Market must be defended: The role of counter-espionage policy in protecting domestic market welfare

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Abstract

Governments of advanced economies are extremely concerned about the illicit acquisition of information on critical technologies employed by their industries, and countering this economic espionage is quickly becoming one of their top priorities. The present paper advances the theoretical analysis of the interaction between economic espionage and counter-espionage, and presents a first approximation to an inquiry into the rationale for the influence of market competition in its dynamics. The proposed model assumes a country with a one-market economy open to international trade whose product is supplied by domestic firms. Moreover, successful economic espionage implying market entry of foreign firms would harm domestic welfare. Considering counter-espionage policy as entry barrier and sufficient efficiency in espionage and counter-espionage efforts, the analysis of the benchmark case characterized by no foreign consumer and one foreign firm suggests that demand characteristics play an important role in the complex influence of competition in espionage. Irrespective of this, optimal counter-espionage effort is always positive although negatively affected by competition.

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1. Introduction

The illicit attempts by countries to acquire information on critical manufacturing processes and technologies employed by industries in other countries is considered *economic espionage*.[1] Although the information technology revolution that the world has undergone since the 1990s has facilitated economic espionage (Nasheri, 2005, pp. 1-2; Glitz and Meyersson, 2020, p. 1099), it is not a new phenomenon. For instance, almost 200 years ago Robert Fortune, on a covert mission, stole the Chinese tea processing technique, causing the fall of the China's tea monopoly (Ben-Attar, 2004).

That branch of economic espionage can have extremely important consequences not only for the companies affected, but also for the general economy of the country being spied on. Although it is arduous to quantify the magnitude of these consequences (Nasheri, 2005, p. 52), the Commission on the Theft of American Intellectual Property estimated in 2017 that the annual cost of economic espionage to the U.S. could be between $225 billion and $600 billion.[2] Furthermore, in 2018 the National Counterintelligence and Security Center identified energy, biotechnology and defense technology sectors as the main targets for foreign intelligence collectors, and warned of the aggressiveness with which China, Russia and Iran would continue gathering information on sensitive technologies from the United States and its companies.

An important objective of these information-gathering activities, and the case of interest in the present paper, is the participation of firms from the spying country in a particular market. For instance, in the biotechnology sector, the participation of Chinese firms in pharmaceutical markets[3] is based on the use of information about drugs from the United States (Lowe, 2011) and to copy

[1] See for instance Nasheri (2005) and the 1996 US Economic Espionage Act.

[2] This wide range clearly reflects the scarcity of data on this activity due to its nature of secrecy (Glitz and Meyersson, 2020, pp. 1055-1056).

[3] Synthesizing data from the *World Trade Organization*, HowMuch.net (2019) highlights that the pharmaceutical industry is quite open to international trade.

them and commercialize generics (Atkinson, 2019), many of which are imported by this country (Palmer and Bermingham, 2019). Another example can be found in the bisphenol-A-free (BPA-free) coating market. As reported by Knox News (2019) and more recently by Bettenhausen (2021) and Goldsberry (2021), information about secret BPA-free technologies from American companies was stolen and passed to a Chinese firm supported by government programs (some of which are suspected of being designed for economic espionage purposes) looking to participate in the BPA-free coating market and compete with American companies.

The governments of advanced economies are concerned about this growing threat (Glitz and Meyersson, 2020, p. 1099) and countering economic espionage has become a priority, with more resources being devoted to establishing measures for the entire country's economy. These measures can be classified, according to Grabiszewski and Minor (2018, pp. 271-272), into two general categories: *ruining measures* and *penalty-enhancing measures*. The objective of the first category of measures is to thwart the success of economic espionage activties and includes informing and raising awareness, developing different programs and protocols, and providing tools, training and assistance at company level. The second category focuses on tightening the law, not only directly increasing penalties but also broadening the limits of what is defined as economic espionage.

