Lemma 3. Suppose that $\alpha = \bar{\alpha}$. Then, the game has multiple equilibrium points: the Incumbent strategy is $(\tilde{p}, 1-\tilde{p})$ where $\frac{c}{1-b+c} \le \tilde{p} \le \frac{1-b}{1-b+c}$ and the Entrant's strategy is (E, NE).

The expected payoffs of the firms are

$$\tilde{\Pi}_M = \frac{c}{1-b+c}$$

$$\tilde{\Pi}_E \in \left[0, \frac{1-b-c}{1-b+c}\right]$$

Next let us prove that the unconditional probability that E enters is decreasing in α.

Consider first the case $\frac{1}{2} < \alpha < \bar{\alpha}$. By Lemma 1 the Entrant enters the market with probability 1 if the signal is ni, and with probability q^* if the signal is i. Hence the probability of the Entrant enters the market is

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

To calculate $Prob(ni)$ and $Prob(i)$ consider Figure 8 (replacing p by p^*). We have

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

and

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

By (A1),

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

And it is decreasing in α,

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

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

Let us show why this probability is decreasing in α. Note that

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

has two components. The first one is the probability that E enters when she receives the signal ni, i.e., the probability of ni, $Prob(ni)$,

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

which is increasing in α,

$$\frac{\partial Prob(ni)}{\partial \alpha} = 4\alpha - 2 > 0, \forall \alpha, \tfrac{1}{2} < \alpha < 1$$

The second one is the probability that E enters when she receives the signal i, $q^* Prob(i)$, which is decreasing in α. That is, when α increases and E receives the signal i, she "trusts" this signal (as the IS is more accurate) and enters the market with lower probability. But she is making a "mistake", because this signal i is wrong with higher probability as α increases (since M invests with lower probability):

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

$$\frac{\partial Prob(i)}{\partial \alpha} = 2 - 4\alpha < 0, \forall \alpha, \tfrac{1}{2} < \alpha < 1$$

It turns out that the negative effect (the positive effect on M's payoff) produced by the probability that E enters when she receives the signal i (the "mistake") is greater than the positive effect (the negative effect on M's payoff) produced by the probability that E enters when she receives the signal ni, and, hence, the unconditional probability that E enters is decreasing in α.

Next assume that $\bar{\alpha} < \alpha < 1$. By Lemma 2, the probability that E enters is

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

Using the tree in Figure 8 (replacing p by $\hat{p}$) we have

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

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>

(1) Suppose that $E(\alpha) > \bar{\alpha}$ where $\bar{\alpha} = \frac{1-b}{1-b+c}$. Consider first the case where M expands his capacity with probability $\frac{1}{2} < p < 1$. Let $E_\alpha \Pi_M(p)$ be the expected payoff of M, if he plays the mixed strategy $(p, 1-p)$. In this case, M expands his capacity with probability p, the signal i is observed with probability α and the signal ni is observed with probability $1-\alpha$. Hence

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

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

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

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

$$E_\alpha \Pi_M(p) = p\left[c + (b-c)\int_{p}^{1} (1-\alpha) f(\alpha)\, d\alpha\right] + (1-p)\left[1 - \int_{p}^{1} \alpha\, f(\alpha)\, d\alpha\right] \qquad \text{(A3)}$$

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) does not change, but the probabilities of the signals do change. 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

$$E_\alpha\, \Pi_M\,(0) = E_\alpha\, \Pi_M\,(1) \tag{A4}$$

By (A3) and (A4)

$$c + (b-c)\int_p^1 (1-\alpha) f(\alpha)\, d\alpha = 1 - \int_p^1 \alpha\, f(\alpha)\, d\alpha \tag{A5}$$

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

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 $f(p) > 0$

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

Hence $g(p)$ is decreasing for $\frac{1}{2} \le p < 1$ since $\frac{c-b}{1-b+c} < \frac{1}{2}$. Since $g\left(\frac{1}{2}\right) > 0$ and $g(1) < 0$ then g intersects the x-axis only once. Namely, there is a unique $\overline{p}_1$ such that $g(\overline{p}_1) = 0$ and $\frac{1}{2} < \overline{p}_1 < 1$. Then $\overline{p}_1$ is the unique solution of (A5) and $\overline{p}_1 > \frac{1}{2}$ which is consistent with our assumption.

Next observe that there is no equilibrium strategy $(\overline{p}, 1-\overline{p})$ such that $\overline{p} \le \frac{1}{2}$ and $E(\alpha) > \frac{1-b}{1-b+c}$. Otherwise (A5) 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

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

a contradiction. We conclude that whenever $E(\alpha) > \frac{1-b}{1-b+c}$ there exists a unique equilibrium. M chooses to expand capacity with probability $\overline{p}_1 > \frac{1}{2}$ and E takes an action as described in (3) or (4). Namely, if E observes the signal i, she doesn't enter the market irrespective of her type α. If the signal is ni E does not enter the market iff $\frac{1}{2} < \alpha < \overline{p}_1$.

Next let us prove that $\frac{\partial \overline{p}_1}{\partial c} > 0$, $\frac{\partial \overline{p}_1}{\partial b} > 0$ and $\frac{\partial \overline{p}_1}{\partial c} > \frac{\partial \overline{p}_1}{\partial b}$.

We know that

$$c + (b-c)\int_{\overline{p}_1(b,c)}^{1} (1-\alpha) f(\alpha)\, d\alpha = 1 - \int_{\overline{p}_1(b,c)}^{1} \alpha\, f(\alpha)\, d\alpha \qquad \text{(A6)}$$

Deriving (A6) with respect to c and operating we have

$$1 + (c-b)\left[1-\overline{p}_1(b,c)\right] f(p)\frac{\partial \overline{p}_1(b,c)}{\partial c} - \int_{\overline{p}_1(b,c)}^{1} (1-\alpha) f(\alpha)\, d\alpha = pf(p)\frac{\partial \overline{p}_1(b,c)}{\partial c}$$

$$\left\{c-b-\overline{p}_1(b,c)[1-b+c]\right\} f(p)\frac{\partial \overline{p}_1(b,c)}{\partial c}=\int_{\overline{p}_1(b,c)}^{1}(1-\alpha) f(\alpha)\, d\alpha-1 \qquad \text{(A7)}$$

Note that $c-b-\overline{p}_1(b,c)[1-b+c]<0$ since $\frac{c-b}{1-b+c}<\frac{1}{2}$ and $\overline{p}_1(b,c)>\frac{1}{2}$. Hence, $\frac{\partial \overline{p}_1(b,c)}{\partial c}>0$.

Deriving (A6) with respect to b and operating we have

$$\int_{\overline{p}_1(b,c)}^{1}(1-\alpha) f(\alpha)\, d\alpha+(c-b)\left[1-\overline{p}_1(b,c)\right] f(p)\frac{\partial \overline{p}_1(b,c)}{\partial b}=pf(p)\frac{\partial \overline{p}_1(b,c)}{\partial b}$$

$$\left\{c-b-\overline{p}_1(b,c)[1-b+c]\right\} f(p)\frac{\partial \overline{p}_1(b,c)}{\partial b}=-\int_{\overline{p}_1(b,c)}^{1}(1-\alpha) f(\alpha)\, d\alpha \qquad \text{(A8)}$$

Similarly to the previous case we can conclude that $\frac{\partial \overline{p}_1(b,c)}{\partial b}>0$.

From (A7) and (A8) we know that

$$\frac{\partial \overline{p}_1(b,c)}{\partial c}=\frac{\int_{\overline{p}_1(b,c)}^{1}(1-\alpha) f(\alpha)\, d\alpha-1}{\left\{c-b-\overline{p}_1(b,c)[1-b+c]\right\} f(p)}$$

$$\frac{\partial \overline{p}_1(b,c)}{\partial b}=\frac{-\int_{\overline{p}_1(b,c)}^{1}(1-\alpha) f(\alpha)\, d\alpha}{\left\{c-b-\overline{p}_1(b,c)[1-b+c]\right\} f(p)}$$

Note that $\frac{\partial \overline{p}_1(b,c)}{\partial c}>\frac{\partial \overline{p}_1(b,c)}{\partial b}$ since

$$\int_{\overline{p}_1(b,c)}^{1}(1-\alpha) f(\alpha)\, d\alpha \leq \frac{1}{2}\int_{\overline{p}_1(b,c)}^{1} f(\alpha)\, d\alpha<\frac{1}{2}\int_{1/2}^{1} f(\alpha)\, d\alpha=\frac{1}{2}$$

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

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

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

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

$$E_\alpha \Pi_M(p) = p\left[b + (c-b)\int_{1-p}^{1} \alpha f(\alpha)\, d\alpha\right] + (1-p)\left[\int_{1-p}^{1}(1-\alpha)\, f(\alpha)\, d\alpha\right] \tag{A9}$$

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

$$E_\alpha \Pi_M(0) = E_\alpha \Pi_M(1) \tag{A10}$$

By (A9) and (A10) we have

$$b + (c-b)\int_{1-p}^{1} \alpha f(\alpha)\, d\alpha = \int_{1-p}^{1}(1-\alpha)\, f(\alpha)\, d\alpha \tag{A11}$$

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.

By our assumption

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

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 unique $0 < \bar{p}_2 < 1$ such that $\bar{p}_2$ is the unique solution of (A11), 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 $p \ge \frac{1}{2}$ while $E(\alpha) < \frac{1-b}{1-b+c}$. We conclude that whenever $E(\alpha) < \frac{1-b}{1-b+c}$ there exists a unique equilibrium: M expands his capacity with probability $\bar{p}_2$, $0 < \bar{p}_2 < \frac{1}{2}$. As for E, if the signal is i, E enters the market iff $\alpha < 1 - \bar{p}_2$. If the signal is ni, E enters the market, irrespective of α.

It is also easy to verify that there is no equilibrium where M is playing a pure strategy. Suppose that M expands his capacity with probability 1. The strategy of E is not to enter the market irrespective of the signal or of α. Hence, M obtains c. If he does not expand his capacity and E does not enter the market, he obtains $1 > c$. Similarly, if in equilibrium, M does not expand his capacity with probability 1, then E's best reply strategy is to enter the market irrespective of α and M obtains 0. If he expands capacity, he obtains $b > 0$. Consequently, M is better off deviating from any one of his pure strategies. This completes the proof of the proposition.

■

<u>Proof of Proposition 4.</u>

By (3), (4) and Proposition 3 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.

■

<u>Proof of Proposition 5:</u>

By (3), (4) and Proposition 3 it is easy to verify that

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

Note that when $E(\alpha)<\bar{\alpha}$, $\left[\bar{p}_2(1-b+c)-1\right]\alpha+1-\bar{p}_2(1-b)$ at $\alpha=1-\bar{p}_2$ is $\bar{p}_2 b+(1-\bar{p}_2)\bar{p}_2(1-b+c)$, and at $\alpha=1$ is $\bar{p}_2 c$.

Next note that $\bar{p}_2 b+(1-\bar{p}_2)\bar{p}_2(1-b+c)>\bar{p}_2 c$ iff $\bar{p}_2<\frac{1}{1-b+c}$, but this always holds because $0<\bar{p}_2<\frac{1}{2}$ and $\frac{1}{2}<\frac{1}{1-b+c}<1$. Similarly it can be shown that $\left[\bar{p}_2(1-b+c)-1\right]\alpha+1-\bar{p}_2(1-b)$ is decreasing in α.

Next consider the case where $E(\alpha)>\bar{\alpha}$.

Note that $\left[\bar{p}_1(1-b+c)-1\right]\alpha+1-\bar{p}_1(1-b)$ at $\alpha=\bar{p}_1$ is $\bar{p}_1\left[\bar{p}_1(1-b+c)-2+b\right]+1$, and $\bar{p}_1\left[\bar{p}_1(1-b+c)-2+b\right]+1<\bar{p}_1 c+(1-\bar{p}_1)$ iff $\bar{p}_1(1-b+c)(\bar{p}_1-1)<0$, i.e., always.

Next note that $\left[\bar{p}_1(1-b+c)-1\right]\alpha+1-\bar{p}_1(1-b)$ at $\alpha=1$ is $\bar{p}_1 c$, and $\bar{p}_1\left[\bar{p}_1(1-b+c)-2+b\right]+1>\bar{p}_1 c$ iff $\frac{1}{2}<\bar{p}_1<\frac{1}{1-b+c}$.

Similarly, $\left[\ \overline{p}_1(1-b+c)-1\right]\alpha+1-\overline{p}_1(1-b)$ is decreasing in α iff $\frac{1}{2}<\overline{p}_1<\frac{1}{1-b+c}$.

Let us now prove that $g\left(\frac{1}{1-b+c}\right)>0$ if c is sufficiently close to 1.

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

If c is sufficiently close to 1, $g\left(\frac{1}{1-b+c}\right)$ is sufficiently close to

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

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

$$>(b-1)\int_{\frac{1}{2-b}}^{1}f(\alpha)\,d\alpha+\int_{\frac{1}{2-b}}^{1}f(\alpha)\,d\alpha=b\int_{\frac{1}{2-b}}^{1}f(\alpha)\,d\alpha>0$$

Since $g'(p)<0$ for all $p, \frac{1}{2}<p<1$, and $g\left(\frac{1}{1-b+c}\right)>0$ for c sufficiently large, we have that $\overline{p}_1>\frac{1}{1-b+c}$.

■

Next let us prove the two examples.

Example 1: Consider the uniform distribution where $f(\alpha)=2$ for $\frac{1}{2}\leq\alpha\leq 1$ and $f(\alpha)=0$ otherwise. In this case $E(\alpha)=\frac{3}{4}$ and $E(\alpha)>\overline{\alpha}$ implies that $b+3c>1$.

From (A5) we have,

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

Operating and solving for p, we obtain

$$(1+c-b)\,p^2+2(b-c)\,p-b=0$$

$$\overline{p}_1 = \frac{(c-b)+\sqrt{c^2+b-bc}}{1-b+c} \tag{A12}$$

Note that $\frac{(c-b)+\sqrt{c^2+b-bc}}{1-b+c} > \frac{1}{1-b+c}$ iff $b^2+b(1-c)+1-2c<0$, or equivalently,

$0<b<\frac{-(1-c)+\sqrt{c^2+6c-3}}{2}$.

Note also that $0<\frac{-(1-c)+\sqrt{c^2+6c-3}}{2}<c$ iff $\frac{1}{2}<c<1$.

■

Example 2: Suppose that $b=c-\frac{1}{2}$. In this case $\frac{1}{2}<c<1$ and the equilibrium ex-post expected payoff $\pi_M(\alpha)$ of M is given by

$$\pi_M(\alpha)=\begin{cases} \overline{p}_2\left(c-\frac{1}{2}\right) & , \; E(\alpha)<\overline{\alpha},\; \frac{1}{2}<\alpha<1-\overline{p}_2 \\ \left[\frac{3}{2}\overline{p}_2-1\right]\alpha+1-\overline{p}_2\left(\frac{3}{2}-c\right) & , \; E(\alpha)<\overline{\alpha},\; 1-\overline{p}_2<\alpha<1 \\ \overline{p}_1c+(1-\overline{p}_1) & , \; E(\alpha)>\overline{\alpha},\; \frac{1}{2}<\alpha<\overline{p}_1 \\ \left[\frac{3}{2}\overline{p}_1-1\right]\alpha+1-\overline{p}_1\left(\frac{3}{2}-c\right) & , \; E(\alpha)>\overline{\alpha},\; \overline{p}_1<\alpha<1 \end{cases}$$

It is easy to verify that if $E(\alpha)>\overline{\alpha}$, $\pi_M(\alpha)$ is strictly decreasing for $\overline{p}_1<\alpha<1$ if $\frac{1}{2}<\overline{p}_1<\frac{2}{3}$, and is strictly increasing if $\frac{2}{3}<\overline{p}_1<1$.

Now consider, like in example 1, the uniform distribution where $f(\alpha)=2$ for $\frac{1}{2}\le\alpha\le 1$ and $f(\alpha)=0$ otherwise. Note that $E(\alpha)=\frac{3}{4}$ and $E(\alpha)>\overline{\alpha}$ implies that $c>\frac{3}{8}$.

Replacing $b=c-\frac{1}{2}$ in (A12), we have

$$\overline{p}_1 = \frac{1+\sqrt{6c-2}}{3}$$

Note that $\frac{1+\sqrt{6c-2}}{3} > \frac{2}{3}$ iff $\frac{1}{2} < c < 1$. Then the equilibrium ex-post expected payoff $\pi_M(\alpha)$ of M is increasing in α for $\overline{p}_1 < \alpha < 1$.

■

Chapter 3. Strategic Choice of the Intelligence System

3.1. Introduction.

The precision of the intelligence system operated by the potential entrant may be both exogenously given[38] or endogenous. The first one would be the case if the entrant firm has already a spying technology before she considers entering the market where the incumbent firm is operating (e.g. she has the ability to plant a Trojan Horse in the computer system of the incumbent firm). The second one would be the case of entrant firm hiring managers and workers from the incumbent firm trying to obtain industrial secrets (in this case information about the incumbent's action) from them.

In this chapter we analyze the model in Chapter 2 when the Intelligent System and its precision α are a costly choice of E. While in Chapter 2 α is exogenously given (and it can either be commonly known or a private information of its owner E), in the present chapter we assume that the value of α is common knowledge to both firms and it is a strategic choice of E. In this case M can either observe or not this choice of E.

Consider first the case where α is a strategic choice of E and her choice is perfectly observed by M. Suppose that the cost of an IS of precision α is increasing and convex in α. Ex-post M could make two possible mistakes. The first type mistake is that M (unnecessarily) expands his capacity and E decides to stay out. The second type mistake is when M does not invest and E enters. Our results depend on whether the penalty of M from the first type mistake is smaller or larger than that of the second type mistake.

Suppose first that the penalty is smaller for the second type mistake. Then the optimal choice of E is to build an IS of a precision of at most $\bar{\alpha}$. Depending on the cost structure, any α in between $1/2$ and $\bar{\alpha}$ can be the optimal choice of E. If however the penalty of M from committing the first type mistake is smaller, the optimal choice of E is not to build any IS, irrespective of how small is the cost to build it (provided that it is positive). The intuition is as follows. This is the case where the penalty of not

[38] Like in Chapters 2 and 4 of this thesis.

expanding the capacity (and E enters) is higher than the penalty of the other mistake of expanding capacity (and E stays out). In this case M invests with probability higher than $\frac{1}{2}$ and E expects to observe the signal i with high probability. Therefore, if E observes i, she stays out for sure. If, however, E observes the less expected signal ni, she is "confused" and mixes between entering and not entering. This can happen only if she is indifferent between these two choices and E obtains zero irrespective of α. Hence if the cost of building an IS is positive, she is best off not spying on M. Sadly for M, this is the worst case scenario. M benefits the higher is the precision of the IS, provided that the value of α is common knowledge to both firms.

The case where M does not observe the choice α of E is more difficult to analyze. If building an IS of precision α is cost free, then the only equilibrium is that E chooses to build a perfect IS ($\alpha = 1$) and M chooses to invest. In this case E stays out and obtains zero. Nevertheless, given that M invests, E will not enter no matter what is α and she cannot benefit from reducing α. Suppose next that the cost of building an IS is linear and the marginal cost of α is constant. If the marginal cost is relatively high, E does not spy on M. The difficult part is when the marginal cost is relatively low, but positive. It can be shown that there is no equilibrium where E selects a certain α with probability 1. While it is shown that equilibrium exists, we could not find the equilibrium probability distribution over α. Similar results are obtained when the cost of building an IS is constant, i.e, it does not depend on the precision α.

The closest related paper to this chapter is Solan and Yariv (2004), but they focus on the case where the spied player observes the precision of the device chosen by the spying player. In a different set-up, Provan (2008) also considers that the objective of the espionage is to obtain information about the opponent's strategy and analyzes the situation where the player has to choose which informational probe he will employ, but the opponent does not know which one he will be using. In Gaisford and Whitney (1999) the objective of the spying activities is not the opponent's strategy, but they also consider that the precision of the intelligence system is the strategic choice of its owner[39].

The contribution of this chapter is to extend the model in Chapter 2 assuming that the precision of the IS is a strategic choice of its owner, E. In this chapter we consider the case where the spied player (M, in this case) does not observe the choice of E (the spying player), scarcely considered in the literature.

The structure of the chapter is as follows. Sections 3.2 and 3.3 analyze the case when M observes α and where M does not observe it, respectively. Section 3.4 concludes the chapter. The proofs of all the results are given in the Appendix of this chapter.

3.2. The Strategic Choice of α when M Observes It.

Let Γ_0 be defined like the game G_α (see Chapter 2) except that α is a strategic variable of E and $\gamma(\alpha)$ is the cost of building an IS of quality α. We assume that M observes the choice α of E before he chooses whether to invest or not. The game Γ_1, defined later on, deals with the case where M does not observe E's choice of α.

The game Γ_0 is a four-stage game in which E chooses first the precision α of the IS. In the second stage M observes α and chooses whether to invest or not to invest. In the third stage the IS sends a signal "i" or "ni", and in the last stage, based on the signal observed, E chooses whether or not to enter. We analyze the subgame perfect equilibrium (s.g.p.e.) of Γ_0.

3.2.1. The General Case.

Suppose that the cost of building an IS is $\gamma(\alpha)$. Assume that $\gamma(1/2)=0$, $\gamma'(\alpha)>0$ and $\gamma''(\alpha)>0$.

Ex-post M could make two possible mistakes. The first type mistake is that M (unnecessarily) expands his capacity and E decides to stay out. The second type mistake is when M does not invest and E enters. Note that $1-c$ is the penalty of M from the first type mistake and b is his penalty from the second type mistake (see

[39] For more details about these papers see the literature review in Chapter 1.

Figure 3 in Chapter 2). Our results depend on whether the penalty of M from the first type mistake is smaller or larger than that of the second type mistake.

Consider first the case where $b+c<1$, namely, the penalty is smaller for the second type mistake. In this case $\bar{\alpha}=\frac{1-b}{1-b+c}>\frac{1}{2}$. By Proposition 2 in Chapter 2, for every α the equilibrium expected payoff of E is given by

$$\Pi_E(\alpha)=\begin{cases} 2\alpha-1-\gamma(\alpha), & \frac{1}{2}\le\alpha<\bar{\alpha} \\ -\gamma(\alpha), & \bar{\alpha}<\alpha\le 1 \\ \in\left[-\gamma(\bar{\alpha}),\frac{1-b-c}{1-b+c}-\gamma(\bar{\alpha})\right], & \alpha=\bar{\alpha} \end{cases} \tag{1}$$

The next proposition characterizes the subgame perfect equilibrium choice of α.

<u>Proposition 1.</u> Let $b+c<1$. The game Γ_0 has a unique subgame perfect equilibrium. Suppose that $\gamma(\frac{1}{2})=0$, $\gamma'(\alpha)>0$ and $\gamma''(\alpha)>0$ for all $\alpha\in\left[\frac{1}{2},1\right]$. Let α^* be the equilibrium choice of E. Then, (i) $\alpha^*=\frac{1}{2}$ and E does not operate an IS on M iff $\gamma'\left(\frac{1}{2}\right)\ge 2$, (ii) $\alpha^*=\bar{\alpha}$ iff $\gamma'(\bar{\alpha})\le 2$, (iii) $\frac{1}{2}<\alpha^*<\bar{\alpha}$ and $\alpha^*=(\gamma')^{-1}(2)$ iff $\gamma'\left(\frac{1}{2}\right)<2$ and $\gamma'(\bar{\alpha})>2$. In the last two cases E obtains a positive net payoff and in the first case his payoff is zero.

<u>Proof.</u> See Appendix.

The following figure summarizes Proposition 1:

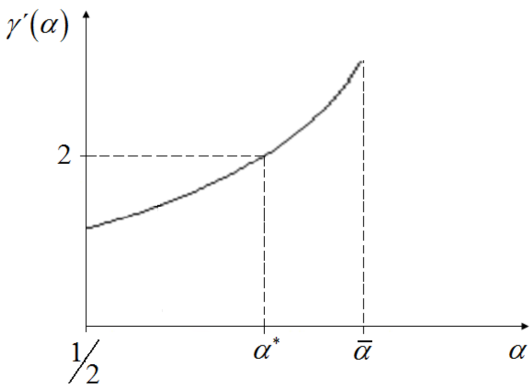

Figure 1

Proposition 1 asserts that, when the penalty is smaller for the second type mistake, E only benefits from spying on M if $\gamma'\left(\frac{1}{2}\right) < 2$ and the optimal choice of E is to build an IS of a precision of at most $\bar{\alpha}$. Depending on the cost structure, any α in between $\frac{1}{2}$ and $\bar{\alpha}$ can be the optimal choice of E.

Note that, although there are multiple equilibrium strategies for M in G_α in case $\alpha = \bar{\alpha}$ (see Proposition 2 of Chapter 2), the game Γ_0 has a unique s.g.p.e. even when $\alpha^* = \bar{\alpha}$ is the equilibrium choice of E. This is because there is no equilibrium where M chooses at $\alpha = \bar{\alpha}$ to invest with probability higher than $1-\bar{\alpha}$ since, if M invests with probability higher than $1-\bar{\alpha}$, E has an incentive to slightly lower α below $\bar{\alpha}$. We conclude that the unique subgame perfect equilibrium outcome in this case is $\alpha = \bar{\alpha}$, and M invests in capacity with probability $1-\bar{\alpha}$.

Consider next the case where $b+c \geq 1$, namely, the penalty of M from committing the first type mistake is smaller. In this case the entrant obtains zero payoff even if the cost $\gamma(\alpha)$ is zero (see Proposition 1 in Chapter 2), and her payoff is negative if the cost is positive, unless $\alpha = \frac{1}{2}$. Hence the entrant in this case does not build an IS, that is $\alpha^* = \frac{1}{2}$.

We summarize this case by the following proposition.

<u>Proposition 2.</u> Suppose that $b+c \geq 1$. Then any subgame perfect equilibrium of Γ_0 and for every increasing cost function $\gamma(\alpha)$ with $\gamma(\frac{1}{2}) = 0$, $\alpha^* = \frac{1}{2}$.

3.2.2. Examples.

In this section we consider three examples to better understand the last results.

<u>Example 1.</u>

Consider a specific case of the cost function $\gamma(\alpha)$ where

$$\gamma(\alpha) = k\left(\frac{1}{1-\alpha} - 2\right)$$

The only interesting case is where $b+c<1$. In this case $\bar{\alpha} = \frac{1-b}{1-b+c} > \frac{1}{2}$. By (1),

$$\Pi_E(\alpha)=\begin{cases} 2\alpha-1-k\left(\frac{1}{1-\alpha}-2\right), & \frac{1}{2}\le\alpha<\bar{\alpha} \\ -k\left(\frac{1}{1-\alpha}-2\right), & \bar{\alpha}<\alpha<1 \\ \in\left[-k\left(\frac{1}{1-\bar{\alpha}}-2\right),\frac{1-b-c}{1-b+c}-k\left(\frac{1}{1-\bar{\alpha}}-2\right)\right], & \alpha=\bar{\alpha} \end{cases}.$$

Claim 1. (1) Suppose that $\frac{2c^2}{(1-b+c)^2}<k<\frac{1}{2}$. Then $\alpha^*=1-\sqrt{\frac{k}{2}}$ and $\frac{1}{2}<\alpha^*<\bar{\alpha}$. E obtains a net payoff of $\left(1-\sqrt{2k}\right)^2>0$.

(2) Suppose that $k\ge\frac{1}{2}$. Then $\alpha^*=\frac{1}{2}$ and E does not operate an IS on M and obtains zero expected payoff.

(3) Suppose that $0<k\le\frac{2c^2}{(1-b+c)^2}$. Then $\alpha^*=\bar{\alpha}$, M chooses at $\bar{\alpha}$ to invest in capacity with probability $1-\bar{\alpha}$ and E obtains a net payoff of $(1-b-c)\left(\frac{1}{1-b+c}-\frac{k}{c}\right)$.

Proof. See Appendix.

Example 2.

Consider that the cost is linear, namely $\gamma(\alpha)=\gamma\left(\alpha-\frac{1}{2}\right)$, $\gamma\ge0$.

This case can be easily analyzed using the results of Chapter 2. As before let $\bar{\alpha}=\max\left[\frac{1}{2},\frac{1-b}{1-b+c}\right]$.

Claim 2. (1) Suppose that $\gamma\ne2$. Then there exists a unique s.g.p.e. in Γ_0 and it is characterized as follows: If $b+c<1$ then

(i) For $\gamma>2$ we have $\alpha^*=\frac{1}{2}$, namely E does not build an IS and the equilibrium strategies are that of $G_{\frac{1}{2}}$. E obtains zero payoff.

(ii) For $\gamma < 2$ we have $\alpha^* = \bar{\alpha}$, namely E builds an IS of precision $\bar{\alpha}$, M invests with probability $\frac{c}{1-b+c}$ and E enters the market iff the signal is ni. E Obtains positive payoff.

If $b+c \geq 1$ then for any $\gamma \geq 0$ we have $\alpha^* = \frac{1}{2}$ and E obtains zero payoff.

(2) Suppose that $\gamma = 2$. Then every α, $\frac{1}{2} \leq \alpha \leq \bar{\alpha}$ can be supported as s.g.p.e. outcome, and E does not benefit from building an IS.

Proof. See Appendix.

The only case where E benefits from spying on M is when $b+c<1$ and the marginal cost γ of building an IS is less than 2. When $b+c<1$ M invests with probability less than $\frac{1}{2}$. Actually, the higher is α up to $\bar{\alpha}$, the lower is the probability that M invests. For $\alpha > \bar{\alpha}$ this probability is increasing and approaches 1, as α approaches 1. Hence, at $\bar{\alpha}$ the probability that M invests is the lowest and E benefits the most (see Proposition 2 of Chapter 2). This result does not change even when the cost of building an IS is increasing in α provided that $\gamma < 2$.

In contrast, in the case where $b+c \geq 1$ the probability that M invests is increasing in α for all $\frac{1}{2} \leq \alpha \leq 1$ and E obtains zero irrespective of the magnitude of α (see Proposition 1 of Chapter 2). In this case E has no incentive to build an IS.

Note that there are multiple equilibrium strategies for M in G_α in case $\alpha = \bar{\alpha}$. Nevertheless, the game Γ_0 has a unique s.g.p.e. even when $\alpha^* = \bar{\alpha}$ is the equilibrium choice of E (in case $b+c<1$ and $\gamma < 2$).

Let $R(\gamma) \equiv \frac{1-b-c}{1-b+c} - \gamma\left(\bar{\alpha} - \frac{1}{2}\right)$.

Then $R(\gamma) < 0$ iff $\gamma > 2$. In this case the payoff of E is negative for all α except $\alpha = \frac{1}{2}$. If $\gamma < 2$ then $R(\gamma) > 0$ and E obtains positive payoff at $\alpha = \bar{\alpha}$ If given γ, M chooses $\tilde{p}$ which is sufficiently close to $\frac{c}{1-b+c}$. However if M chooses any

$\tilde{p} > \frac{c}{1-b+c}$ then E is better off reducing α slightly below $\bar{\alpha}$ (see Figure 7 in Chapter 2). Thus the only equilibrium is where E chooses $\bar{\alpha}$ following by (NE, E) and M chooses $\tilde{p} = \frac{c}{1-b+c}$.

Example 3.

Suppose next that the cost of building an IS does not depend on the quality α, $\frac{1}{2} < \alpha \le 1$. Namely,

$$\gamma(\alpha) = \begin{cases} 0, & \alpha = \frac{1}{2} \\ \gamma, & \frac{1}{2} < \alpha \le 1 \end{cases}$$

It is easy to verify the following result,

Claim 3. Suppose that for all $\frac{1}{2} < \alpha \le 1$ $\gamma(\alpha) \equiv \gamma$, $\gamma \ge 0$ and $\gamma\left(\frac{1}{2}\right) = 0$. The game Γ_0 has a unique s.g,p.e.

(1) If $b + c < 1$ then

  (i) For $\gamma > \frac{1-b-c}{1-b+c}$ we have $\alpha^* = \frac{1}{2}$, namely E does not build an IS and the equilibrium strategies are that of $G_{\frac{1}{2}}$. E obtains zero payoff.

  (ii) For $\gamma < \frac{1-b-c}{1-b+c}$ we have $\alpha^* = \bar{\alpha}$, namely E builds an IS of precision $\bar{\alpha}$, M invests with probability $\frac{c}{1-b+c}$ and E enters the market iff the signal is ni. E obtains positive payoff.

  (iii) For $\gamma = \frac{1-b-c}{1-b+c}$ both $\alpha = \bar{\alpha}$ and $\alpha = \frac{1}{2}$ can be supported as s.g.p.e. outcome. In both cases E obtains zero.

(2) If $b + c \ge 1$ then for any $\gamma \ge 0$ we have $\alpha^* = \frac{1}{2}$ and E obtains zero payoff.

<u>Proof.</u> See Appendix.

Note that the only case where E is better off spying on M is when $b + c < 1$ and $0 \le \gamma < \frac{1-b-c}{1-b+c}$.

3.3. The Strategic Choice of α when M does not Observe It.

Let Γ_1 be defined like Γ_0 except that we assume now that M does not observe the choice α of E before he chooses whether to invest or not.

This case is more difficult to analyze and we consider three particular cases: the case where the cost of building an IS is linear, the case where the IS is cost free and the case where the cost is constant.

Suppose first that the cost of building an IS of any precision is zero. Namely, $\gamma(\alpha)=0$ $\forall\alpha$, $\frac{1}{2}\leq\alpha\leq1$.

Proposition 3. If the IS is cost free, the game Γ_1 has a unique s.g.p.e., $\alpha^*=1$. Namely E builds a perfect IS and the equilibrium strategies are that of G_1[40]. E obtains zero payoff.

Proof. See Appendix.

Proposition 3 asserts that when building an IS of precision α is cost free, the only equilibrium is that E chooses to build a perfect IS ($\alpha=1$) and M chooses to invest. In this case E stays out and obtains zero. Nevertheless, given that M invests, E will not enter no matter what is α and she cannot benefit from reducing α.

Proof. See Appendix.

Suppose next that the cost is linear, namely $\gamma(\alpha)=\gamma\left(\alpha-\frac{1}{2}\right)$, $\gamma>0$. Then,

Proposition 4. If $0<\gamma<1$, there is no equilibrium of Γ_1 where E chooses some α with probability 1. If $\gamma\geq1$, the game Γ_1 has a unique s.g.p.e., $\alpha^*=\frac{1}{2}$. Namely E does not build an IS and the equilibrium strategies are that of $G_{\frac{1}{2}}$[41]. E obtains zero payoff.

Proof. See Appendix.

Finally, suppose that the cost of building an IS does not depend on the precision α, $\frac{1}{2}<\alpha\leq1$. Namely, $\gamma(\alpha)=\begin{cases}0, & \alpha=\frac{1}{2}\\ \gamma, & \frac{1}{2}<\alpha\leq1\end{cases}$, where $\gamma>0$. Then we can prove that,

[40] See Chapter 2.

[41] See Chapter 2.

Proposition 5. If $0 < \gamma < \frac{1}{2}$, there is no equilibrium of Γ_1 where E chooses some α with probability 1. If $\gamma \geq \frac{1}{2}$, the game Γ_1 has a unique s.g.p.e., $\alpha^* = \frac{1}{2}$. Namely E does not build an IS and the equilibrium strategies are that of $G_{\frac{1}{2}}$. E obtains zero payoff.

Proof. See Appendix.

By propositions 4 and 5, if the cost of building an IS is relatively high, E does not spy on M. The difficult parts are when the cost is relatively low, but positive. While it is shown that equilibrium in mixed strategies exists, we could not find the equilibrium probability distribution over α.

3.4. Conclusion.

This chapter analyzed the industrial espionage model in Chapter 2 when the precision α of the IS is commonly known by both firms and it is the strategic choice of E. We have shown that, when the choice of E is observed by M and E benefits from spying on him, the optimal choice of E is to build an IS of a precision of at most $\bar{\alpha}$. When the choice of E is not observed by M and the IS is cost free, E builds a perfect IS ($\alpha = 1$), but this situation is more beneficial for M than for E, since M benefits the higher is the precision of the IS while E does not, provided that the value of α is common knowledge to both firms. For the case where the cost of the IS is positive, we have focused on linear and constant cost functions. In these cases, when the cost is relatively high, E does not spy on M. And when the cost is relatively low, we have shown that in equilibrium E does not choose some α with probability 1, but E assigns some probability distribution over α. We could not find this mixed strategy equilibrium, and this would be interesting for future research. However, the most interesting research would be to analyze the general case where M does not observe the choice of E.

3.5. Appendix

Proof of Proposition 1.

First recall that the equilibrium strategy of M is

$$\sigma_M(\alpha)=\begin{cases}1-\alpha, & \tfrac{1}{2}\le\alpha<\bar{\alpha}\\ \alpha, & \bar{\alpha}<\alpha\le 1\\ \in[1-\bar{\alpha},\bar{\alpha}] & \alpha=\bar{\alpha}\end{cases}$$

Next notice that there is no equilibrium where $\alpha>\bar{\alpha}$ since $\Pi_E(\alpha)<0$ for $\alpha>\bar{\alpha}$ and $\Pi_E\left(\tfrac{1}{2}\right)=0$. Any maximizer of $\Pi_E(\alpha)$ in $\left[\tfrac{1}{2},\bar{\alpha}\right)$ can be supported in a subgame perfect equilibrium by the following equilibrium strategy of M:

$$\bar{\sigma}_M(\alpha)=\begin{cases}1-\alpha, & \tfrac{1}{2}\le\alpha<\bar{\alpha}\\ \alpha, & \bar{\alpha}\le\alpha\le 1\end{cases}$$

Note that when M plays $\bar{\sigma}_M(\alpha)$, E obtains $-\gamma(\bar{\alpha})$ when $\alpha=\bar{\alpha}$, and does not have an incentive to deviate to $\bar{\alpha}$.