In this regard, Spain has its own plans and programs against economic espionage (Vilas-Rodríguez, 2017), and also recently passed the Ley 1/2019 de Secretos Empresariales which reinforces the protection against all types of espionage. United States, the paradigmatic example of an economic espionage target, increased its efforts to protect national industries with the 2012 Foreign and Economic Espionage Penalty Enhancement Act. Moreover, "countering espionage has been designated the FBI's second highest priority, ranked only behind countering terrorism" (Overfield, 2016). In this sense, this intelligence and security service has defined a broad program to counter economic espionage.[4]

The present paper advances the theoretical analysis of the interaction between economic espionage and counter-espionage based on *ruining measures*. Focusing on the case of interest mentioned above, the main objective of this analysis is the most elemental effect of the level of competition in a particular spied market on the dynamics of this interaction. Given that counter-espionage measures are established for the entire country's economy (in which different markets are interrelated), the general theoretical framework for the analysis assumes that the economy of the country countering espionage consists of only one market, although it is open to international trade.

In this study, the product commercialized in this international market is assumed to be initially supplied only by firms from this country (denoted by C),[5] while other firms from a foreign country (denoted by F) are interested in participating in the market, supplying the product from their country. However, a secret technology only known by C's firms is needed to participate in this market. In this context, the government of F, taking into account the welfare related to the participation of its economic agents in the market, decides what effort to exert in espionage activities to attempt to acquire the information necessary to replicate this secret technology. This decision is made considering the cost of the espionage activities and the probability of success in acquiring such information, as this also depends on the counter-espionage policy that might be deployed by the government of C.

The government of C, considering this possibility of economic espionage and knowing that (given the characteristics of the international market and the number of F's firms willing to participate in it) such participation is harmful for the aggregate welfare of C's market participants, decides the level of effort to exert in deploying a counter-espionage policy focused on *ruining measures*.

[4]See for instance `https://www.fbi.gov/investigate/counterintelligence`.

[5]The term "from" in this sentence means that, on the one hand, these firms *are from C* and, on the other hand, they *supply the product from C*.

Weighing up the potential loss in welfare and the cost of this effort, the aim of C's counter-espionage policy is to thwart the foreign attempts at obtaining the necessary information to replicate the secret technology needed to participate in the market. Therefore, this policy is considered in its role as barrier to entry with the aim of protecting the welfare generated by the market to C's participants. In this context, C decides the counter-espionage effort taking into account that the failure of these attempts also depends on the effort exerted in the espionage activities. Nevertheless, this espionage effort is unobservable to C, similarly as the counter-espionge effort is unobservable to F.

As mentioned above, the analysis carried out in the present paper, as a first approximation towards studying the rationale behind the influence of the level of market competition on the dynamics of the interaction between espionage and counter-espionage, aims to highlight the most elemental aspects of this influence. This aim has two important implications. The general theoretical framework outlined above focuses on the simplest possible characterization of the international market and the aspects related to the product value chain such that the higher the initial level of market competition (that is, the larger the initial number of C's firms in the market), the higher the aggregate welfare of all the market participants. However, despite this simplicity, this general theoretical framework still implies some complexities which would obscure the aim of the paper, such as the existence of cases in which competition might not have such a positive effect on the aggregate welfare of C's market participants and the relatively high number of parameters.

So, although the paper develops in some depth the general theoretical framework, to avoid these complexities the analysis focuses on a benchmark case in which there is only one firm from F interested in participating in the international market and the product commercialized is only demanded by C's consumers. In this benchmark case, the initial level of market competition always has not only a positive effect on the aggregate welfare of C's market participants,[6] but also a negative one on the welfare generated by the participation of F's firm in it. These effects are behind the results obtained which, despite avoiding the complexities mentioned above, suggest that the most elemental influence of the initial level of market competition is characterized by a non-trivial relationship between espionage and this level of competition.

More precisely, considering that both C and F are sufficiently efficient in exerting their respective efforts, these results show two basic patterns in their behavior. First, C is always willing to increase the effort in its counter-espionage policy the higher F's effort espionage, and F is always prepared to decrease this effort the higher the effort exerted by C. Namely, C regards every espionage effort as a strategic complement while F regards every counter-espionage effort as a strategic substitute, and therefore, there is a strategic asymmetry (Tombak, 2006) between C and F. And second, both F and C will exert smaller efforts in their respective espionage and counter-espionage activities given the effort of the rival the higher the initial level of competition in the market. In the case of F, the profits its firm can obtain from participating in the market decrease with this level of competition. In the case of C, the higher the initial level of competition, the smaller the loss in welfare of its domestic participants implied by the participation of F's firm in the market.