Our next goal is to find the maximizer of $\Pi_E(\alpha)$ in $\left[\tfrac{1}{2},\bar{\alpha}\right)$. Define for all $\alpha\in\left[\tfrac{1}{2},\bar{\alpha}\right)$,

$$f(\alpha)=\Pi_E(\alpha)=2\alpha-1-\gamma(\alpha)$$

Since $\gamma(\alpha)$ is strictly convex, $f(\alpha)$ is strictly concave. The FOC for the maximizer of $f(\alpha)$ is

$$f'(\alpha)=2-\gamma'(\alpha)\le 0$$

and equality holds if the maximizer α^* is an interior point.

We can extend the definition of f to $\left[\tfrac{1}{2},\bar{\alpha}\right]$ and define

$$f(\alpha)=\begin{cases}2\alpha-1-\gamma(\alpha), & \tfrac{1}{2}\le\alpha<\bar{\alpha}\\ \dfrac{1-b-c}{1-b+c}-\gamma(\bar{\alpha}), & \alpha=\bar{\alpha}\end{cases}$$

Then f is continuos in $\left[\tfrac{1}{2},\bar{\alpha}\right]$ and strictly concave, and hence it has a unique maximizer. Note that E obtains $f(\bar{\alpha})$ when she chooses $\alpha=\bar{\alpha}$ if M is playing

$$\bar{\bar{\sigma}}_M(\alpha)=\begin{cases}1-\alpha, & \tfrac{1}{2}\le\alpha\le\bar{\alpha}\\ \alpha, & \bar{\alpha}<\alpha\le 1\end{cases}$$

Let us consider three cases regarding the behavior of $f'(\alpha)$.

<u>Case 1:</u> $\gamma'\left(\tfrac{1}{2}\right)<2$ and $\gamma'(\bar{\alpha})>2$. In this case since γ' is continuous, by the Mean Value Theorem the maximizer α^* of f is interior, namely $\tfrac{1}{2}<\alpha^*<\bar{\alpha}$ and $\gamma'(\alpha^*)=2$. Also $\Pi_E(\alpha^*)=f(\alpha^*)>f\left(\tfrac{1}{2}\right)=0$.

<u>Case 2:</u> $\gamma'\left(\tfrac{1}{2}\right)\ge 2$. In this case the unique maximizer is $\alpha^*=\tfrac{1}{2}$ and E obtains zero.

<u>Case 3:</u> $\gamma'(\bar{\alpha})\le 2$. In this case $\alpha^*=\bar{\alpha}$ maximizes $f(\alpha)$.

Claim 4. $f(\bar{\alpha})>0$.

<u>Proof:</u> Note that there exists $\hat{\alpha}$, $\tfrac{1}{2}<\hat{\alpha}<\bar{\alpha}$ s.t.

$$\frac{\gamma(\bar{\alpha})-\gamma\left(\tfrac{1}{2}\right)}{\bar{\alpha}-\tfrac{1}{2}}=\gamma'(\hat{\alpha})<2$$

Since $\gamma\left(\tfrac{1}{2}\right)=0$,

$$\gamma(\bar{\alpha})<2\bar{\alpha}-1$$

and

$$f(\bar{\alpha})=\frac{1-b-c}{1-b+c}-\gamma(\bar{\alpha})>\frac{1-b-c}{1-b+c}-\frac{2(1-b)}{1-b+c}+1=0$$

The graph of $\Pi_E(\alpha)$ is depicted below,

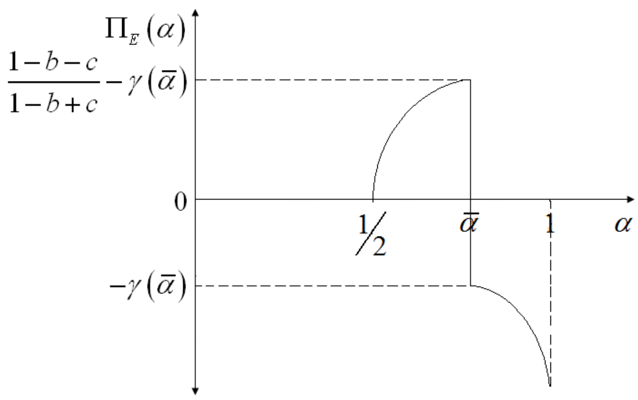

Figure 2

Note that there is no equilibrium where M chooses at $\alpha = \bar{\alpha}$ to invest with probability higher than $1-\bar{\alpha}$. If M invests with probability higher than $1-\bar{\alpha}$, E obtains less than $f(\bar{\alpha})$. Since f is continuous at any point in $\left[\frac{1}{2}, \bar{\alpha}\right]$ (including at $\bar{\alpha}$), E has an incentive to slightly lower α below $\bar{\alpha}$.

We conclude that the unique subgame perfect equilibrium outcome in this case is $\alpha = \bar{\alpha}$, and M invests in capacity with probability $1-\bar{\alpha}$.

■

Proof of Claim 1.

Note that $\gamma(\alpha) = \frac{k}{(1-\alpha)^2}$ and $\alpha^* = (\gamma)^{-1}(2) = 1-\sqrt{\frac{k}{2}}$. Also,

$$\gamma\left(\tfrac{1}{2}\right) = 2 \text{ iff } k \geq \frac{1}{2}$$

and

$$\gamma(\bar{\alpha}) = 2 \text{ iff } k = \frac{2c^2}{(1-b+c)^2}$$

Now the proof follows immediately by Proposition 1.

■

Proof of Claim 2.

Suppose first that $b+c<1$. In this case $\bar{\alpha} = \frac{1-b}{1-b+c} > \frac{1}{2}$. Then by Proposition 2 in Chapter 2, for every α the equilibrium expected payoff of E is given by

$$\Pi_E(\alpha) = \begin{cases} 2\alpha - 1 - \gamma\left(\alpha - \tfrac{1}{2}\right), & \tfrac{1}{2} < \alpha < \bar{\alpha} \\ -\gamma\left(\alpha - \tfrac{1}{2}\right), & \bar{\alpha} < \alpha < 1 \\ \in \left[-\gamma\left(\bar{\alpha} - \tfrac{1}{2}\right), \frac{1-b-c}{1-b+c} - \gamma\left(\bar{\alpha} - \tfrac{1}{2}\right)\right], & \alpha = \bar{\alpha} \end{cases}.$$

Or equivalently,

$$\Pi_E(\alpha)=\begin{cases}\left(\alpha-\tfrac{1}{2}\right)(2-\gamma), & \tfrac{1}{2}<\alpha<\bar{\alpha}\\ -\gamma\left(\alpha-\tfrac{1}{2}\right), & \bar{\alpha}<\alpha<1\\ \in\left[-\gamma\left(\alpha-\tfrac{1}{2}\right),\dfrac{1-b-c}{1-b+c}-\gamma\left(\bar{\alpha}-\tfrac{1}{2}\right)\right], & \alpha=\bar{\alpha}\end{cases}$$

When $b+c\geq 1$ the entrant obtains zero even if the cost is zero, and her payoff is negative if the cost is positive, unless $\alpha=\tfrac{1}{2}$.

■

Proof of Claim 3.

Follows immediately from the equilibrium payoff of E given by

$$\Pi_E(\alpha)=\begin{cases}2\alpha-1-\gamma, & \tfrac{1}{2}<\alpha<\bar{\alpha}\\ -\gamma, & \bar{\alpha}<\alpha<1\\ \in\left[-\gamma,\dfrac{1-b-c}{1-b+c}-\gamma\right], & \alpha=\bar{\alpha}\end{cases}$$

■

In the following three proofs we analyze the subgame perfect equilibrium of Γ_1 using Figure 6 and Proposition 2 in Chapter 2.

Proof of Proposition 3.

Suppose that in equilibrium E chooses α, s.t. $\alpha>\bar{\alpha}$. Then E assigns positive probability to (E, NE) and (NE, NE) only. M chooses I with probability α and E obtains zero profit. The net payoff of E is zero $\forall\alpha>\bar{\alpha}$. Suppose that E deviates to $\bar{\alpha}<\alpha<\alpha'$ follwing by (E, NE). Then she obtains $\alpha(-1+\alpha')+(1-\alpha)\alpha'=\alpha'-\alpha>0$ since $\alpha'>\alpha$. Hence, E will deviate. The only candidate is $\alpha=1$, M chooses the pure strategy I and E chooses (NE, NE). In this case E obtains zero. Any deviation of E will yield a negative payoff (holding the strategy I of M fixed).

Suppose next that in equilibrium E chooses $\alpha = \bar{\alpha}$ and $\bar{\alpha} > \frac{1}{2}$. Similarly to the previous proof, if $\tilde{p} = \frac{c}{1-b+c}$, E obtains $\frac{1-b-c}{1-b+c}$, and if $\tilde{p} = \frac{1-b}{1-b+c}$ then E obtains zero.

If M assigns the lowest probability $\frac{c}{1-b+c}$ to I, E benefits by deviating to $\alpha' > \bar{\alpha}$ following by the strategy (E, NE). In this case E obtains $\alpha' - \frac{c}{1-b+c}$. If M chooses the highest probability $\frac{1-b}{1-b+c}$ to I, E obtains zero. If E deviates to $\alpha' > \bar{\alpha}$ following by (E, NE), she obtains $\alpha' - \frac{1-b}{1-b+c}$ which is greater than zero iff $\alpha' > \bar{\alpha}$. Hence E has always incentive to deviate to $\alpha' > \bar{\alpha}$. M in this case chooses I with probability $1-\alpha$.

Suppose that in equilibrium $\frac{1}{2} < \alpha < \bar{\alpha}$. Then E assigns positive probability to (E,E) and (E, NE) only and obtains a profit equals to $2\alpha - 1$. M in this case chooses I with probability $1-\alpha$. In this case E benefits by deviating to $\alpha' > \alpha$ following by the strategy (E, NE).

Suppose that $\alpha = \frac{1}{2}$ is the equilibrium choice of E. Then M plays $\left(\frac{1}{2}, \frac{1}{2}\right)$ and E mixes (E, E) and (NE, NE) and obtains zero. If E deviates to $\alpha' > \frac{1}{2}$ following by (E, NE) she will obtain $\alpha' - \frac{1}{2} > 0$ and E is best off deviating from $\alpha = \frac{1}{2}$.

■

<u>Proof of Proposition 4.</u>

Suppose that in equilibrium E chooses α, s.t. $\alpha > \bar{\alpha}$. Then E assigns positive probability to (E, NE) and (NE, NE) only. M chooses I with probability α and E obtains zero profit. The net payoff of E is $-\gamma\left(\alpha - \frac{1}{2}\right)$.

Suppose that E deviates to α' s.t. $\bar{\alpha} < \alpha' < \alpha$. If E chooses to play the pure strategy (NE, NE) she will obtain zero profit and a net payoff of $-\gamma\left(\alpha' - \frac{1}{2}\right)$. Since

$-\gamma\left(\alpha' - \frac{1}{2}\right) > -\gamma\left(\alpha - \frac{1}{2}\right)$, E is better off deviating to α'. We conclude that there is no equilibrium where E chooses α s.t. $\bar{\alpha} < \alpha' < \alpha$.

Suppose next that in equilibrium E chooses $\alpha = \bar{\alpha}$ and $\bar{\alpha} > \frac{1}{2}$. This implies that $b + c < 1$ (recall that for $b + c \geq 1$, $\bar{\alpha} = \frac{1}{2}$). As we have shown before if $\alpha = \bar{\alpha}$ and if it is common knowledge, then M has multiple equilibrium strategies. Namely, to choose I with any probability $\tilde{p} \in \left[\frac{c}{1-b+c}, \frac{1-b}{1-b+c}\right]$. E has a unique equilibrium strategy, namely to select the pure strategy (E, NE). The net payoff of E is decreasing in $\tilde{p}$. If $\tilde{p} = \frac{c}{1-b+c}$, E obtains $\frac{1-b-c}{1-b+c} - \gamma\left(\bar{\alpha} - \frac{1}{2}\right)$, and if $\tilde{p} = \frac{1-b}{1-b+c}$ then E obtains $-\gamma\left(\bar{\alpha} - \frac{1}{2}\right)$. Clearly if $\gamma\left(\bar{\alpha} - \frac{1}{2}\right) > \frac{1-b-c}{1-b+c}$ or equivalently, if $\gamma > 2$ then E is better off choosing $\alpha = \frac{1}{2}$ following by (NE, NE), where E obtains zero. Hence $\alpha = \bar{\alpha}$ can not be an equilibrium if $\gamma > 2$. Assume that $\gamma \leq 2$.

If M assigns the lowest probability $\frac{c}{1-b+c}$ to I, E benefits by deviating to $\alpha = \frac{1}{2}$ following by the strategy (E, E). In this case E obtains $\frac{1-b-c}{1-b+c}$. If M chooses the highest probability $\frac{1-b}{1-b+c}$ to I, E obtains $-\gamma\left(\bar{\alpha} - \frac{1}{2}\right)$. If E deviates to $\alpha = \frac{1}{2}$ following by (NE, NE), she obtains a zero net payoff which is greater than $-\gamma\left(\bar{\alpha} - \frac{1}{2}\right)$. Hence E has always incentive to deviate to $\alpha = \frac{1}{2}$.

Suppose that in equilibrium $\frac{1}{2} < \alpha < \bar{\alpha}$. Then E assigns positive probability to (E,E) and (E, NE) only and obtains a profit equals to $2\alpha - 1$. The net payoff of E is $2\alpha - 1 - \gamma\left(\alpha - \frac{1}{2}\right)$.

M in this case chooses I with probability $1-\alpha$. Clearly, $\gamma\left(\alpha-\frac{1}{2}\right)>2\alpha-1$ iff $\gamma>2$. Thus if $\gamma>2$ E obtains a negative payoff. But then E is better off choosing $\alpha=\frac{1}{2}$ following by (NE, NE), where E obtains zero.

Hence $\frac{1}{2}<\alpha<\bar{\alpha}$ can not be an equilibrium if $\gamma>2$.

Suppose that $\gamma\leq 2$. In this case E benefits by deviating to $\alpha=\frac{1}{2}$ following by the strategy (E, E). In this case E obtains $2\alpha-1$. We conclude that there is no equilibrium where E chooses α s.t. $\frac{1}{2}<\alpha<1$.

Suppose that $\alpha=\frac{1}{2}$ is the equilibrium choice of E. Then M plays $\left(\frac{1}{2},\frac{1}{2}\right)$ and E mixes (E, E) and (NE, NE) and obtains zero. If E deviates to $\alpha'>\frac{1}{2}$ following by (E, NE) she will obtain $\alpha'-\frac{1}{2}-\gamma\left(\alpha'-\frac{1}{2}\right)$, which is greater than zero iff $\gamma<1$. Hence if $\gamma<1$, again E is better off deviating from $\alpha=\frac{1}{2}$. But if $\gamma\geq 1$, E has no incentive to deviate and $\alpha=\frac{1}{2}$ is an equilibrium.

Finally suppose that in equilibrium $\alpha=1$. Then M chooses the pure strategy I and E obtains $-\frac{1}{2}\gamma$. If E deviates to $\alpha=\frac{1}{2}$ following by (NE, NE) she obtains zero. Hence $\alpha=1$ is also not an equilibrium.

Next let us show that the game Γ_1 has an equilibrium in mixed strategies. Suppose that $0<\gamma<1$.

We can represent any pure strategy of E by either $\alpha(1,0,0)$ or $\alpha(0,1,0)$ or $\alpha(0,0,1)$, where $\alpha(1,0,0)$ stands for choosing a precisión α following by (E, E). Similarly, $(0,1,0)$ stands for (E, NE) and $(0,0,1)$ stands for (NE, NE).

Let

$$S_E^1=\left\{\alpha(1,0,0)\middle|\ \frac{1}{2}\leq\alpha\leq 1\right\}$$

$$S_E^2=\left\{\alpha(0,1,0)\middle|\ \frac{1}{2}\leq\alpha\leq 1\right\}$$

$$S_E^3 = \left\{ \alpha(0,0,1) \middle| \, 1/2 \le \alpha \le 1 \right\}$$

and let $S_E = S_E^1 \bigcup S_E^2 \bigcup S_E^3$ be the set of all pure strategies of E. It is a compact subset of $\mathbb{R}^3$.

Let $S_M = \{0,1\}$ be the set of pure strategies of M where 0 stands for "invest".

Let $\sigma \in S_E$. Then the payoff function of M, $\Pi_M(k,\sigma)$ where $k = 0,1$, is given by

$$\Pi_M(0,\sigma) = \begin{cases} b, & \sigma \in S_E^1 \\ b + (c-b)\alpha, & \sigma \in S_E^2 \\ c, & \sigma \in S_E^3 \end{cases}$$

$$\Pi_M(1,\sigma) = \begin{cases} 0, & \sigma \in S_E^1 \\ 1-\alpha, & \sigma \in S_E^2 \\ 1, & \sigma \in S_E^3 \end{cases}$$

The payoff function of E, $\Pi_E(k,\sigma)$, taking into account the cost of building an IS, is given by

$$\Pi_E(0,\sigma) = \begin{cases} -1-\gamma\left(\alpha - 1/2\right), & \sigma \in S_E^1 \\ \alpha-1-\gamma\left(\alpha - 1/2\right), & \sigma \in S_E^2 \\ -\gamma\left(\alpha - 1/2\right), & \sigma \in S_E^3 \end{cases}$$

$$\Pi_E(1,\sigma) = \begin{cases} 1-\gamma\left(\alpha - 1/2\right), & \sigma \in S_E^1 \\ \alpha-\gamma\left(\alpha - 1/2\right), & \sigma \in S_E^2 \\ -\gamma\left(\alpha - 1/2\right), & \sigma \in S_E^3 \end{cases}$$

$\Pi_E(k,\cdot)$ is continuous. Suppose $\sigma_n \to \sigma$ as $n \to \infty$. Since $S_E^i \bigcap S_E^j = \varnothing$ for $i \ne j$ if $\sigma \in S_E^i$ then $\sigma_n \in S_E^i$ for all n sufficiently large and hence $\Pi_E(k,\sigma_n) \to \Pi_E(k,\sigma)$, as $n \to \infty$.

We conclude that both payoff functions of the players are continuous in their strategies. By Glicksberg's (1952) theorem, the game Γ_1 has a Nash equilibrium in mixed strategies.

Actually, we know that if $\gamma = 0$ or $\gamma \geq 1$, the game has a s.g.p.e. in pure strategies. But when $0 < \gamma < 1$ the game has an equilibrium but only in mixed strategies.

■

<u>Proof of Proposition 5.</u>

Suppose that in equilibrium E chooses α, s.t. $\alpha > \bar{\alpha}$. Then E assigns positive probability to (E, NE) and (NE, NE) only. M chooses I with probability α and E obtains zero profit. The net payoff of E is $-\gamma$. Suppose that E deviates to $\bar{\alpha} < \alpha < \alpha'$ follwing by (E, NE). Then she obtains $\alpha(-1+\alpha') + (1-\alpha)\alpha' - \gamma = \alpha' - \alpha - \gamma > -\gamma$ since $\alpha' > \alpha$. Hence, E will deviate. The only candidate is $\alpha = 1$.

Suppose that in equilibrium M $\alpha = 1$. Then M chooses the pure strategy I and E chooses (NE, NE) and obtains $-\gamma$. But if E deviates to $\alpha = 1/2$ follwing by (NE, NE), she obtains zero and she will deviate.

Suppose next that in equilibrium E chooses $\alpha = \bar{\alpha}$ and $\bar{\alpha} > 1/2$. Similarly to the previous proofs, if $\tilde{p} = \frac{c}{1-b+c}$, E obtains $\frac{1-b-c}{1-b+c} - \gamma$, and if $\tilde{p} = \frac{1-b}{1-b+c}$ then E obtains $-\gamma$. Clearly if $\gamma > \frac{1-b-c}{1-b+c}$ then E is better off choosing $\alpha = 1/2$ following by (NE, NE), where E obtains zero. Hence $\alpha = \bar{\alpha}$ can not be an equilibrium if $\gamma > \frac{1-b-c}{1-b+c}$. Assume that $\gamma \leq \frac{1-b-c}{1-b+c}$.

If M assigns the lowest probability $\frac{c}{1-b+c}$ to I, E benefits by deviating to $\alpha = 1/2$ following by the strategy (E, E). In this case E obtains $\frac{1-b-c}{1-b+c}$. If M chooses the highest probability $\frac{1-b}{1-b+c}$ to I, E obtains $-\gamma$. If E deviates to $\alpha = 1/2$ following by (NE, NE), she obtains a zero net payoff which is greater than $-\gamma$. Hence E has always incentive to deviate to $\alpha = 1/2$.

Suppose that in equilibrium ${1}/{2} < \alpha < \bar{\alpha}$. Then E assigns positive probability to (E,E) and (E, NE) only and obtains a profit equals to $2\alpha - 1$. The net payoff of E is $2\alpha - 1 - \gamma$. M in this case chooses I with probability $1-\alpha$. Clearly, if $\gamma > 2\alpha - 1$ E obtains a negative payoff. Then E is better off choosing $\alpha = {1}/{2}$ following by (NE, NE), where E obtains zero.

Hence ${1}/{2} < \alpha < \bar{\alpha}$ can not be an equilibrium if $\gamma > 2\alpha - 1$.

Suppose that $\gamma \leq 2\alpha - 1$. In this case E benefits by deviating to $\alpha = {1}/{2}$ following by the strategy (E, E). In this case E obtains $2\alpha - 1$.

Suppose that $\alpha = {1}/{2}$ is the equilibrium choice of E. Then M plays $\left({1}/{2}, {1}/{2}\right)$ and E mixes (E, E) and (NE, NE) and obtains zero. If E deviates to $\alpha' > {1}/{2}$ following by (E, NE) she will obtain $\alpha' - {1}/{2} - \gamma$, which is greater than zero iff $\gamma < \alpha' - {1}/{2}$. As E tries to maximize her payoff, she will choose $\alpha' = 1$, then $\gamma < {1}/{2}$. Hence if $\gamma < {1}/{2}$, E is better off deviating from $\alpha = {1}/{2}$. But if $\gamma \geq {1}/{2}$, E has no incentive to deviate and $\alpha = {1}/{2}$ is an equilibrium.

Next, let us show that if $0 < \gamma < {1}/{2}$, the game Γ_1 has an equilibrium in mixed strategies. This proof is similar to that in Proof of Proposition 4, but taking into account that in this case the payoff function of E, $\Pi_E(k, \sigma)$, is given by

$$\Pi_E(0, \sigma) = \begin{cases} -1-\gamma, & \sigma \in S_E^1 \\ \alpha - 1 - \gamma, & \sigma \in S_E^2 \\ -\gamma, & \sigma \in S_E^3 \end{cases}$$

$$\Pi_E(1, \sigma) = \begin{cases} 1-\gamma, & \sigma \in S_E^1 \\ \alpha - \gamma, & \sigma \in S_E^2 \\ -\gamma, & \sigma \in S_E^3 \end{cases}$$

But this is also continuous in the strategies of E. Hence, since both payoff functions of the players are continuous in their strategies, by Glicksberg's (1952) theorem, the game Γ_1 has a Nash equilibrium in mixed strategies.

Actually, we know that if $\gamma = 0$ or $\gamma \geq 1/2$, the game has a s.g.p.e. in pure strategies. But when $0 < \gamma < 1/2$ the game has an equilibrium, but only in mixed strategies.

■

Chapter 4. Entry with Two Correlated Signals

4.1. Introduction.

Other very important information for a firm contemplating market entry is the cost structure of the incumbent firm. Since this information is usually available in statements for internal use, the entrant firm could obtain it spying on the incumbent firm.

In this chapter we deal with a monopoly, M, who is engaged in R&D activity with the aim to reduce his cost of production from the current cost $C_H(q)$ to $C_L(q)$, where q is the production level. The outcome of the R&D project is the private information of M. A potential entrant, E, assigns a certain probability, $\mu > 0$, that M fails to reduce his cost and probability $1-\mu > 0$ that the project was successful. If the project fails and E enters, she obtains positive profit. Otherwise, if the project succeeds and E enters, she will not be able to cover her entry cost and she will end up with negative profit.

The entrant has an access to an Intelligence System (IS) that allows her to collect (noisy) information about the cost structure of M. The IS sends one out of two signals. The signal h, which indicates that the investment was not successful (in which case we refer to M as having the type H), and the signal l, which indicates that the investment was successful (namely, M is of type L). The precision of the IS is α, $1/2 \le \alpha \le 1$. That is, the signal sent by the IS is correct with probability α (for simplicity, whether the cost function is $C_H(q)$ or $C_L(q)$). The case where $\alpha = 1/2$ is equivalent to the case where E does not use an IS. The case $\alpha = 1$ is the one where E knows exactly the outcome of the project.

It is assumed that the precision α of the IS is exogenously given. As we pointed out, this would be the case if the entrant firm has already a spying technology before she considers entering the market where the incumbent firm is operating (e.g. she has the ability to plant a Trojan Horse in the computer system of the incumbent firm). The second one would be the case of entrant firm hiring managers and workers from the incumbent firm trying to obtain industrial secrets (in this case information about the incumbent's action) from them.

The entrant decides whether or not to enter the market based on a pair of signals: the price, p, that M charges for his product and the signal s (h or l) sent by the IS. If E enters the market, she competes with M (whether it is a Cournot or Bertrand competition, or any other mode of competition). It is assumed that the above is commonly known (including the precision α of the IS).

The interaction between E and M is described as a three stage game, $G(\alpha)$. In the first stage, M who knows the outcome of the R&D project, sets a price p and the IS sends a signal s (h or l). Based on the signals (p,s), E in the second stage decides whether or not to enter the market. If she decides to enter, then E in the third stage is engaged in a certain mode of competition with M.

The game $G(\alpha)$ is a game of incomplete information and, using Harsanyi's approach, we analyze it as a three player game, where the players are the two types, H and L, of M and the entrant, E. We analyze the sequential equilibria of $G(\alpha)$.

The case where $\alpha = 1/2$, namely, where the IS has no value (and, therefore, can be ignored), is exactly the limit pricing model of Milgrom and Roberts (1982) (hereafter MR). Therefore, our model is an extension of the MR model where the entrant has an access to an intelligence system and it is only for $1/2 < \alpha < 1$.

We distinguish two cases: the first one is the separating equilibrium where the two types of M charge different prices p_H and p_L, $p_H \neq p_L$; the second one is the pooling equilibrium case where $p_H = p_L$.

We show that the separating equilibria of our model coincide with that of MR and the IS makes no difference for either E or M. This is not very surprising since in a separating equilibrium E identifies the type of M with or without the use of the IS. Even though the off equilibrium behavior of E is affected by the signal of the IS, it does not affect the separating equilibria. The same result is obtained for pooling equilibria if the precision α of the IS is sufficiently low (close to $1/2$) to affect the decision of E. For the other extreme, if α is very accurate (close to 1), then contrary to the MR model, pooling equilibrium does not exist. In this case, E identifies with high probability the type of M and she will enter the market if the signal is h and she will stay out if the signal is l. The H type monopolist, who knows that his type is detected with high probability, has an incentive to deviate to his monopoly price, upsetting a pooling equilibrium. Let us next deal with the intermediate case, where α is bounded away from $1/2$ and 1. We show that the set of pooling equilibria is non-empty and the monopoly price of the L-type monopoly is the highest pooling equilibrium price. The decision of E is still entering if the signal is h and staying out if the signal is l. To compare this result with the result obtained in the MR model, suppose first that prior to the completion of the R&D project, the expected payoff of E from entering the market is positive. Then, contrary to our model, no pooling equilibrium exists in the MR model. Otherwise, E in a pooling equilibrium enters the market expecting positive profit and, hence, both types of M are best off with their monopoly prices, upsetting a pooling equilibrium. In the game $G(\alpha)$ where α is bounded away from 1, M of type H knows that with significant probability E will obtain the wrong signal l and will stay out. Hence, H succeeds to fool E about his type with significant probability. However, the precision α of the IS should not be too low. Otherwise, E will not trust the signal of the IS and she will enter the market whether the signal is h or l. In this case, the two types of M are best off with their monopoly prices, upsetting a pooling equilibrium.

Note that in the MR model the entrant never enters in a pooling equilibrium. Hence, the use of the IS with high probability increases competition in pooling equilibrium. The entrant enters the market for intermediate levels of α if the signal is h. This is true even when pooling equilibrium does not exist in the MR model. From this point of view, spying on incumbent firms increases competition with high probability.

This chapter is related to Perea and Swinkels (1999) and Ho (2007, 2008) since they also consider espionage in the context of asymmetric information. However, in the present model the IS is not a decision maker who can act strategically as in Perea and Swinkels (1999) and Ho (2007, 2008). The chapter is also related to Sakai (1985) since he considers two firms and one objective of the information gathering activity is, like in our model, the cost structure of the opponent firm. However, unlike us, the paper considers that both firms know neither the costs of their opponent nor their own costs [42].

Another related paper is Bagwell and Ramey (1988). They extend the MR model by allowing the incumbent to signal his costs with both price and advertisements. Hence, while in this paper both signals are sent by the incumbent, in our model he only signals his costs by the price, the other signal is generated by the IS operated by the entrant. Bagwell (2007) extends Bagwell and Ramey (1988) and considers a more general game in which the incumbent has two dimensions of private information, his costs and his level of patience[43].

The contribution of this chapter is to extend the MR model to the case where the potential entrant has an access to an intelligence system to better detect the cost structure of the cost structure of the monopolist. Assuming that the precision α of the IS is common knowledge, we show that spying on incumbent firms increases competition with high probability.

The remainder of the chapter is organized as follows. Section 4.2 sets out the model. The strategy of E is presented in Section 4.3. Section 4.4 analyzes separating equilibria of the game. Pooling equilibria is analyzed in Section 4.5. Section 4.6 concludes the chapter. Most proofs of the results are presented in the Appendix.

4.2. The Model.

We start with the benchmark case of the limit price model of MR. Their game, which is denoted G_{MR}, consists of a monopoly M and a potential entrant E. The cost function of M is a private information and it can be of two types: L (low cost) and H (high cost). A potential entrant, E, assigns probability μ that M is of type H. In the first period M

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[42] For more details about all these papers see the literature review in Chapter 1.

[43] For other extensions of MR model see Albaek and Overgaard (1992a, 1992b), Bagwell (1992), Bagwell and Ramey (1990, 1991), Harrington (1986, 1987) and Linnemer (1998).

chooses a price as a function of his type. The price serves as a signal for E, who then decides whether to enter the market or stay out. If E enters, she incurs an entry cost K. In the second period, if E enters, E and M compete in the market.

The form of competition (Cournot, Bertrand or other) is commonly known and once E enters, the outcome of the competition is assumed to be uniquely determined. By confining the analysis to sequential equilibria, the strategic interaction takes place only in the first period.

The strategy of the t-type monopoly is a first period price p_t for $t \in \{H, L\}$. The strategy of E is assumed to be of the form

$$\sigma_E(p) = \begin{cases} "\textit{Stay out}", & p \leq \bar{p} \\ "\textit{Enter}", & p > \bar{p} \end{cases}$$

where the threshold $\bar{p}$ is the choice of E.

Let $Q(p)$ be the demand function and $C_t(q)$ be the cost function of the t-type monopoly.

Let D_H and D_L be the duopoly profits of the H-type and the L-type monopolists, respectively. For short we denote by H and L the H-type and the L-type monopolists, respectively. Let $\Pi_H(p)$ be the profit of H and let $\Pi_L(p)$ be the profit of L when they set the price p and when E does not enter. Denote by $D_E(H)$ and $D_E(L)$ the duopoly profits of E when she competes with H and L respectively. Denote by p_H^M and p_L^M the monopoly prices of H and L respectively (and by q_H^M and q_L^M the monopoly quantities). Finally, let $\hat{p}$ and p_0 be s.t.

$$\Pi_H(\hat{p}) = D_H \text{ and } \hat{p} < p_H^M$$

and

$$\Pi_L(p_0) = D_L \text{ and } p_0 < p_L^M .$$

See Figures 1 and 2 below.

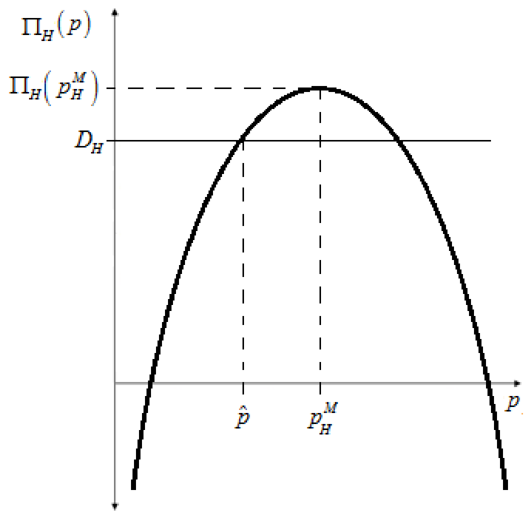

Figure 1

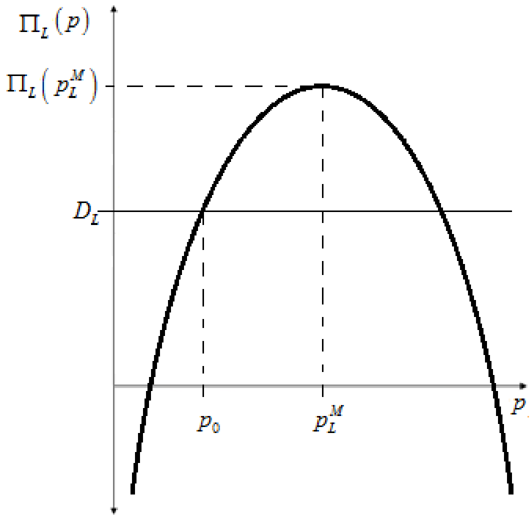

Figure 2

Assumptions

1. $D_E(L) - K \equiv \Delta_E(L) < 0$ and $D_E(H) - K \equiv \Delta_E(H) > 0$.
2. $\Pi_t(p)$, $t \in \{H, L\}$, is increasing in p whenever $p \le p_t^M$ and is decreasing in p whenever $p \ge p_t^M$.
3. $\Pi_L(p_L^M) - D_L > \Pi_H(p_H^M) - D_H$. Namely, L loses from entry more than H.
4. The cost functions $C_t(x)$, $t \in \{H, L\}$, are differentiable, $C'_H(q) > C'_L(q)$ and $C_H(0) \ge C_L(0)$.
5. $Q(p)$ is differentiable and $Q'(p) < 0$ for all $p \ge 0$.

6. All the parameters of the model and the above five assumptions are commonly known.

Lemma 1. (i) $\Pi_L(p) - \Pi_H(p)$ decreases in p.

(ii) $p_H^M > p_L^M$.

(iii) $\hat{p} > p_0$.

Proof: Appears in the Appendix.

Let p_H and p_L be the equilibrium strategies of H an L respectively. In a separating equilibrium $p_H \neq p_L$, and in a pooling equilibrium $p_H = p_L = p^*$.

Propositions 1 and 2 below are due to Milgrom and Roberts (1982) and they characterize the separating and pooling equilibrium respectively for the case where E does not operate an IS on M.

Proposition 1 (Milgrom and Roberts (1982)). The set of sequential separating equilibria SSE_{MR} in G_{MR} is non-empty and

$$SSE_{MR} = \left\{ (p_H, p_L, \overline{p}) \middle| p_H = p_H^M, p_L = \overline{p}, p_0 \leq p_L \leq \min\left(p_L^M, \hat{p}\right) \right\}$$

Remark: By Lemma 1, $\hat{p} > p_0$ and SSE_{MR} is non-empty.

Proposition 2 (Milgrom and Roberts (1982)). The set of all sequential pooling equilibria in G_{MR}, $\sigma = (p_H, p_L, \overline{p})$, is characterized by

(i) $p_H = p_L = p^* = \overline{p}$

and

(ii) $\hat{p} \leq p^* \leq p_L^M$

Our goal is to extend the MR results to the case where E uses an Intelligence System (IS) to spy on M to better detect his type. Denote by $G(\alpha)$ the game that extends G_{MR} to allow espionage activity and where the Intelligence System operated by E is of precision α, $\frac{1}{2} \leq \alpha \leq 1$.

The game $G(\alpha)$ is a three-stage game. In the first stage M sets a price and the IS sends a signal, h or l. In the second stage, E who observes both the price set by M and the signal sent by the IS, decides whether or not to enter the market. Finally, in the third stage, if E enters, M and E compete in the market. As mentioned above, the third stage competition is assumed to generate a unique equilibrium outcome $\left(D_H, D_L, D_E\left(H\right), D_E\left(L\right)\right)$ if E enters and $\left(\Pi_H\left(p_H^M\right), \Pi_L\left(p_L^M\right)\right)$ if E does not enter.

It is assumed that Assumptions 1-6 hold and, in addition, α is commonly known.

4.3. The Strategy of E in $G(\alpha)$.

Given α, for every pair of signals (s, p), $s \in \{h, l\}$, $p \in \mathbb{R}_+$, let $Prob(H|s, p)$ and $Prob(L|s, p) = 1 - Prob(H|s, p)$ be the off equilibrium probability that E assigns to the event that M is of type H and of type L, respectively.

It is assumed that, conditional on the type of M, the signals are mutually independent. Namely, M chooses the price p independently of the choice of the IS. Nevertheless, the signals p and s are correlated. If E observes a very high price, then it is more likely that she will observe the signal h. If however E observes a low price, it is more likely that she will observe the signal l.

Hence, the off equilibrium probability that E assigns to the types of M is

$$Prob(H|h, p) = \frac{Prob(h, p|H)Prob(H)}{Prob(h, p|H)Prob(H) + Prob(h, p|L)Prob(L)}$$

$$= \frac{Prob(h|H)Prob(p|H)Prob(H)}{Prob(h|H)Prob(p|H)Prob(H) + Prob(h|L)Prob(p|L)Prob(L)}$$

Equivalently,

$$Prob(H|h, p) = \frac{\mu\alpha f(p|H)}{\mu\alpha f(p|H) + (1-\mu)(1-\alpha) f(p|L)} \tag{1}$$

Similarly,

$$Prob(H|l, p) = \frac{\mu(1-\alpha) f(p|H)}{\mu(1-\alpha) f(p|H) + (1-\mu)\alpha f(p|L)} \tag{2}$$

where $f(p|t)$ is the (density) probability that E assigns to the event that M of type t, $t \in \{H, L\}$ sends the signal p.