These reductions in efforts, together with the strategic asymmetry between C and F, imply that, on the one hand, a higher initial level of market competition always has a negative effect on the equilibrium counter-espionage effort and, on the other hand, the effect of this higher level of competition on the equilibrium espionage effort depends on the relationship between both reductions, which is influenced by the characteristics of market demand. In particular, an elastic

[6] As considered in the last section of the paper together with other potential lines of future research, extending the analysis to the general theoretical framework, and therefore, to cases in which market competition might not have such positive effect, would move this study of counter-espionage even closer to the strand of theoretical research analyzing the desirability of regulation of market entry, briefly presented in the next section of the paper.

demand would enhance the positive effect of a higher initial level competition on the aggregate welfare of C's market participants, given that the decrease in prices would lead to a proportionally higher increase in sales. An elastic demand would also weaken the negative effect of this higher competition on the profits that F's firm would obtain from participating in the market. Similar positive effects of market's willingness to pay come through in its influence in when the demand can be considered as sufficiently elastic.

This implies that if the demand were sufficiently elastic (inelastic), the reduction in C's counter-espionage effort due to a higher initial level of competition would be high (small) relative to F's reduction. Consequently, given the strategic asymmetry between C and F, the latter would be better off increasing (decreasing) its espionage effort and, as a result, an increase in the initial level of market competition would have a positive (negative) effect on the equilibrium espionage effort. However, there are two crucial aspects related to this influence of elasticity of demand. Firstly, considering the demand as sufficiently elastic/inelastic in this sense also depends on the pair of initial number of firms in the market defining the increase in the initial level of competition. Secondly, there exists a sufficiently high initial number of firms in the market such that, no matter how elastic the demand is, the reduction in C's effort due to an increase in the initial level of competition is always small relative to F's reduction. Namely, there exists a critical initial number of firms from which the equilibrium espionage effort decreases with the initial level of competition.

This role played by price elasticity of demand, influenced by market's willingness to pay and contingent to the initial number of firms in the market, is behind the complex dynamics of the equilibrium espionage effort under variations in the initial level of market competition. According to this role, the smaller the elasticity of demand, the fewer pairs of initial number of firms in the market exist with respect to which the demand can be considered sufficiently elastic and, therefore, the above-mentioned critical number of firms decreases. If the elasticity of demand is low enough, the equilibrium espionage effort decreases with the initial level of competition regardless of the initial number of firms competing in the market. However, when the elasticity of demand increases, the critical number of firms becomes larger and the behavior of the equilibrium espionage effort, for competitive intensities lower than the one defined by this critical number of firms, does not necessarily decrease. Furthermore, it strictly increases when elasticity of demand is sufficiently high.

The remainder of the paper is organized as follows. Section 2 presents the related literature and Section 3 sets out the general model. Section 4 develops this general model and analyzes the equilibrium of the benchmark case. Espionage and counter-espionage efforts in the equilibrium of the benchmark case are discussed in Section 5, while Section 6 is devoted to analyzing how the level of market competition affects these efforts. Finally, Section 7 concludes the paper and suggests several lines for future research.

2. Related literature

The present paper contributes to the model-based analyses of economic espionage and counter-espionage activities. This section briefly reviews some of the most important contributions to these analyses and shows that, given the different roles in which economic espionage and counter-espionage feature, these analyses are related to different strands of the theoretical literature.