In a pure strategy equilibrium, if H assigns probability 1 to the event that $p = p_H$, then $f(p_H|H) = 1$ and $f(p|H) = 0$ if $p \neq p_H$. In this case, $f(p|H)$ is identified with the probability that H selects p. Similarly, $f(p_L|L) = 1$ and $f(p|L) = 0$, $\forall p \neq p_L$. Hence, for $p \neq p_H$ and $p \neq p_L$ (1) and (2) are not well defined for $p \notin \{p_H, p_L\}$ since the numerators and denominators are zero.

Using the notion of sequential equilibrium, we approach $f(p|t)$ by a sequence $\left(f_n(p|t)\right)_{n=1}^{\infty}$, such that $f_n(p|t) > 0$ and $\lim_{n\to\infty} f_n(p|t) = f(p|t)$ for all $p \in \mathbb{R}_+$. Let

$$Prob_n(H|h,p) \equiv \frac{\mu\alpha f_n(p|H)}{\mu\alpha f_n(p|H) + (1-\mu)(1-\alpha) f_n(p|L)} \quad (3)$$

$$Prob_n(H|l,p) \equiv \frac{\mu(1-\alpha) f_n(p|H)}{\mu(1-\alpha) f_n(p|H) + (1-\mu)\alpha f_n(p|L)} \quad (4)$$

Now $Prob_n(H|h,p)$ is well defined for all $p \in \mathbb{R}_+$ and (1) can be modified to be

$$Prob(H|h,p) \equiv \lim_{n\to\infty} \frac{\mu\alpha f_n(p|H)}{\mu\alpha f_n(p|H) + (1-\mu)(1-\alpha) f_n(p|L)}$$

We modify (2) in the same way. Note that different sequences of $\left(f_n(p|t)\right)_{n=1}^{\infty}$ generate different conditional probabilities $Prob(t|s,p)$, $t \in \{H, L\}$, $s \in \{h, l\}$, $p \in \mathbb{R}_+$.

Let $\Pi_E(s,p)$ be the expected payoff of E given her on and off equilibrium beliefs, namely

$$\Pi_E(s,p) \equiv Prob(H|s,p)\Delta_E(H) + Prob(L|s,p)\Delta_E(L) \quad (5)$$

In a sequential equilibrium, if $\Pi_E(s,p) < 0$, E will not enter the market and if $\Pi_E(s,p) > 0$, E will enter. To simplify the analysis we assume that E stays out also when $\Pi_E(s,p) = 0$. Namely, E stays out if and only if she observes (s,p) such that

$$\Pi_E(s,p) \equiv Prob(H|s,p)\Delta_E(H) + Prob(L|s,p)\Delta_E(L) \leq 0$$

<u>Assumption 7.</u>

(1) For each $t \in \{H, L\}$ and each n, $f_n(p|t)$ is differentiable in p for all $p \geq 0$.

(2) Let

$$g_n(p) = \frac{f_n(p|H)}{f_n(p|L)}$$

Then $g_n(p)$ is increasing in n for each p, and is increasing in p for each n. Furthermore, for every n, $\lim_{p\to 0} g_n(p) = 0$ and $\lim_{p\to\infty} g_n(p) = \infty$.

(3) Let $g(p) = \lim_{n\to\infty} g_n(p)$. Then, $g(p)$ is continuous in p.

Lemma 2. (i) For each $s \in \{h, l\}$ and $t \in \{H, L\}$, $Prob(t|s, p)$ is continuous in p and $Prob(H|s, p)$ is non-decreasing in p, $p \geq 0$.

(ii) For every $p \geq 0$, $Prob(H|h, p) > Prob(H|l, p)$.

(iii) Let $J_s = \{p \geq 0 | \Pi_E(s, p) \leq 0\}$. Then, J_s and $\mathbb{R}_+ \setminus J_s$ are both non-empty sets.

Proof:

(i) By (3),

$$Prob_n(H|h, p) = \frac{\mu\alpha \frac{f_n(p|H)}{f_n(p|L)}}{\mu\alpha \frac{f_n(p|H)}{f_n(p|L)} + (1-\mu)(1-\alpha)}$$

Hence,

$$Prob(H|h, p) = \frac{\mu\alpha g(p)}{\mu\alpha g(p) + (1-\mu)(1-\alpha)} \qquad (6)$$

and by Assumption 7, $Prob(H|h, p)$ is continuous in p.

The proof that $Prob(H|l, p)$ is continuous is similarly derived by (4).

Since $Prob(L|s, p) = 1 - Prob(H|s, p)$, then $Prob(L|s, p)$ is also continuous.

Next note that $g(p)$ is non-decreasing in p since $g_n(p)$ is increasing in p for all n.

It is easy to verify by (6) that $\frac{\partial}{\partial p} Prob(H|h, p) \geq 0$ iff $g'(p) \geq 0$ and thus

$Prob(H|h,p)$ is non-decreasing in p. The proof that $Prob(H|l,p)$ is non-decreasing is similar.

(ii) Let

$$x_n(p)=\frac{Prob_n(H|h,p)}{Prob_n(H|l,p)}$$

By (3) and (4),

$$\begin{aligned} x_n(p)-1 &= \frac{\frac{\alpha}{1-\alpha}\left[\mu(1-\alpha)f_n(p|H)+(1-\mu)\alpha f_n(p|L)\right]}{\mu\alpha f_n(p|H)+(1-\mu)(1-\alpha)f_n(p|L)}-1 \\ &= \frac{(1-\mu)\frac{\alpha^2}{1-\alpha}f_n(p|L)-(1-\mu)(1-\alpha)f_n(p|L)}{\mu\alpha f_n(p|H)+(1-\mu)(1-\alpha)f_n(p|L)} \\ &= \frac{(1-\mu)f_n(p|L)(2\alpha-1)}{(1-\alpha)\left[\mu\alpha f_n(p|H)+(1-\mu)(1-\alpha)f_n(p|L)\right]} \\ &= \frac{(1-\mu)(2\alpha-1)}{(1-\alpha)\left[\mu\alpha g_n(p)+(1-\mu)(1-\alpha)\right]} \end{aligned}$$

Hence,

$$\lim_{n\to\infty}\left[x_n(p)-1\right]=\frac{(1-\mu)(2\alpha-1)}{(1-\alpha)\left[\mu\alpha g(p)+(1-\mu)(1-\alpha)\right]}>0$$

Hence $\lim_{n\to\infty}x_n(p)>1$ and, consequently, for every $p\geq 0$,

$$Prob(H|h,p)>Prob(H|l,p) \tag{7}$$

(iii) By (5),

$$\begin{aligned} \Pi_E(s,p) &= Prob(H|s,p)\Delta_E(H)+Prob(L|s,p)\Delta_E(L) \\ &= Prob(L|s,p)\left[\frac{Prob(H|s,p)}{Prob(L|s,p)}\Delta_E(H)+\Delta_E(L)\right] \end{aligned} \tag{8}$$

Let $s=h$. For every p,

$$\frac{Prob(H|h,p)}{Prob(L|h,p)}=\lim_{n\to\infty}\frac{\mu\alpha f_n(p|H)}{(1-\mu)(1-\alpha)f_n(p|L)}=\frac{\mu\alpha}{(1-\mu)(1-\alpha)}g(p)$$

We claim that $g(p) \to 0$ as $p \to 0$. This follows by Dini's theorem, as $g_n(p)$ is increasing in n, $g_n(p)$ is continuous in p and $g(p)$ is also continuous. Hence, for every $\delta > 0$, $\lim_{n\to\infty} g_n(p) = g(p)$ uniformly on $[0,\delta]$. Since for every n, $g_n(p) \to 0$ as $p \to 0$, we have $g(p) \to 0$ as $p \to 0$. Consequently,

$$\lim_p \frac{Prob(H|h,p)}{Prob(L|h,p)} = 0 \text{, as } p \to 0 \tag{9}$$

Inequality (9) holds also when h is replaced by l (the proof is similar).

Next, let us show that $Prob(L|h,p) > 0$ for small p.

$$\begin{aligned} Prob_n(L|h,p) &= \frac{(1-\mu)(1-\alpha) f_n(p|L)}{\mu\alpha f_n(p|H) + (1-\mu)(1-\alpha) f_n(p|L)} \\ &= \frac{1}{1 + \dfrac{\mu\alpha g_n(p)}{(1-\mu)(1-\alpha)}} \end{aligned} \tag{10}$$

Again, since $g_n(p) \to g(p)$ as $n \to \infty$ uniformly in any interval $[0,\delta]$, $\delta > 0$, and since $g(p) \to 0$ as $p \to 0$,

$$Prob(L|h,p) = \lim_n Prob_n(L|h,p) \to 1 \text{, as } p \to 0$$

In particular, $Prob(L|h,p) > 0$ for p sufficiently small. In a similar way, we can prove that $Prob(L|l,p) > 0$ for p sufficiently small.

Now, (8), (9) and the fact that $\Delta_E(L) < 0$ and $Prob(L|s,p) > 0$ for small p, imply that for sufficiently small p, $\Pi_E(s,p) < 0$ and $J_s \neq \emptyset$.

Let us show that for p sufficiently large, $\Pi_E(s,p) > 0$. We use the following claim.

Claim 1. $\lim_p Prob(L|s,p) = 0$ as $p \to \infty$.

Proof: Let $n = 1$ and $s = h$. By Assumption 7.2, $\lim \dfrac{f_1(p|H)}{f_1(p|L)} = \infty$. By (10),

$$Prob_1(L|h,p) \to 0 \text{ as } p \to \infty$$

Hence, for every $\varepsilon > 0$, there exists P s.t. for all $p > P$,

$$Prob_1\left(L\middle|h,p\right)<\varepsilon$$

By (3),

$$Prob_n\left(H\middle|h,p\right)=\frac{\mu\alpha}{\mu\alpha+(1-\mu)(1-\alpha)\dfrac{f_n\left(p\middle|L\right)}{f_n\left(p\middle|H\right)}}$$

By Assumption 7.2, $Prob_n\left(H\middle|h,p\right)$ is increasing in n and, hence, $Prob_n\left(L\middle|h,p\right)$ is decreasing in n for every p. Thus, for all $p>P$,

$$Prob_n\left(L\middle|h,p\right)<Prob_1\left(L\middle|h,p\right)<\varepsilon$$

Hence, for every $\varepsilon>0$ and for all $p>P$,

$$Prob\left(L\middle|h,p\right)=\lim_{n\to\infty}Prob_n\left(L\middle|h,p\right)\le\varepsilon$$

implying that

$$\lim_{p\to\infty}Prob\left(L\middle|h,p\right)=0$$

The proof that $\underset{p}{Prob}\left(L\middle|l,p\right)=0$, as $p\to\infty$ is similarly derived.

■

Claim 1 together with (5) imply that for p sufficiently large, $\Pi_E\left(s,p\right)>0$, and the proof of Lemma 2 is completed.

■

By part (i) of Lemma 2 and by (5), $\Pi_E\left(s,p\right)$ is continuous and non-decreasing in p (this follows from the fact that $Prob\left(H\middle|s,p\right)$ is continuous and non-decreasing in p, $\Delta_E\left(H\right)>0$, $Prob\left(L\middle|s,p\right)=1-Prob\left(H\middle|s,p\right)$ and $\Delta_E\left(L\right)<0$).

By part (iii) of Lemma 2, $\Pi_E\left(s,p\right)<0$ for small p and $\Pi_E\left(s,p\right)>0$ for sufficiently large p. Let

$$p_h=\max\left\{p\ge 0\middle|\Pi_E\left(h,p\right)\le 0\right\}$$

$$p_l=\max\left\{p\ge 0\middle|\Pi_E\left(l,p\right)\le 0\right\}$$

By the continuity of $\Pi_E\left(s,p\right)$ in p,

$$\Pi_E(h, p_h) = \Pi_E(l, p_l) = 0 \tag{11}$$

and E enters the market iff she observes either (h, p) s.t. $p > p_h$ or (l, p) s.t. $p > p_l$.

By (7) it is easy to verify that

$$\Pi_E(h, p) > \Pi_E(l, p) \tag{12}$$

By (11) and (12)

$$\Pi_E(l, p_l) = \Pi_E(h, p_h) > \Pi_E(l, p_h)$$

and since $\Pi_E(s, p)$ is non-decreasing in p, we have $p_l > p_h$.

We conclude that the decision rule of E when she observes the pair of signals (s, p) is given by Figure 3 below.

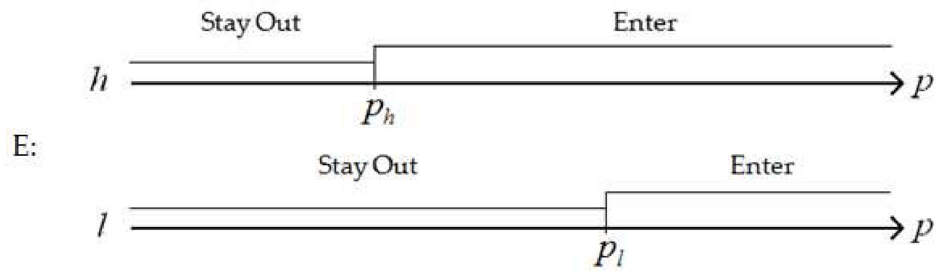

Figure 3

We summarize the above in the following lemma.

Lemma 3. Suppose that Assumption 1 holds. Then, any beliefs of E which satisfy Assumption 7, uniquely determine p_h and p_l, $p_h < p_l$, s.t. in every sequential equilibrium with these beliefs, E enters the market iff she observes the signal (h, p) with $p > p_h$ or the signal (l, p) with $p > p_l$.

Our next goal is to characterize the sequential equilibrium of $G(\alpha)$ given the above decision rule of E. We start with separating equilibria.

4.4. Separating Equilibria.

In a separating equilibrium $p_H \neq p_L$ and E identifies with probability 1 the type of M. Hence, E enters the market when observing the price p_H irrespective of the signal of the IS, and E stays out when observing p_L, again irrespective of s. Therefore, $p_H > p_l$ and $p_L \leq p_h$.

Notation: Let $\tilde{p}_t(\alpha)$ be the (unique) solution in p of the following equation,

$$\Pi_t(p) = \alpha\Pi_t(p_t^M) + (1-\alpha)D_t, \; t \in \{H, L\}$$

(see Figure 4)

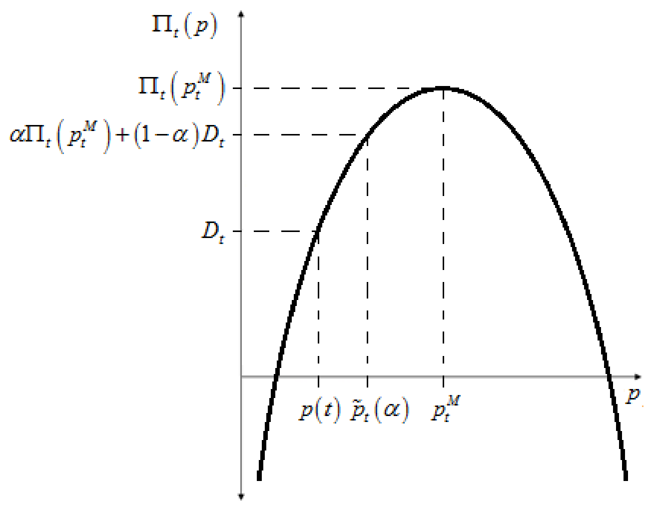

Figure 4

And let $\hat{p}_t(\alpha)$ be the unique solution in p of the following equation,

$$\Pi_t(p) = (1-\alpha)\Pi_t(p_t^M) + \alpha D_t$$

(see Figure 5)

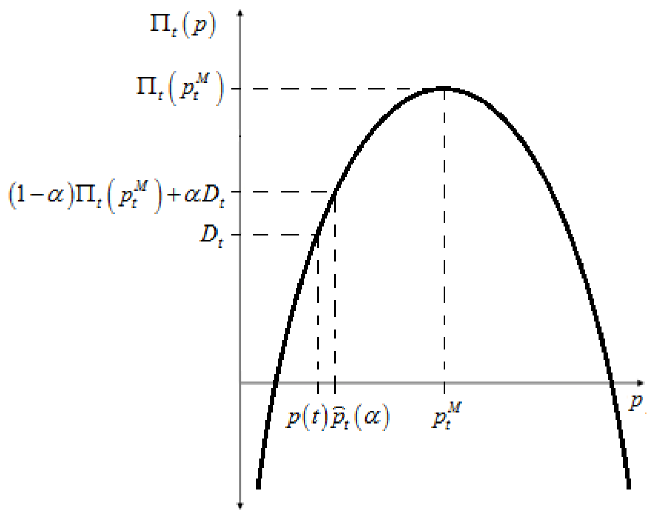

Figure 5

where $p(t) = \hat{p}$ if $t = H$ and $p(t) = p_0$ if $t = L$.

The following proposition characterizes the sequential separating equilibrium of $G(\alpha)$.

Proposition 3. Consider the game $G(\alpha)$ for $\frac{1}{2} < \alpha < 1$, and let SSE be the set of all sequential separating equilibrium points of $G(\alpha)$. Let SSE_t be the set of all equilibrium prices of the *t*-type monopolist in SSE. Then,

(1) $SSE_L = \left\{ p_L \middle| p_0 \le p_L \le \min\left(p_L^M, \hat{p}\right)\right\}$ and $SSE_H = \left\{ p_H^M \right\}$.

(2) Let $p_L \in SSE_L$. If $p_L < p_L^M$, then $p_L = p_h$. If $p_L = p_L^M$, then $p_L^M \le p_h$.

(3) The set SSE coincides with SSE_{MR}, the set of all sequential separating equilibrium points of G_{MR}.

(4) Let $p_L \in SSE_L$ and suppose that $p_L < p_L^M$. Let p_h and $\overline{p}$ be the equilibrium cutoff price for entry in $G(\alpha)$ and in G_{MR} respectively. Then, $\overline{p} = p_h$.

(5) Let $p_L \in SSE_L$ and suppose that $p_L < p_L^M$. Then the equilibrium strategy of E in $G(\alpha)$ coincides with the equilibrium strategy of E in G_{MR} for all $p_L \notin \left(p_h, p_l\right]$. If $p_L \in \left(p_h, p_l\right]$, then E in $G(\alpha)$ enters the market with positive probability (which is α if M is of type H and $1-\alpha$ if M is of type L) and stays out for sure in G_{MR}.

Proof: Appears in the Appendix.

Part (5) of Proposition 3 asserts that in $G(\alpha)$ E is less inclined to enter the market. For all prices below $\overline{p} = p_h$ E stays out of the market in both games G_{MR} and $G(\alpha)$. For prices above p_l, E enters for sure in both these games. But for prices p, $p_h < p \le p_l$, E in $G(\alpha)$ enters the market iff the signal sent by the IS is h. In contrast, E in this region enters the market for sure in the game G_{MR}. The difference between $G(\alpha)$ and G_{MR} with regard to sequential separating equilibrium is only in the behavior of E off the equilibrium path.

4.5. Pooling Equilibrium.

By pooling equilibrium we refer to triples of the form $\sigma = (s_E, p_H, p_L)$ where s_E is the strategy of E and $p_H = p_L \equiv p^*$.