One of the first theoretical studies of economic espionage, by Whitney and Gaisford (1999), also analyzed its interaction with counter-espionage, but its approach differs in several aspects from the analysis in the present paper. Firstly, Whitney and Gaisford's (1999) model considers a context in which there are only two firms competing in an international market and the objective of economic espionage is to obtain the cost-reducing technology owned by one of the firms. Secondly, although the effort exerted in counter-espionage is endogenous and the effects on consumers' surplus of its interaction with espionage are considered, the aim of such counter-espionage is to maximize the expected profit of the domestic firm, not the expected domestic welfare generated by the market. Lastly, they do not study the effects of the level of competition in the market on the dynamics of the interaction between espionage and counter-espionage efforts.

Despite these differences, Whitney and Gaisford (1999), like the present paper, considered successful espionage as an illicit technology transfer (Glitz and Meyersson, 2020). But espionage can also be considered a medium of direct knowledge spillovers across countries (see Lee, 2005, footnote 2, p. 337). This is the perspective of the more recent theoretical analysis by Grabiszewski and Minor (2018), in which a firm in a given country commits a certain effort towards R&D and a foreign firm conducts espionage activities in an attempt to obtain the former's innovation. As the authors pointed out, this perspective on espionage parallels the intellectual property and patent literature. In this sense, it would also be related to the study of secrecy and defensive publishing as alternatives to patenting (for example Johnson, 2014), and the analysis of commercial piracy. Some relatively recent theoretical studies of the latter and its regulatory aspects are Martínez-Sánchez (2010), López-Cuñat and Martínez-Sánchez (2015), Banerjee (2011, 2013) and Lu and Poddar (2012, 2018).

Grabiszewski and Minor (2018) also included in their analysis the counter-espionage policy of the government in the innovator firm's country, but in its role as a cost-enhancing barrier to the acquisition of the innovation by the foreign firm and, therefore, to the latter's participation in the same market as the innovator firm. Therefore, despite their differences in nature, the exogenous counter-espionage policy in Grabiszewski and Minor's (2018) model shares the entry-barrier spirit of the endogenous counter-espionage policy considered in the present paper. This model-based study of the entry-barrier aspect of counter-espionage is also connected to the theoretical literature analyzing the desirability of regulation or deregulation of market entry and, therefore, the convenience of establishing or relaxing barriers to entry.

The theoretical literature studying the desirability of market entry regulation is based on a comparison of the number of firms that would operate in a market under free entry with the number of firms that would maximize the welfare of market participants. This strand of research found market circumstances under which the latter is smaller than the former and, therefore, regulation of entry might be desirable. Two prominent early contributions along these lines are Mankiw and Whinston (1986) and Suzumura and Kiyono (1987). Among the wide array of later studies considering different market environments, a recent contribution by Kang et al. (2019) provided a generalization of Mankiw and Whinston's (1986) theoretical model considering, as in the present paper, an international market.

Model-based studies dealing with market entry deregulation examined its convenience also under several different circumstances. One of the first of these studies is by McCormick et al. (1984), presenting arguments according to which monopoly deregulation might not be as convenient as generally thought. While some later contributions explicitly highlighted circumstances that limit the scope of these arguments (e.g., Crew and Rowley, 1986; Poitras and Sutter, 1997, 2000), others found that entry deregulation might not be desirable in contexts in which the market is not necessarily dominated by a monopoly.

Focusing on a market regulated through licenses, Kang and Lee's (2001) model captures market characteristics under which social welfare is harmed by partial deregulation due to rent-seeking by the incumbents and the potential entrants. According to the generalization of this model by Lee and Cheong (2005), although complete deregulation is unlikely to be obtained, they found a particular case in which partial deregulation is likely to be welfare-improving. However, Lee and Cheong (2005) agreed with Kang and Lee (2001) in indicating the convenience of carefully designing the deregulation process to reduce the losses due to rent-seeking (for example, auctioning off new licenses).

Returning to the theoretical analysis of espionage, Sakai (1985), Billand et al. (2016) and Kozlovskaya (2018) did not consider measures to counter espionage activities, but they paid special attention to the effect of information-gathering activities among firms on social welfare. The effects of such activities on market entry are analyzed by a relatively new strand in this literature, represented by Barrachina et al. (2014, 2021) and Barrachina (2019). They focused on a context, not necessarily characterized by international free trade, in which an incumbent wishes to deter a potential entrant from entering the market.[7]

3. The general model

The proposed model considers the interaction between economic espionage and counter-espionage based on *ruining measures*[8] when the objective of gathering information on sensitive technologies is the participation of firms from the spying country in a particular market.[9] As mentioned in the Introduction, given that countries define their counter-espionage policy based on their entire economy (in which different markets are interrelated), the model assumes that the economy of the country countering espionage consists of only one market, although it is open to international trade. The aim of this assumption is to allow to isolate the influence of the level of competition in a particular spied market on the dynamics of the interaction between economic espionage and counter-espionage, this being the focus of the present paper.

The model assumes that the product commercialized in this international market is initially only supplied by n firms from this country, denoted by C,[10] the reason being that participation in this market requires a specific and secret technology only known by C's firms. However, there are m firms from a foreign country F interested in participating in this market, with a view to supplying the product from their country. Therefore, the government of F, knowing this requirement to participate in the market, decides what level of espionage effort to exert in an attempt to obtain the necessary information to replicate this

[7] See Barrachina et al. (2014, 2021) and Barrachina (2019) for a more detailed discussion of the sparse theoretical literature analyzing espionage and information-gathering activities not only in economic contexts.

[8] The objective of these measures is to thwart the success of economic espionage activties providing programs, protocols and tools at company level. See the Introduction for more details about this category of counter-espionage measures and how it differs from the *penalty-enhancing measures*.

[9] See the Introduction for real examples of this case of interest.

[10] The meaning of the term "from" in this sentence is twofold. It means that, on the one hand, these n firms *are from* C. And on the other hand, they *supply the product from* C.

secret technology. In particular, F decides an espionage effort $0 \leq e \leq 1$ whose main objective is to maximize the expected economic welfare related to the participation of its economic agents in the market. If the espionage is successful, which happens with probability e, there is a chance for F to acquire the information to replicate the secret technology. In this case, its firms could start supplying the product, competing with the n companies from C.

Weighing up the possibility of espionage, the government of C decides on an effort $0 \leq c \leq 1$ in deploying a counter-espionage policy (focused on *ruining measures*, as stated above), which is successful with probability c. A successful outcome of this counter-espionage policy means that C was able to prevent F from acquiring the necessary information to replicate the secret technology needed to participate in the market. For instance, $c = 1$ would imply that F is prevented from obtaining such information regardless of the effort exerted in espionage.[11] The concern of C's government when deploying this counter-espionage policy is the protection of the aggregate economic welfare of its domestic market participants.[12] Therefore, analysis of this interaction between economic espionage and counter-espionage must focus on contexts in which the participation of F's firms in the international market is harmful for the aggregate welfare of C's participants. These contexts in the present framework are

[11] Exerting effort in espionage or counter-espionage activities implies, on the one hand, funds and time to obtain the required agents and infrastructures, and on the other hand, funds and time spent by them carrying out the activity.

[12] As stated in Section 2, C's counter-espionage shares, despite differences in nature, the entry-barrier spirit of the exogenous counter-espionage policy in Grabiszewski and Minor's (2018) model. Also, the present model is related to those in the theoretical literature studying the desirability of regulation or deregulation of market entry, such as Mankiw and Whinston (1986), Kang and Lee (2001), Lee and Cheong (2005) and Kang et al. (2019). Although Kang et al.'s (2019) theoretical framework also considered an international market, as does the present study, a crucial difference with all these models (which actually makes results incomparable) is that a counter-espionage framework such as the one considered by the present model must be based on contexts where the ideal situation would be that no firms from a spying country were willing to participate in the market.

described in detail in the next section.

It could be considered that information leakages with respect to the secret technology may occur more easily when the initial number of C's firms in the market is high (for example, the higher the number of firms, the more likely the existence of an insider willing to accept a certain bribe for providing the information about the secret technology).[13] However, since the theoretical characterization of the present model is not wanted to compromise too much the analytical tractability, it abstracts from the complexities implied by this aspect[14] (continuing with the example, finding such an insider among a higher number of firms would imply devoting more time, this is, exerting higher effort in espionage) assuming that, as explained above, the effectiveness of both espionage and counter-espionage in their interaction only depends on the efforts exerted in them.