Given the signal l of the IS, the expected payoff of E is

$$\Pi_E(l|\alpha) \equiv Prob(H|l)\Delta_E(H) + Prob(L|l)\Delta_E(L)$$

Equivalently,

$$\Pi_E(l|\alpha) = \frac{\mu(1-\alpha)}{\mu(1-\alpha)+(1-\mu)\alpha}\Delta_E(H) + \frac{(1-\mu)\alpha}{\mu(1-\alpha)+(1-\mu)\alpha}\Delta_E(L)$$

Hence, if the IS sends the signal l, E does not enter the market when observing the price p^* iff

$$\Pi_E(l|\alpha) \le 0 \tag{13}$$

Let

$$\bar{\alpha}_l = \frac{\mu\Delta_E(H)}{\mu\Delta_E(H)-(1-\mu)\Delta_E(L)} \tag{14}$$

Note that (13) holds and E does not enter iff $\alpha \ge \bar{\alpha}_l$.

Since $\Delta_E(L) < 0$, $0 < \bar{\alpha}_l < 1$ and $\bar{\alpha}_l < 1/2$ iff

$$\mu\Delta_E(H) + (1-\mu)\Delta_E(L) < 0 \tag{15}$$

Thus, for $1/2 < \alpha < 1$, E does not enter iff (15) holds.

Suppose next that the IS sends the signal h. Then the expected payoff of E is

$$\Pi_E(h|\alpha) \equiv Prob(H|h)\Delta_E(H) + Prob(L|h)\Delta_E(L)$$

Equivalently,

$$\Pi_E(h|\alpha) = \frac{\mu\alpha}{\mu\alpha+(1-\mu)(1-\alpha)}\Delta_E(H) + \frac{(1-\mu)(1-\alpha)}{\mu\alpha+(1-\mu)(1-\alpha)}\Delta_E(L)$$

Hence, if the IS sends the signal h, E does not enter the market when observing the price p^* iff

$$\Pi_E(h|\alpha) \le 0$$

Let

$$\bar{\alpha}_h = \frac{-(1-\mu)\Delta_E(L)}{\mu\Delta_E(H)-(1-\mu)\Delta_E(L)} \tag{16}$$

Note that $\Pi_E(h|\alpha) \le 0$ iff $\alpha \le \bar{\alpha}_h$.

Since $\Delta_E(L) < 0$, $0 < \bar{\alpha}_h < 1$. Note that $\bar{\alpha}_h > 1/2$ iff (15) holds.

Corollary 1. Suppose that $1/2 < \alpha < 1$ and

$$\mu\Delta_E(H) + (1-\mu)\Delta_E(L) < 0$$

Then E stays out iff she observes the signal l or if $\alpha \le \bar{\alpha}_h$.

In other words, if (15) holds, the entrant enters the market if and only if the signal is h and $\alpha > \bar{\alpha}_h$. Let

$$\delta = \frac{\Pi_H(p_L^M) - D_H}{\Pi_H(p_H^M) - D_H} = \frac{\Pi_H(p_L^M) - \Pi_H(\hat{p})}{\Pi_H(p_H^M) - \Pi_H(\hat{p})} \tag{17}$$

Clearly $0 < \delta < 1$.

The following proposition characterizes the pooling equilibria of the game $G(\alpha)$.

Proposition 4. Consider the game $G(\alpha)$, where $1/2 < \alpha < 1$. Let $SPEP$ be the set of all sequential pooling equilibrium prices and SPE the set of all sequential pooling equilibria of $G(\alpha)$.

(1) If $p_L^M \le \hat{p}$, then $SPE = \varnothing$, unless $p_L^M = \hat{p}$ and $\alpha \le \bar{\alpha}_h$. In this case $SPEP = \{p_L^M\}$.

(2) Suppose that $p_L^M > \hat{p}$ and $\mu\Delta_E(H) + (1-\mu)\Delta_E(L) < 0$. Then,

(i) For $\alpha \le \bar{\alpha}_h$, in every equilibrium in SPE, E stays out irrespective of the signal s and $SPEP = [\hat{p}, p_L^M]$. The set $SPEP$ coincides with the set $SPEP_{MR}$ of all sequential pooling equilibrium prices of the game G_{MR}.

(ii) If $\bar{\alpha}_h < \delta$, then for all α, $\bar{\alpha}_h < \alpha \le \delta$, E enters iff $s = h$, $SPE \ne \varnothing$ and $SPEP = [\max(\tilde{p}_H(\alpha), \bar{p}_L(\alpha)), p_L^M]$.

(iii) For $\alpha > \delta$, $SPE = \varnothing$.

(3) Suppose that $p_L^M > \hat{p}$ and $\mu\Delta_E(H) + (1-\mu)\Delta_E(L) > 0$. Then,

(i) For $\alpha < \bar{\alpha}_l$, $SPE = \varnothing$.

(ii) If $\bar{\alpha}_l \le \delta$, then for all α, $\bar{\alpha}_l \le \alpha \le \delta$, E enters iff $s = h$, $SPE \ne \varnothing$ and $SPEP = \left[\max\left(\tilde{p}_H(\alpha), \hat{p}_L(\alpha)\right), p_L^M\right]$.

(iii) For $\alpha > \delta$, $SPE = \varnothing$.

(4) Suppose that $\delta < \max\left(\bar{\alpha}_l, \bar{\alpha}_h\right)$. Then $SPE = \varnothing$ [44].

Proof: Appears in the Appendix.

Proposition 4 asserts that sequential pooling equilibrium does not exist if either $p_L^M < \hat{p}$ or if $\alpha > \delta$. The first condition, $p_L^M < \hat{p}$, implies that the cost function of H is significantly higher than that of L. Even the duopoly price $\hat{p}$, when H competes with E, is above the monopoly price of L. In this case, it is too costly for H to mimick L and to fool E about his type. The other condition, $\alpha > \delta$, means that the IS is sufficiently accurate so that when E observes the signal h, she knows that the true type of M is H with high probability, and she is best off entering the market. In this case, H, who knows that his type is detected with high probability, has no reason to pool and he is best off charging the monopoly price p_H^M, upsetting the pooling equilibrium.

For intermediate values of α ($\bar{\alpha}_h < \alpha \le \delta$ or $\bar{\alpha}_l \le \alpha \le \delta$), the set of pooling equilibria is non-empty and the decision of E is to enter the market if and only if the signal sent by the IS is h. In this case, M of type H knows that α is sufficiently low so with significant probability E will obtain the wrong signal l and will stay out. However, we also need the precision α to be not too low since, otherwise, E will not trust the signal and she will enter whether the signal is h or l. But then, the two type monopolists are best off with their monopoly prices, upsetting a pooling equilibrium.

Note that when $\alpha = \delta$, then $\max\left(\tilde{p}_H(\alpha), \hat{p}_L(\alpha)\right) = \tilde{p}_H(\alpha) = p_L^M$ and $SPEP = \left\{p_L^M\right\}$.

[44] It is easy to verify that if $\delta = \bar{\alpha}_h$, then $SPE = \varnothing$.

Proposition 4 also asserts that if $\mu\Delta_E(H)+(1-\mu)\Delta_E(L)>0$ (in which case $\bar{\alpha}_h<\bar{\alpha}_l$) and if α is relatively small ($\alpha<\bar{\alpha}_l$), then $SPE=\varnothing$. Without the use of the IS, when the expected profit of the entrant is positive, pooling equilibrium does not exist since E will enter the market and both types of M are best off deviating to their monopoly price. Hence, the use of a relatively not accurate IS has no impact on this result.

The relationship between δ and $\bar{\alpha}_h$ or $\bar{\alpha}_l$ is not obvious and in general it is quite complex. But in light of part (3) of Proposition 4 it is important to shed a light on this relationship. We next analyze this relationship for the linear demand and linear cost functions case, assuming a Cournot competition if E enters the market.

Suppose that $p=a-Q$ is the total demand function and suppose that the cost functions are given by

$$C_L(q)=C_E(q)=c_Lq$$

$$C_H(q)=c_Hq$$

where $c_L<c_H$. Proposition 5 summarizes the results of this linear model.

Proposition 5. Consider the linear model and assume that, if entry occurs, E and M are engaged in a Cournot competition. (1) if $\mu\Delta_E(H)+(1-\mu)\Delta_E(L)<0$, there exists $\bar{K}$ s.t. if $\frac{a-c_L}{c_H-c_L}>\frac{5}{2}$ and if $K<\bar{K}$, then $\delta>\bar{\alpha}_h$ and for every $\alpha\in(\bar{\alpha}_h,\delta]$ the set $SPEP$ is non-empty and contains p_L^M; (2) if $\mu\Delta_E(H)+(1-\mu)\Delta_E(L)>0$, there exists $\tilde{K}$ s.t. if $\frac{a-c_L}{c_H-c_L}>\frac{5}{2}$ and if $K\geq\tilde{K}$, then $\delta\geq\bar{\alpha}_l$ and for every $\alpha\in[\bar{\alpha}_l,\delta]$ the set $SPEP$ is non-empty and contains p_L^M.

Remark: The nature of Proposition 5 essentially does not change if we replace Cournot competition by Bertrand competition.

Proof: Appears in the Appendix.

Proposition 5 asserts that in the linear model, if α is not very accurate and the demand is not too small (it is sufficient that the demand intensity, a, exceeds $2.5c_H$), then

$\delta > \max\left(\bar{\alpha}_l, \bar{\alpha}_h\right)$ and p_L^M is a sequential pooling equilibrium price. In particular $SPEP \neq \varnothing$.

Finally, suppose that $\frac{a-c_L}{c_H-c_L} \leq \frac{1+3\sqrt{14}}{5}$. Then it can be verified that, if $\mu\Delta_E\left(H\right)+\left(1-\mu\right)\Delta_E\left(L\right)<0$, then $SPEP = \varnothing$ for all $\alpha > \bar{\alpha}_h$. Also if $\mu\Delta_E\left(H\right)+\left(1-\mu\right)\Delta_E\left(L\right)>0$, then $SPEP = \varnothing$ for all $\alpha \geq \bar{\alpha}_l$.

4.6. Conclusion.

In this chapter we analyzed industrial espionage when a potential entrant, E, does not observe the outcome of the R&D project carried out by an incumbent monopolist with the aim to reduce his cost of production and deter E from entering the market. E develops an Intelligence System (IS) of precision α that allows her to collect noisy information about the cost structure of M. Based on this information and the price that M charges for his product, E decides whether or not to enter the market. We assumed that α is exogenously given and commonly known by both firms.

We showed that the separating equilibria of our model are not affected by the spying activity of E. This is not very surprising since in a separating equilibrium E identifies the type of M with or without the use of the IS. The same result is obtained for pooling equilibria if the precision α of the IS is sufficiently low to affect E's decision of staying out. If α is very accurate, then pooling equilibrium does not exist. For intermediate values of α we find that pooling equilibrium exists and E enters the market if the IS tells her the cost of M is high. Hence, the use of the IS with high probability increases competition in pooling equilibrium. And, from this point of view, spying on incumbent firms increases competition with high probability.

An interesting suggestion for further research might be to analyze the more realistic scenario where α is the private information of E.

4.7. Appendix

Proof of Lemma 1.

(i)

$$\Pi_L(p)-\Pi_H(p)=C_H(Q(p))-C_L(Q(p))$$

$$\frac{\partial}{\partial p}\left[\Pi_L(p)-\Pi_H(p)\right]=Q'(p)\left[C'_H(Q(p))-C'_L(Q(p))\right]$$

By Assumptions 4 and 5 the right side is negative.

(ii)

$$p_L^M q_L^M - C_L\left(q_L^M\right) \geq p_H^M q_H^M - C_L\left(q_H^M\right)$$
$$p_H^M q_H^M - C_H\left(q_H^M\right) \geq p_L^M q_L^M - C_H\left(q_L^M\right)$$

Adding the two inequalities we have

$$C_H\left(q_L^M\right)-C_L\left(q_L^M\right) \geq C_H\left(q_H^M\right)-C_L\left(q_H^M\right)$$

By Assumption 4 we have that $q_L^M \geq q_H^M$ and hence $p_L^M \leq p_H^M$.

Let us show that $p_L^M < p_H^M$. If not, then $p_L^M = p_H^M$. Since the First Orden Condition (FOC) for M of type *t* is

$$\frac{\partial \Pi_t}{\partial p}(Q(p))=0 \leftrightarrow C'_t(Q(p))=p+\frac{Q(p)}{Q'(p)}$$

the solution does not depend on *t*, namely $C'_L\left(Q\left(p_L^M\right)\right)=C'_H\left(Q\left(p_L^M\right)\right)$. But this contradicts Assumption 4.

(iii)

By Assumption 3,

$$\Pi_L\left(p_L^M\right)-D_L > \Pi_H\left(p_H^M\right)-D_H$$

Note that $D_L = \Pi_L(p_o)$ and $D_H = \Pi_H(\hat{p})$. Hence this inequality can be written as

$$\Pi_L\left(p_L^M\right)-\Pi_L(p_0) > \Pi_H\left(p_H^M\right)-\Pi_H(\hat{p})$$

Thus,

$$\Pi_L\left(p_L^M\right)-\Pi_H\left(p_L^M\right)+\underbrace{\Pi_H\left(p_L^M\right)-\Pi_H\left(p_H^M\right)}_{<0} > \Pi_L(p_0)-\Pi_H(\hat{p})$$

Hence,

$$\Pi_L\left(p_L^M\right)-\Pi_H\left(p_L^M\right)>\Pi_L\left(p_0\right)-\Pi_H\left(\hat{p}\right) \tag{A1}$$

Since $p_0 \le p_L^M$, we have by section (i) of Lemma 1

$$\Pi_L\left(p_0\right)-\Pi_H\left(p_0\right)>\Pi_L\left(p_L^M\right)-\Pi_H\left(p_L^M\right)$$

This together with (A1) imply that

$$\Pi_H\left(\hat{p}\right)>\Pi_H\left(p_0\right)$$

But $p_0 < p_H^M$ and $\hat{p} < p_H^M$ and by Assumption 2 $p_0 < \hat{p}$.

■

Proof of Proposition 3.

The H-type monopoly, knowing that entry will occur is best off choosing the price p_H^M. Thus $SSE_H = \left\{p_H^M\right\}$ and E enters for sure when she observes the price p_H^M. In particular, $p_H^M > p_l$.

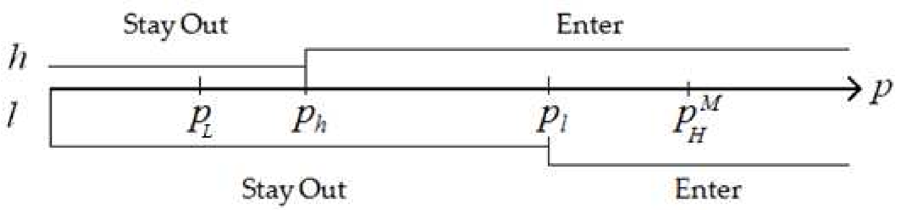

Figure 6

Next let us show that $SSE_L = \left\{p_L \middle| p_0 \le p_L \le \min\left(p_L^M, \hat{p}\right)\right\}$ for all α, $\frac{1}{2} < \alpha < 1$. We consider two cases.

Case 1: Suppose first that $p_L^M \le \hat{p}$. We show that $p_L = p_L^M$ can be supported as a separating equilibrium price. Let p_h and p_l be s.t.

$$p_L = p_L^M \le p_h \le \hat{p} < p_l \le \tilde{p}_H\left(\alpha\right) < p_H^M \tag{A2}$$

To make sure that H has no incentive to deviate to either p_h or p_l, the following two inequalities should hold

$$\Pi_H\left(p_H^M\right)+D_H \ge \Pi_H\left(p_h\right)+\Pi_H\left(p_H^M\right) \tag{A3}$$

and

$$\Pi_H\left(p_H^M\right)+D_H \ge \Pi_H\left(p_l\right)+\alpha D_H+(1-\alpha)\Pi_H\left(p_H^M\right) \tag{A4}$$

These two are equivalent to

$$\Pi_H(\hat{p}) = D_H \geq \Pi_H(p_h)$$

and

$$\Pi_H(p_l) \leq \alpha \Pi_H(p_H^M) + (1-\alpha) D_H = \Pi_H(\tilde{p}_H(\alpha))$$

(see Figure 4). Thus $p_h \leq \hat{p}$ and $p_l \leq \tilde{p}_H(\alpha)$.

By (A2) the two incentive compatibility constraints of H are satisfied and hence $p_L^M \in SSE_L$

Next let p_L be s.t. $p_0 \leq p_L < p_L^M$. Let us show that we can support p_L as a separtaing equilirium price. Let p_h and p_l be s.t.

$$p_L = p_h < p_l < p_L^M \leq \hat{p} < \tilde{p}_H(\alpha) < p_H^M \quad \text{(A5)}$$

Similarly to the previous case (A3) and (A4) must hold and thus $p_h \leq \hat{p}$ and $p_l \leq \tilde{p}_H(\alpha)$.

Since $p_L^M \leq \hat{p} < \tilde{p}_H(\alpha)$, by (A5) the two incentive compatibility constraints of H hold.

Next, since $p_L^M > p_l$, there are two relevant incentive compatibility constraints for L

$$\Pi_L(p_L) + \Pi_L(p_L^M) \geq \Pi_L(p_L^M) + D_L \quad \text{(A6)}$$

and

$$\Pi_L(p_L) + \Pi_L(p_L^M) \geq \Pi_L(p_l) + \alpha \Pi_L(p_L^M) + (1-\alpha) D_L \quad \text{(A7)}$$

(A6) and (A7) are equivalent to

$$\Pi_L(p_L) \geq D_L = \Pi_L(p_0) \quad \text{(A8)}$$

and

$$\Pi_L(p_L) \geq \Pi_L(p_l) - (1-\alpha)\left[\Pi_L(p_L^M) - D_L\right] \quad \text{(A9)}$$

Since $p_h = p_L \geq p_0$, (A8) holds. As for (A9), it holds for every $\alpha < 1$, provided that p_h is sufficiently close to p_l. Hence (A5) guarantees that, for all $\frac{1}{2} < \alpha < 1$, $p_L \in SSE_L$ provided that $p_L = p_h$, p_l is sufficiently close to p_h and $p_l < p_L^M$.

<u>Case 2:</u> Suppose next that $\hat{p} < p_L^M$ and let p_L be s.t. $p_0 \le p_L \le \hat{p}$. We will show that for all α, $\frac{1}{2} < \alpha < 1$, $p_L \in SSE_L$. Let p_h and p_l be s.t.

$$p_L = p_h \le \hat{p} < p_l < \min\left(p_L^M, \tilde{p}_H(\alpha)\right) < p_H^M \tag{A10}$$

As in (A3) and (A4), the incentive compatibility constraints of H are equivalent to $p_h \le \hat{p}$ and $p_l \le \tilde{p}_H(\alpha)$. By (A10) the two incentive compatibility constraints of H are satisfied.

Next, since $p_L^M > p_l$, in order for L not to deviate (A8) and (A9) must hold. Since $p_h = p_L \ge p_0$, (A8) holds. Similar to Case 1, for every $\alpha < 1$, (A9) holds if p_l is sufficiently close to p_h. Hence (A10) guarantees that, for all $\frac{1}{2} < \alpha < 1$, $p_L \in SSE_L$ provided that $p_l - p_h$ is sufficiently small and $p_l < \min\left(p_L^M, \tilde{p}_H(\alpha)\right)$.