We specify that such interaction is modeled as a two-stage game of complete but imperfect information, $G(e, c)$, whose timing is the following. In Stage 1, both F and C decide simultaneously and independently their respective espionage and counter-espionage efforts. Then, F decides an espionage effort knowing that the probability of acquiring the necessary information to replicate the secret technology needed by its firms to participate in the market not only depends on this espionage effort, but also on the effort C may exert to prevent the acquisition of this information, which is unobservable to F. C decides how much effort to exert in this counter-espionage policy knowing that the probability of F's failure to acquire the information also depends on its espionage effort, which is unobservable to C.

In Stage 2 there are two possible scenarios. If the espionage conducted by F is not successful (probability $1 - e$), or if it is successful but so is the counter-espionage policy of C (with probability ec), F does not obtain the necessary information to replicate the secret technology and its firms cannot participate

[13]We thank an anonymous referee for this comment.

[14]This is an interesting line for future research, as detailed in the last section of the paper.

in the market (*Scenario 1*). The probability of this scenario is $1 - e + ec$. If the espionage carried out by F is successful (probability e) and the counter-espionage policy of C is not (probability $1 - c$), F acquires the information to replicate the secret technology and the m firms from F can participate in the market, competing with the n firms from C (*Scenario 2*). The probability of this second scenario is $e(1 - c)$.

As mentioned in the Introduction, the main objective of the present paper is to highlight the most elemental effect of the initial level of market competition on the dynamics of this interaction between F's espionage activities and C's counter-espionage policy. In this sense, the general model represented by $G(e, c)$ is based on a simple theoretical characterization in order to avoid an unreasonable number of parameters and unnecessary computational complexities in the analysis of these dynamics.[15] Three additional considerations complete the above characterization of $G(e, c)$. The first consideration is regarding the cost structures of F's espionage activities and C's counter-espionage policy. It is assumed that the cost for F of exerting an effort e in conducting espionage is e^2 and the cost for C is c^2 for exerting a level of effort c in its counter-espionage policy.[16] Nevertheless, the analysis carried out in the present paper will consider the whole cost spectrum, and how these particular cost structures contribute to facilitating the achievement of the paper's main objective.

A second consideration is the international market. As already stated, the product commercialized in the market is initially only supplied by n identical

[15] Assuming that the application by C's firms of the programs, protocols and tools provided by C's counter-espionage policy is costless also contributes to this aim, allowing the attention to be focused on the case of interest in which such an application is affordable for every firm.

[16] Convexity in the cost of these efforts captures the limited nature of the resources, funds and time, devoted by each country's government to espionage or counter-espionage activities. Given the limited nature of these resources, the higher the amount of resources devoted to one of these activities, the higher the marginal value of other governmental activities. In other words, the marginal opportunity cost of funds and time devoted to one of these activities is increasing and, therefore, so must be the marginal cost of the effort exerted.

firms from C (where $n \in \mathbb{Z}^+$ and defines the initial level of market competition). Moreover, the product is homogeneous and firms compete *à la Cournot*. With respect to the demand, it is assumed that all the consumers have identical preferences and $\alpha, \beta \in [0, 1]$, such that $\alpha+\beta \leq 1$, are, respectively, the proportions of C's and F's consumers in the international market. Therefore, consumers from other countries represent a proportion $1 - \alpha - \beta$ of the international demand, which is given by the following inverse demand function:

$$p(Q) = a - bQ \tag{1}$$

where $Q = \sum_{i=1}^{n} q_i$ is the total amount of product in the market; q_i is the amount of product supplied by firm i, $i = 1, ..., n$; and a, b are strictly positive parameters $(a, b > 0)$ characterizing the demand for the product.[17] In particular, it is well known that price elasticity of demand is inversely related to parameter b, and a represents the market's willingness to pay for the product. As shown later, these two parameters play an important role in the most elemental effect of the initial level of market competition on the dynamics of the interaction between F's espionage effort and C's effort in his counter-espionage policy.

Lastly, we consider the aspects related to the value chain of the product. In this respect, production and export costs are assumed to be zero to simplify the analysis as explained above. The cost of the initial investment to participate in the international market is also assumed to be equal to zero not only to simplify the analysis but also to focus it on the case of interest in which this cost is

[17] This market characterization shares some aspects with those considered in some of the previously mentioned theoretical studies of market entry regulation/deregulation. For example, this is the same characterization as in Kang and Lee (2001), except for its international conceptualization in the present model. Note that, according to this conceptualization, model specifications exist in which either the government of C is not concerned about the welfare of all the consumers in the market, this is when $\alpha \in]0, 1[$, or it does not take into account consumers' welfare, i.e., $\alpha = 0$. This international conceptualization of demand is similar to the one in Kang et al. (2019).

sufficiently low that the m firms from F have incentives to participate in the market.

As discussed later, although under the present framework C's firms are always negatively affected by the success of F's espionage activities and the participation of its firms in the international market,[18] there are contexts in which this participation does not have such a negative effect on the aggregate welfare of C's market participants. The conditions defining the appropriate contexts in the framework considered by $G(e,c)$ on which the analysis of the interaction between economic espionage and counter-espionage must be focused are specified in the following section.

4. Equilibrium analysis

As stated in the previous section, the main concern of C and F when deciding their respective counter-espionage and espionage efforts is the welfare generated by the international market for their own economic agents participating in it. According to $G(e,c)$, C and F can decide their efforts in the first stage of the game anticipating the welfare for their respective economic agents in each possible scenario of the second stage, and therefore, $G(e,c)$ can be solved backwards. More precisely, by applying backward induction the two-stage game $G(e,c)$ can be analyzed as a one-shot game of imperfect information defining the appropriate objective (payoffs) functions for C and F including the welfare generated by the market. The following subsection deals with the definition of these objective functions.

4.1. Welfare generated by the international market and the objective functions

As stated above, C and F decide their counter-espionage and espionage efforts in the first stage of $G(e,c)$, taking into account the welfare generated by

[18] The willingness of every firm from C to carry out a perfect application of the programs, protocols and tools provided by the counter-espionage policy is ensured in this framework by the assumed costeless nature of this application (considered before) and the negative effect of the participation of F's firms in the market.

the international market for their own economic agents in the second stage of the game. This welfare is represented by the surpluses that economic agents obtain from participating in the market. Note that the assumption of the general model that all the firms' expenses related to the product are equal to zero implies that firms (considered as sellers) are the only agents involved in the product value chain and, therefore, suppliers' surplus represents welfare on that side of the market.[19]

The surpluses that economic agents obtain from participating in the international market in the two possible scenarios considered in the second stage of $G(e, c)$ are summarized in the following lemma, whose proof is presented in the Appendix.

Lemma 1. *Consider the second stage of $G(e, c)$. The surpluses generated by the international market for its participants in Scenario 1 are:*

$$SS_n = \frac{na^2}{(n+1)^2 b} \tag{2}$$

$$CS_n = \frac{1}{2b}\left(\frac{na}{n+1}\right)^2 \tag{3}$$

where SS_n is the suppliers' surplus of C's domestic firms and CS_n is the surplus of all the consumers in the international market. The surpluses in Scenario 2 are:

$$SS^F_{n+m} = \frac{ma^2}{(n+m+1)^2 b} \tag{4}$$

$$SS^C_{n+m} = \frac{na^2}{(n+m+1)^2 b} \tag{5}$$

[19] If this assumption were relaxed, then welfare should include the surpluses of all the agents involved in the value chain of the product, which would add considerable computational complexity when analyzing the dynamics of the interaction between e and c for different initial levels of competition in the international market. As mentioned in the last section of the paper, an interesting line for future research would be to extend the general model to a general equilibrium framework which considers the markets related to the value chain of the product supplied in this international market.

$$CS_{n+m} = \frac{1}{2b}\left(\frac{(n+m)a}{n+m+1}\right)^2 \tag{6}$$

where SS^F_{n+m} and SS^C_{n+m} are the suppliers' surpluses of F's and C's firms respectively, and CS_{n+m} is consumers' surplus.