Cases 1 and 2 prove that any price $p_L \in SSE_L$ if $p_0 \le p_L \le \min\left(p_L^M, \hat{p}\right)$. Finally, we need to show that if $p_L \notin \left[p_0, \min\left(p_L^M, \hat{p}\right)\right]$, then $p_L \notin SSE_L$.

Let $Q = \left[p_0, \min\left(p_L^M, \hat{p}\right)\right]$.

<u>Case A:</u> $p_L^M \le \hat{p}$.

<u>Subcase A.1.</u> Suppose that $p_L^M \le \hat{p} < p_h$. There is no separating equilibrium in this case since by (A3) $p_h \le \hat{p}$, a contradiction.

<u>Subcase A.2.</u> Suppose that $p_L^M \le p_h \le \hat{p}$. Then by Assumption 2 L is best off choosing $p_L = p_L^M$ and $p_L^M \in Q$.

<u>Subcase A.3.</u> Suppose that $p_h < p_L^M \le p_l$. Since $p_L \le p_h < p_L^M$, by Assumption 2 L is best off choosing $p_L = p_h < p_L^M$.

From the incentive compatibility constraint of L we have

$$\Pi_L(p_h) + \Pi_L\left(p_L^M\right) \ge \Pi_L\left(p_L^M\right) + \alpha\Pi_L\left(p_L^M\right) + (1-\alpha)D_L \tag{A11}$$

or

$$\Pi_L(p_h) \ge \alpha\Pi_L\left(p_L^M\right) + (1-\alpha)D_L = \Pi_L\left(\tilde{p}_L(\alpha)\right)$$

(see Figure 4). Thus $p_h \geq \tilde{p}_L(\alpha)$. Consequently,

$$p_0 < \tilde{p}_L(\alpha) \leq p_L = p_h < p_L^M$$

and hence $p_L \in Q$.

<u>Subcase A.4.</u> Suppose that $p_l < p_L^M$. Similarly to the previous case, L is best off choosing $p_L = p_h < p_L^M$.

In order for L not to deviate, (A8) must hold. Equivalently, $p_h \geq p_0$. Hence

$$p_0 \leq p_L = p_h < p_L^M$$

and $p_L \in Q$.

<u>Case B:</u> $\hat{p} < p_L^M$.

<u>Subcase B.1.</u> Suppose that $p_L^M \leq p_h$. There is no separating equilibrium in this case since by (A3) $p_h \leq \hat{p}$, a contradiction.

<u>Subcase B.2.</u> Suppose that $p_h < p_L^M \leq p_l$. Then, L is best off choosing $p_L = p_h$.

By (A3), in order for H not to deviate, $p_h \leq \hat{p}$ must hold. By (A11), L has no incentive to deviate if $p_h \geq \tilde{p}_L(\alpha)$. Consequently,

$$p_0 < \tilde{p}_L(\alpha) \leq p_L = p_h \leq \hat{p}$$

and $p_L \in Q$.

<u>Subcase B.3.</u> Suppose that $p_l < p_L^M$. Again, L is best off choosing $p_L = p_h$ and $p_h \leq \hat{p}$ must hold. To guarantee that L has no incentive to deviate, $p_h \geq p_0$ must hold (see (A8)). Hence

$$p_0 \leq p_L = p_h \leq \hat{p}$$

and $p_L \in Q$.

■

<u>Proof of Proposition 4.</u>

Let $A_l = \left\{\alpha \middle| \Pi_E(l|\alpha) \leq 0\right\}$ and $A_h = \left\{\alpha \middle| \Pi_E(h|\alpha) \leq 0\right\}$.

Case 1. $\mu\Delta_E(H)+(1-\mu)\Delta_E(L)<0$.

In this case $\bar{\alpha}_l < \frac{1}{2} < \bar{\alpha}_h < 1$. Hence, $\alpha > \bar{\alpha}_l$ and by Corollary 1, $\alpha \in A_l$ $\forall \alpha$, $\frac{1}{2} < \alpha < 1$. Namely, if the IS sends the signal l, E does not enter the market when observing the price p^* irrespective the precision α of the IS.

Subcase 1.1. $\frac{1}{2} < \alpha \le \bar{\alpha}_h$.

In this case $\alpha \in A_l \cap A_h$. Namely, E does not enter the market when observing the price p^* irrespective of the signal sent by the IS.

Let us characterize the pooling equilibria in this case. We start with a lemma.

Lemma 4. Suppose that $\mu\Delta_E(H)+(1-\mu)\Delta_E(L)<0$ and $\frac{1}{2} < \alpha \le \bar{\alpha}_h$. Then in every pooling equilibrium

(i) $p_H^M > p_h$

(ii) $p^* \le p_l$

Proof: (i) Suppose to the contrary that $p_H^M \le p_h$. Then also $p_L^M < p_h$ and E stays out whether she observes p_L^M or p_H^M. Hence, both types of M will set their (different) monopoly prices, a contradiction.

(ii) Suppose to the contrary that $p^* > p_l$. Then at least one type of M has an incentive to deviate. Indeed if $p_L^M > p_l$ and $p^* = p_L^M$, the H-type monopoly is better off deviating to p_H^M or p_l depending on α and the parameters of the model. Similarly, if $p_L^M > p_l$ and $p^* = p_H^M$ the L-type monopoly is better off deviating to p_L^M or p_l depending on α and the parameters of the model. Finally, if $p_L^M \le p_l$, at least one type of M has an incentive to deviate to his monopoly price, a contradiction.

■

Lemma 5. Suppose that $\mu\Delta_E(H)+(1-\mu)\Delta_E(L)<0$, $\frac{1}{2}<\alpha\leq\bar{\alpha}_h$ and $p_L^M<\hat{p}$. Then $SPE=\varnothing$.

Proof: Suppose to the contrary that $p^*\in SPEP$ and suppose that p_h and p_l are the equilibrium thresholds of E. We consider six cases.

Case 1. Suppose that $p_L^M\leq p_h$. First note that in this case $p^*=p_L^M$. Next observe that the incentive compatibility constraint of H

$$\Pi_H\left(p_L^M\right)+\Pi_H\left(p_H^M\right)\geq\Pi_H\left(p_H^M\right)+D_H \tag{A12}$$

requiring that H has no incentive to deviate to p_H^M, is equivalent to

$$\Pi_H\left(p_L^M\right)\geq D_H=\Pi_H\left(\hat{p}\right)$$

and hence $p_L^M\geq\hat{p}$ (see Figure 4), a contradiction.

Case 2. Suppose that $p_h<p_L^M<p_H^M\leq p_l$.

In this case $p^*\leq p_h$ (otherwise, by Lemma 4, $p^*\in\left(p_h,p_l\right]$ and at least one type of M has an incentive to deviate to his monopoly price). Therefore $p^*=p_h$ must hold.

The incentive compatibility constraint of H is,

$$\Pi_H\left(p_h\right)+\Pi_H\left(p_H^M\right)\geq\Pi_H\left(p_H^M\right)+\alpha D_H+(1-\alpha)\Pi_H\left(p_H^M\right) \tag{A13}$$

Equivalently,

$$\Pi_H\left(p_h\right)\geq\alpha D_H+(1-\alpha)\Pi_H\left(p_H^M\right)=\Pi_H\left(\widehat{p}_H(\alpha)\right)$$

or $\widehat{p}_H(\alpha)\leq p_h<p_H^M$ (see Figure 5). But $p_L^M<\hat{p}<\widehat{p}_H(\alpha)$ and in particular $p_L^M<p_h$, a contradiction.

Case 3. Suppose that $p^*\leq p_h<p_L^M\leq p_l<p_H^M$.

In this case again $p^*=p_h$. The incentive compatibility constraint of H is

$$\Pi_H\left(p_h\right)+\Pi_H\left(p_H^M\right)\geq\Pi_H\left(p_H^M\right)+D_H \tag{A14}$$

Equivalently,

$$\Pi_H\left(p_h\right)\geq D_H=\Pi_H\left(\hat{p}\right)$$

or $\hat{p} \le p_h$ (see Figure 4). But we deal with the case where $p_h < p_L^M < \hat{p}$, a contradiction.

Case 4. Suppose that $p_h < p_L^M \le p_l < p_H^M$ and $p^* \in (p_h, p_l]$.

In this case $p^* = p_L^M$. In order for H not to deviate from p_L^M to p_H^M, the inequality

$$\Pi_H\left(p_L^M\right) + \alpha D_H + (1-\alpha)\Pi_H\left(p_H^M\right) \ge \Pi_H\left(p_H^M\right) + D_H \qquad \text{(A15)}$$

should hold. Equivalently,

$$\alpha \le \frac{\Pi_H\left(p_L^M\right) - D_H}{\Pi_H\left(p_H^M\right) - D_H} = \frac{\Pi_H\left(p_L^M\right) - \Pi_H\left(\hat{p}\right)}{\Pi_H\left(p_H^M\right) - \Pi_H\left(\hat{p}\right)} \equiv \delta < 0$$

a contradiction.

Case 5. Suppose that $p^* \le p_h < p_l < p_L^M < p_H^M$.

In this case $p^* = p_h$ and (A14) guarantees that H has no incentive to deviate from p^* to p_H^M. By (A14), $\hat{p} \le p_h < p_L^M$, a contradiction.

Case 6. Suppose that $p_h < p_l < p_L^M < p_H^M$ and $p^* \in (p_h, p_l]$.

Clearly in this case $p^* = p_l$ and E follows the signal sent by the IS.

In order for H not to deviate from p_l to p_H^M, the inequality

$$\Pi_H\left(p_l\right) + \alpha D_H + (1-\alpha)\Pi_H\left(p_H^M\right) \ge \Pi_H\left(p_H^M\right) + D_H \qquad \text{(A16)}$$

must hold. Equivalently,

$$\Pi_H\left(p_l\right) \ge \alpha\Pi_H\left(p_H^M\right) + (1-\alpha)D_H = \Pi_H\left(\tilde{p}_H(\alpha)\right)$$

and $\tilde{p}_H(\alpha) \le p_l < p_H^M$. But $p_L^M < \hat{p} < \tilde{p}_H(\alpha)$, a contradiction. We conclude that if $p_L^M < \hat{p}$, then $SPE = \varnothing$.

■

We next deal with the case where $\hat{p} < p_L^M$. We need to show that $SPEP = \left\{p^* \middle| \hat{p} \le p^* \le p_L^M\right\}$ for all α, $1/2 < \alpha < 1$.

First we prove the following lemma.

Lemma 6. Suppose that $\mu\Delta_E(H)+(1-\mu)\Delta_E(L)<0$, $1/2<\alpha\leq\bar{\alpha}_h$ and $\hat{p}<p_L^M$. Then

$$\left\{p^*\middle|\hat{p}\leq p^*\leq p_L^M\right\}\subseteq SPEP$$

Proof: We start by showing that $p_L^M\in SPEP$.

Let p_h and p_l be s.t.

$$p^*=p_h=p_L^M<p_l<p_H^M \tag{A17}$$

Clearly L is best off with p_L^M and has no incentive to deviate.

The two incentive compatibility constraints of H in this case are:

(i) H has no incentive to deviate from p_L^M to p_l. Namely,

$$\Pi_H\left(p_L^M\right)+\Pi_H\left(p_H^M\right)\geq\Pi_H\left(p_l\right)+\alpha D_H+(1-\alpha)\Pi_H\left(p_H^M\right) \tag{A18}$$

Equivalently,

$$\Pi_H\left(p_l\right)-\Pi_H\left(p_L^M\right)\leq\alpha\left[\Pi_H\left(p_H^M\right)-D_H\right]$$

(ii) H has no incentive to deviate from p_L^M to p_H^M if (A12) holds.

Since $\hat{p}<p_L^M$, (A12) holds. As for (A18), it holds for every $1/2<\alpha<1$, provided that p_l is sufficiently close to p_L^M. Hence (A17) for p_l sufficiently close to p_L^M, guarantees that, for all $1/2<\alpha<1$, $p_L^M\in SPEP$.

Next let p_h and p_l be s.t.

$$\hat{p}\leq p^*=p_h<p_l<p_L^M<p_H^M \tag{A19}$$

The incentive compatibility constraints of L in this case are two:

(i) L has no incentive to deviate from p_h to p_l.

$$\Pi_L\left(p_h\right)+\Pi_L\left(p_L^M\right)\geq\Pi_L\left(p_l\right)+\alpha\Pi_L\left(p_L^M\right)+(1-\alpha)D_L \tag{A20}$$

Equivalently,

$$\Pi_L\left(p_l\right)-\Pi_L\left(p_h\right)\leq(1-\alpha)\left[\Pi_L\left(p_L^M\right)-D_L\right]$$

(ii) L has no incentive to deviate from p_h to p_L^M.

$$\Pi_L\left(p_h\right)+\Pi_L\left(p_L^M\right)\geq\Pi_L\left(p_L^M\right)+D_L \tag{A21}$$

Equivalently,

$$\Pi_L(p_h) \geq D_L = \Pi_L(p_0)$$

or $p_0 \leq p_h$ (see Figure 4).

The two incentive compatibility constraints of H are the one given by (A14) and

$$\Pi_H(p_h) + \Pi_H(p_H^M) \geq \Pi_H(p_l) + \alpha D_H + (1-\alpha)\Pi_H(p_H^M) \qquad \text{(A22)}$$

Equivalently,

$$\Pi_H(p_l) - \Pi_H(p_h) \leq \alpha\left[\Pi_H(p_H^M) - D_H\right]$$

(A14) and (A21) imply $\hat{p} \leq p_h$ and $p_0 \leq p_h$ respectively. By Lemma 1, $\hat{p} > p_0$. Hence, $\hat{p} \leq p_h$, which is consistent with (A19). (A20) and (A22) hold for every $1/2 < \alpha < 1$ provided that p_h is sufficiently close to p_l. Hence (A19) for $0 < p_l - p_h$ sufficiently small, guarantees that, for all $1/2 < \alpha < 1$, $p^* \in SPEP$, and the proof of Lemma 6 is complete.

■

<u>Lemma 7.</u> Suppose that $\mu\Delta_E(H) + (1-\mu)\Delta_E(L) < 0$ and $1/2 < \alpha \leq \bar{\alpha}_h$. Then, $SPEP \subseteq \left[\hat{p}, p_L^M\right]$.

<u>Proof:</u> Let $p^* \in SPEP$. By Lemma 4, $p^* \leq p_l$ and $p_H^M > p_h$.

Let $R = \left[\hat{p}, p_L^M\right]$.

The relevant cases are

Case 1. Suppose that $p_L^M \leq p_h$. Then $p^* = p_L^M \in R$.

Case 2. Suppose that $\hat{p} < p_h < p_L^M < p_H^M \leq p_l$.

Similarly to case 2 of Lemma 5, $p^* = p_h$. By the incentive compatibility constraint of H given by (A13), $\hat{p} < \widehat{p}_H(\alpha) \leq p^* = p_h < p_L^M$. Hence $p^* \in R$.

Case 3. Suppose that $p_h \leq \hat{p} < p_L^M < p_H^M \leq p_l$.

Similar to the previous case $\widehat{p}_H(\alpha) \leq p^* = p_h$. Hence, no pooling equilibrium exists in this case since $p_h \leq \hat{p} < \widehat{p}_H(\alpha)$.

Case 4. Suppose that $\hat{p} \leq p^* \leq p_h < p_L^M \leq p_l < p_H^M$. Then clearly $p^* \in R$.

Case 5. Suppose that $p^* \le p_h < \hat{p} < p_L^M \le p_l < p_H^M$.

Similarly to the previous case $p^* = p_h$, and by (A14) $\hat{p} \le p_h$, a contradiction. Hence, there exists no pooling equilibrium in this case.

Case 6. Suppose that $p_h < p_L^M \le p_l < p_H^M$ and $p^* \in (p_h, p_l]$.

Clearly in this case $p^* = p_L^M$ and $p_L^M \in SPEP$.

Case 7. Suppose that $\hat{p} \le p^* \le p_h < p_l < p_L^M < p_H^M$. Then $p^* \in R$.

Case 8. Suppose that $p^* \le p_h < \hat{p} < p_l < p_L^M < p_H^M$.

Similarly to case 5 above, there is no pooling equilibrium in this case.

Case 9. Suppose that $p_h < \hat{p} < p_l < p_L^M < p_H^M$ and $p^* \in (p_h, p_l]$.

Clearly in this case $p^* = p_l$. From the incentive compatibility constraint of H given by (A16), $\hat{p} < \tilde{p}_H(\alpha) \le p^* = p_l < p_L^M$. Hence $p^* \in R$.

Case 10. Suppose that $p_h < p_l \le \hat{p} < p_L^M < p_H^M$ and $p^* \in (p_h, p_l]$.

Similarly to the previous case $\tilde{p}_H(\alpha) \le p^* = p_l$. Hence, no pooling equilibrium exists in this case since $p_l \le \hat{p} < \tilde{p}_H(\alpha)$.

The above 10 cases prove that if $p^* \in SPEP$, then $p^* \in R$, as claimed.

■

Finally, let us show that if $p_L^M = \hat{p}$, then $SPEP = \{p_L^M\}$ for all $1/2 < \alpha < 1$.

Lemma 8. Suppose that $\mu\Delta_E(H) + (1-\mu)\Delta_E(L) < 0$, $1/2 < \alpha \le \bar{\alpha}_h$ and $p_L^M = \hat{p}$. Then $p_L^M \in SPEP$.

Proof: Let p_h and p_l be s.t. (A17) holds. The incentive compatibility constraints of H are given by (A12) and (A18). Clearly (A12) holds since $p_L^M = \hat{p}$. But also (A18) holds for every $1/2 < \alpha < 1$, provided that p_l is sufficiently close to p_L^M. Hence, $p_L^M \in SPEP$ for all $1/2 < \alpha < 1$ is guaranteed by (A17) with p_l sufficiently close to p_L^M.

■

Lemma 9. Suppose that $\mu\Delta_E(H)+(1-\mu)\Delta_E(L)<0$, $\frac{1}{2}<\alpha\le\bar{\alpha}_h$, $p_L^M=\hat{p}$ and $p^*\in SPEP$. Then $p^*=p_L^M$.

Proof: We consider the same six cases as in proof of Lemma 5.

Case 1. Suppose that $p_L^M\le p_h$. Then $p^*=p_L^M$, as claimed.

Case 2. Suppose that $p_h<p_L^M<p_H^M\le p_l$.

Similarly to case 2 of Lemma 5, $p^*=p_h$. By (A13), $\hat{p}<\hat{p}_H(\alpha)\le p_h<p_H^M$ must hold. But $p_h<p_L^M=\hat{p}$, a contradiction. Hence, there is no pooling equilibrium in this case.

Case 3. Suppose that $p^*\le p_h<p_L^M\le p_l<p_H^M$.

In this case again $p^*=p_h$. The incentive compatibility constraint of H is given by (A14) and implies $\hat{p}\le p_h$. But in this case $p_h<p_L^M=\hat{p}$. Consequently, no pooling equilibrium exists in this case.

Case 4. Suppose that $p_h<p_L^M\le p_l<p_H^M$ and $p^*\in(p_h,p_l]$.

In this case $p^*=p_L^M\in SPEP$, as claimed.

Case 5. Suppose that $p^*\le p_h<p_l<p_L^M<p_H^M$.

In this case $p^*=p_h$ and H has no incentive to deviate from p^* to p_H^M if (A14) holds, or equivalently, $\hat{p}\le p_h<p_L^M$, a contradiction. Hence, there is no pooling equilibrium in this case either.

Case 6. Suppose that $p_h<p_l<p_L^M<p_H^M$ and $p^*\in(p_h,p_l]$.

Clearly in this case $p^*=p_l$. From the incentive compatibility constraint of H given by (A16), $\tilde{p}_H(\alpha)\le p_l$ must hold. But $p_L^M=\hat{p}<\tilde{p}_H(\alpha)$. Consequently, no pooling equilibrium exists in this case.

■

Lemmas 8 and 9 establish the second part of part (1) of the proposition.

Subcase 1.2. $\bar{\alpha}_h < \alpha < 1$.

In this case $\alpha \in A_l \setminus \bar{A}_h$. Namely, E enters the market when observing the price p^* if the IS sends the signal h and does not enter if the IS sends the signal l. Hence, accordingly to the strategy of E defined in Lemma 3, $p_h < p^* \le p_l$.

Let us find pooling equilibria in this case.

Lemma 10. Suppose that $\mu\Delta_E(H) + (1-\mu)\Delta_E(L) < 0$ and $\bar{\alpha}_h < \alpha < 1$. Then, in every pooling equilibrium $p_L^M > p_h$ and $p_H^M > p_l$.

Proof: Suppose to the contrary that $p_L^M \le p_h$ or $p_H^M \le p_l$. Then, at least one type of M has an incentive to deviate to his monopoly price.

■

Lemma 11. Suppose that $\mu\Delta_E(H) + (1-\mu)\Delta_E(L) < 0$, $\bar{\alpha}_h < \alpha < 1$ and $p_L^M \le \hat{p}$. Then $SPE = \varnothing$.

Proof: Suppose to the contrary that $p^* \in SPEP$. We consider two cases.

Case 1. Suppose that $p_h < p_L^M \le p_l < p_H^M$. Note that in this case $p^* = p_l = p_L^M$.

In order for H not to deviate from p_L^M to p_H^M, (A15) should hold. Equivalently $\alpha \le \delta \le 0$, a contradiction.

Case 2. Suppose that $p_h < p_l < p_L^M < p_H^M$. Note that in this case $p^* = p_l$.

H has no incentive to deviate from p_l to p_H^M if (A16) holds. Equivalently, $p_l \ge \tilde{p}_H(\alpha)$ (see Figure 4). Since $p_l < p_L^M$, $p_L^M > \tilde{p}_H(\alpha)$ must hold. Equivalently, $\alpha < \delta \le 0$, a contradiction.

■

Note that Lemmas 5 and 11 establish the first part of part (1) of the proposition.

Lemma 12. Suppose that $\mu\Delta_E(H) + (1-\mu)\Delta_E(L) < 0$, $\bar{\alpha}_h < \alpha < 1$ and $\hat{p} < p_L^M$. Then

$$SPEP = \left\{ p^* \middle| \max\left(\tilde{p}_H(\alpha), \hat{p}_L(\alpha)\right) \le p^* \le p_L^M \right\}$$

and this set is non-empty if $\delta > \bar{\alpha}_h$ and for all α, $\bar{\alpha}_h < \alpha \le \delta$.

Proof: We start by showing that $p_L^M \in SPEP$.

Let p_h and p_l be s.t.

$$p_h < p^* = p_L^M = p_l < p_H^M \tag{A23}$$

In order for H not to deviate from p_L^M to p_H^M, (A15) should hold. Equivalently $\alpha \le \delta$, where $0 < \delta < 1$ since $p_L^M > \hat{p}$.

H has no incentive to deviate from p_L^M to p_h, if

$$\Pi_H\left(p_L^M\right) + \alpha D_H + (1-\alpha)\Pi_H\left(p_H^M\right) \ge \Pi_H\left(p_h\right) + \Pi_H\left(p_H^M\right) \tag{A24}$$

holds. Equivalently,

$$\Pi_H\left(p_L^M\right) - \Pi_H\left(p_h\right) \ge \alpha\left(\Pi_H\left(p_H^M\right) - D_H\right)$$

The incentive compatibility constraint of L is given by

$$\Pi_L\left(p_L^M\right) + \alpha\Pi_L\left(p_L^M\right) + (1-\alpha)D_L \ge \Pi_L\left(p_h\right) + \Pi_L\left(p_L^M\right) \tag{A25}$$

Equivalently,

$$\Pi_L\left(p_L^M\right) - \Pi_L\left(p_h\right) \ge (1-\alpha)\left(\Pi_L\left(p_L^M\right) - D_L\right)$$

Note that (A24) and (A25) hold for p_h sufficiently small. Hence (A23) p_h sufficiently small and for $\delta > \bar{\alpha}_h$, guarantees that, for all $\bar{\alpha}_h < \alpha \le \delta$, $p_L^M \in SPEP$.

Next let p_h and p_l be s.t.

$$p_h < \max\left(\tilde{p}_H(\alpha), \hat{p}_L(\alpha)\right) \le p^* = p_l < p_L^M < p_H^M \tag{A26}$$

H has no incentive to deviate from p_l to p_H^M if (A16) holds. Equivalently, $p_l \ge \tilde{p}_H(\alpha)$ (see Figure 4). Since $p_l < p_L^M$, $p_L^M > \tilde{p}_H(\alpha)$ must hold. Equivalently, $\alpha < \delta$. Note that $0 < \delta < 1$ since $p_L^M > \hat{p}$.

In order for H not to deviate from p_l to p_h,

$$\Pi_H\left(p_l\right) + \alpha D_H + (1-\alpha)\Pi_H\left(p_H^M\right) \ge \Pi_H\left(p_h\right) + \Pi_H\left(p_H^M\right) \tag{A27}$$

should hold. Equivalently,

$$\Pi_H\left(p_l\right) - \Pi_H\left(p_h\right) \ge \alpha\left(\Pi_H\left(p_H^M\right) - D_H\right)$$

Next, let us consider the two incentive compatibility constraints of L.

(i) In order for L not to deviate from p_l to p_L^M,

$$\Pi_L\left(p_l\right) + \alpha\Pi_L\left(p_L^M\right) + (1-\alpha)D_L \ge \Pi_L\left(p_L^M\right) + D_L \tag{A28}$$

should hold. Equivalently, $p_l \geq \hat{p}_L(\alpha)$ (see Figure 5).

(ii) In order for L not to deviate from p_l to p_h,

$$\Pi_L(p_l)+\alpha\Pi_L(p_L^M)+(1-\alpha)D_L \geq \Pi_L(p_h)+\Pi_L(p_L^M) \tag{A29}$$

should hold. Equivalently,

$$\Pi_L(p_l)-\Pi_L(p_h) \geq (1-\alpha)\left(\Pi_L(p_L^M)-D_L\right)$$

(A16) and (A28) imply that $\max\left(\tilde{p}_H(\alpha),\hat{p}_L(\alpha)\right) \leq p^* = p_l < p_L^M$, which is consistent with (A26), but it needs $\delta > \bar{\alpha}_h$ and $\bar{\alpha}_h < \alpha < \delta$. Note that (A27) and (A29) hold for p_h sufficiently small. Hence, (A26) for p_h sufficiently small and $\delta > \bar{\alpha}_h$, guarantees that, for all $\bar{\alpha}_h < \alpha < \delta$, $p^* \in SPEP$.

■

<u>Case 2.</u> $\mu\Delta_E(H)+(1-\mu)\Delta_E(L) > 0$.

Note that in this case $\bar{\alpha}_h < 1/2 < \bar{\alpha}_l < 1$. Hence $\alpha > \bar{\alpha}_h$ and $\alpha \notin A_h$, $\forall \alpha$, $1/2 < \alpha < 1$. Namely, if the IS sends the signal h, E enters the market when observing the price p^* irrespective the precision α of the IS.

<u>Subcase 2.1.</u> $1/2 < \alpha < \bar{\alpha}_l$.

In this case $\alpha \notin A_l \cup A_h$. Namely, E enters the market when observing the price p^* irrespective of the signal sent by the IS and, therefore, both H and L should select the prices p_H^M and p_L^M, respectively. Since $p_L^M < p_H^M$, no pooling equilibrium exists in this case.

<u>Subcase 2.2.</u> $\bar{\alpha}_l \leq \alpha < 1$.

In this case $\alpha \in A_l \setminus \bar{A}_h$. Namely, E enters the market when observing the price p^* if the IS sends the signal h and does not enter if the IS sends the signal l. Hence, similarly to Subcase 1.2, if $p_L^M \leq \hat{p}$, then $SPE = \varnothing$. In particular, this together with Lemmas 5 and 11 establish the first part of part (1) of the proposition. If $\hat{p} < p_L^M$, then

$$SPEP = \left\{ p^* \middle| \max\left(\tilde{p}_H(\alpha),\hat{p}_L(\alpha)\right) \leq p^* \leq p_L^M \right\}$$

and this set is non-empty if $\delta \geq \bar{\alpha}_l$ and for all α, $\bar{\alpha}_l \leq \alpha \leq \delta$.

■

Proof of Proposition 5.

In this linear model,

$$p_L^M = \frac{a+c_L}{2},\ p_H^M = \frac{a+c_H}{2}$$

$$\Pi_L\left(p_L^M\right) = \left(\frac{a-c_L}{2}\right)^2,\ \Pi_H\left(p_H^M\right) = \left(\frac{a-c_H}{2}\right)^2$$

$$D_L = \left(\frac{a-c_L}{3}\right)^2,\ D_E\left(L\right) = \left(\frac{a-c_L}{3}\right)^2$$

$$D_H = \left(\frac{a-2c_H+c_L}{3}\right)^2,\ D_E\left(H\right) = \left(\frac{a-2c_L+c_H}{3}\right)^2$$

Note that

$$c_L < c_H \leq \frac{a+c_L}{2} < a \tag{A30}$$

must hold and it is easy to verify that $p_L^M > \hat{p}$.

$$\Delta_E\left(L\right) = \left(\frac{a-c_L}{3}\right)^2 - K$$

$$\Delta_E\left(H\right) = \left(\frac{a-2c_L+c_H}{3}\right)^2 - K$$

Since $\Delta_E\left(L\right) < 0$ and $\Delta_E\left(H\right) > 0$,

$$\left(\frac{a-c_L}{3}\right)^2 < K < \left(\frac{a-2c_L+c_H}{3}\right)^2 \tag{A31}$$

must hold.

(1) Suppose that $\mu\Delta_E\left(H\right)+\left(1-\mu\right)\Delta_E\left(L\right) < 0$. Then,

$$K > \mu\left(\frac{a-2c_1+c_2}{3}\right)^2 + \left(1-\mu\right)\left(\frac{a-c_1}{3}\right)^2 \tag{A32}$$

(A31) together with (A32) imply that

$$\mu\left(\frac{a-2c_1+c_2}{3}\right)^2+(1-\mu)\left(\frac{a-c_1}{3}\right)^2<K<\left(\frac{a-2c_1+c_2}{3}\right)^2 \quad \text{(A33)}$$

We conclude that (A30) and (A33) must hold.

For the existence of a pooling equilibrium we need to have $\delta > \bar{\alpha}_h$ for every $\alpha \in (\bar{\alpha}_h, \delta]$. This holds iff

$$\frac{a-c_L}{c_H-c_L}>\frac{1+3\sqrt{14}}{5} \quad \text{(A34)}$$

and

$$\mu\left(\frac{a-2c_L+c_H}{3}\right)^2+(1-\mu)\left(\frac{a-c_L}{3}\right)^2<K<\bar{K} \quad \text{(A35)}$$

where $\bar{K}$ is the solution to $\delta = \bar{\alpha}_h$ (see (16) and (17)).

It can be shown that when (A34) holds,

$$\mu\left(\frac{a-2c_L+c_H}{3}\right)^2+(1-\mu)\left(\frac{a-c_L}{3}\right)^2<\bar{K}<\left(\frac{a-2c_L+c_H}{3}\right)^2$$

and thus, the set of all K's s.t. (A35) holds, is non-empty.

(2) Suppose that $\mu\Delta_E(H)+(1-\mu)\Delta_E(L)>0$. Hence,

$$K<\mu\left(\frac{a-2c_L+c_H}{3}\right)^2+(1-\mu)\left(\frac{a-c_L}{3}\right)^2 \quad \text{(A36)}$$

(A36) together with (A31) imply

$$\left(\frac{a-c_L}{3}\right)^2<K<\mu\left(\frac{a-2c_L+c_H}{3}\right)^2+(1-\mu)\left(\frac{a-c_L}{3}\right)^2 \quad \text{(A37)}$$

Hence, we conclude that (A30) and (A37) must hold.

For the existence of a pooling equilibrium we need that $\delta \ge \bar{\alpha}_l$ for every $\alpha \in [\bar{\alpha}_l, \delta]$.

This holds iff (A34) holds and

$$\tilde{K}\le K<\mu\left(\frac{a-2c_L+c_H}{3}\right)^2+(1-\mu)\left(\frac{a-c_L}{3}\right)^2 \quad \text{(A38)}$$

where $\tilde{K}$ is the solution to $\delta = \bar{\alpha}_l$ (see (14) and (17)).

It can be shown that when (A34) holds,

$$\left(\frac{a-c_L}{3}\right)^2 < \tilde{K} < \mu\left(\frac{a-2c_L+c_H}{3}\right)^2 + (1-\mu)\left(\frac{a-c_L}{3}\right)^2$$

and the set of all K's s.t. (A38) holds, is non-empty.

■

If we replace Cournot competition by Bertrand competition, we have

$$p_L^M = \frac{a+c_L}{2},\ p_H^M = \frac{a+c_H}{2}$$

$$\Pi_L\left(p_L^M\right) = \left(\frac{a-c_L}{2}\right)^2,\ \Pi_H\left(p_H^M\right) = \left(\frac{a-c_H}{2}\right)^2$$

$$D_L = 0,\ D_E(L) = 0$$

$$D_H = 0,\ D_E(H) = (c_H - c_L)(a - c_H)$$

Note that $c_L < c_H < a$ must hold and $p_L^M > \hat{p}$ iff $c_H < \frac{a+c_L}{2}$. Hence

$$c_L < c_H < \frac{a+c_L}{2} < a \qquad \text{(A39)}$$

must hold.

$\Delta_E(L) = 0 - K$

$\Delta_E(H) = (c_H - c_L)(a - c_H) - K$

Since $\Delta_E(L) < 0$ and $\Delta_E(H) > 0$,

$$0 < K < (c_H - c_L)(a - c_H) \qquad \text{(A40)}$$

must hold.

(1) Suppose that $\mu\Delta_E(H) + (1-\mu)\Delta_E(L) < 0$. Then,

$$K > \mu(c_H - c_L)(a - c_H) \qquad \text{(A41)}$$

(A40) together with (A41) imply that

$$\mu(c_H - c_L)(a - c_H) < K < (c_H - c_L)(a - c_H) \qquad \text{(A42)}$$

We conclude that (A39) and (A42) must hold.

For the existence of a pooling equilibrium we need to have $\delta > \bar{\alpha}_h$ for every $\alpha \in (\bar{\alpha}_h, \delta]$. This holds iff

$$\frac{a-c_H}{c_H-c_L} > \sqrt{2} \tag{A43}$$

and

$$\mu(c_H-c_L)(a-c_H) < K < \bar{K}_1 \tag{A44}$$

where $\bar{K}_1$ is the solution to $\delta = \bar{\alpha}_h$ (see (16) and (17)).

It can be shown that when (A43) holds,

$$\mu(c_H-c_L)(a-c_H) < \bar{K}_1 < (c_H-c_L)(a-c_H)$$

and thus, the set of all K's s.t. (A44) holds, is non-empty.

(2) Suppose that $\mu\Delta_E(H)+(1-\mu)\Delta_E(L) > 0$. Hence,

$$K < \mu(c_H-c_L)(a-c_H) \tag{A45}$$

(A45) together with (A40) imply

$$0 < K < \mu(c_H-c_L)(a-c_H) \tag{A46}$$

Hence, we conclude that (A39) and (A46) must hold.

For the existence of a pooling equilibrium we need that $\delta \geq \bar{\alpha}_l$ for every $\alpha \in [\bar{\alpha}_l, \delta]$. This holds iff (A43) holds and

$$\tilde{K}_1 \leq K < \mu(c_H-c_L)(a-c_H) \tag{A47}$$

where $\tilde{K}_1$ is the solution to $\delta = \bar{\alpha}_l$ (see (14) and (17)).

It can be shown that when (A43) holds,

$$0 < \tilde{K}_1 < \mu(c_H-c_L)(a-c_H)$$

and the set of all K's s.t. (A47) holds, is non-empty.

■

Chapter 5. Conclusions

This thesis contributes to the theoretical analysis of industrial espionage and competitive intelligence activities in the context of entry deterrence, in which this topic has never been analyzed before.

In Chapter 2, in which a potential entrant spies on a monopoly incumbent trying to detect his decision of whether or not to invest in capacity expansion, we showed that, if the precision of the intelligence system is common knowledge, surprisingly, the monopoly incumbent is the one who benefits from a perfect intelligence system and the potential entrant who spies on the monopoly prefers a less accurate one. The results of the case where the precision of the intelligence system is the private information of the potential entrant are less surprising.

Chapter 3 analyzed the model in Chapter 2 assuming that the intelligence system is costly and its precision is commonly known by both firms and the strategic choice of the potential entrant, its owner. If the monopoly observes the choice of the potential entrant, the optimal precision is bounded away from 1. When the monopoly does not observe the choice and the intelligence system is cost free, the entrant builds a perfect intelligence system, but this situation is more beneficial for the monopoly. When the cost is positive and relatively high, the potential entrant does not spy on the monopoly. But it is more complicated when the cost is relatively low but positive. We showed that in equilibrium the entrant assigns some probability distribution over the precision of the intelligence system. We could not find this mixed strategy equilibrium, and this would be interesting for future research. However, the most interesting research would be to analyze the general case where M does not observe the choice of E.

In Chapter 4, in which a potential entrant spies on a monopoly incumbent trying to better know the outcome of a R&D project carried out by the latter in an attempt to reduce his cost of production, we showed (assuming that the precision of the intelligence system is exogenous and common knowledge) that the separating equilibria are not affected by the spying activity of the potential entrant. This is not very surprising since in a separating equilibrium the entrant identifies the cost of the monopoly with or without the use of the intelligence system. Although the same result is obtained for pooling equilibria if the precision of the intelligence system is sufficiently low to affect potential entrant's decision of staying out, if the intelligence system is very accurate, then pooling equilibrium does not exist. But the most interesting result is that for intermediate values of the precision of the intelligence, pooling equilibrium exists and potential entrant enters the market if the intelligence system tells her the cost of M is high. From this point of view, spying on incumbent firms increases competition with high probability.

An interesting suggestion for further research might be to analyze the last model assuming that the precision of the intelligence system is the private information of the potential entrant, its owner. And an interesting way the models in this thesis could be extended would be to assume that the monopoly incumbent conducts counterespionage activities.

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