As shown in the proof of the following lemma (presented in the Appendix), the appropriate payoff functions for C and F such that $G(e,c)$ can be analyzed as a one-shot game of imperfect information can be easily obtained taking into account, on the one hand, those surpluses summarized in Lemma 1 and, on the other hand, the occurrence probabilities of the two possible scenarios that characterize the second stage of $G(e,c)$, the proportions of C's and F's consumers in the international market and the cost of espionage and counter-espionage efforts specified in Section 3.

Lemma 2. *The appropriate payoff functions for F and C, denoted by U_F and U_C respectively, such that $G(e,c)$ can be analyzed as a one-shot game of imperfect information are the following:*

$$U_F = (1-e+ec)\,\beta CS_n + e(1-c)\left(SS^F_{n+m} + \beta CS_{n+m}\right) - e^2 \tag{7}$$

$$U_C = (1-e+ec)\left(SS_n + \alpha CS_n\right) + e(1-c)\left(SS^C_{n+m} + \alpha CS_{n+m}\right) - c^2 \tag{8}$$

Equivalently,

$$U_F = (1-e+ec)\,\frac{\beta}{2b}\left(\frac{na}{n+1}\right)^2 + e(1-c)\frac{\left(2m+\beta(n+m)^2\right)a^2}{2\left(n+m+1\right)^2 b} - e^2 \tag{9}$$

$$U_C = (1-e+ec)\,\frac{na^2(\alpha n+2)}{2(n+1)^2 b} + e(1-c)\frac{\left(2n+\alpha(n+m)^2\right)a^2}{2(n+m+1)^2 b} - c^2 \tag{10}$$

Let us next study in some depth these payoff functions. In this regard, note that (7) and (8) can be written as

$$U_F = \beta CS_n + e(1-c)\left(SS^F_{n+m} + \beta\Delta CS\right) - e^2 \tag{11}$$

$$U_C = SS_n + \alpha CS_n + e(1-c)\left(\Delta SS^C + \alpha\Delta CS\right) - c^2 \tag{12}$$

where $\Delta SS^C = SS^C_{n+m} - SS_n$ is the variation in suppliers' surplus of C's domestic firms and $\Delta CS = CS_{n+m} - CS_n$ the variation in the surplus of all the consumers in the international market, both due to F's firms participation in it. Namely, as shown in (11) and (12), without considering the cost of their respective efforts, the payoff functions of F and C can be divided in two parts. The first part is determined by surpluses of each country's participants in the market in the scenario in which F's espionage activities are not successful. The second part is the expected variation in these surpluses under F's potential acquisition of the information to replicate the secret technology and its firms' participation in the market. It is easy to see that

$$\Delta CS = \frac{a^2}{2b}\frac{m^2 + 2n(nm + m + m^2)}{(n+1)^2(n+m+1)^2} \tag{13}$$

and

$$\Delta SS^C = -\frac{a^2}{b}\frac{nm(2n+m+2)}{(n+1)^2(n+m+1)^2} \tag{14}$$

In the case of F, the expected variation in welfare following the potential success of its espionage activities is always positive because all the consumers benefit from F's firms participation in the market (ΔCS is always strictly positive) since it will imply a lower market price and higher quantities sold. However, firms from C are always adversely affected by such participation (ΔSS^C is always strictly negative) because of the decrease not only in the market price but also in the quantity of product sold by each of them. Thus, the success of F's espionage activities has two opposite effects on the aggregate welfare of C's participants in the market: positive for consumers and negative for firms. It is relatively easy to see that the net variation in this welfare due to such success, $\Delta W = \Delta SS^C + \alpha \Delta CS$, is given by

$$\Delta W = \frac{a^2}{2b}\frac{((1+2n)\alpha - 2n)\, m^2 - (4-2\alpha)n(n+1)m}{(n+1)^2(n+m+1)^2} \tag{15}$$

Therefore, although the payoff functions of F and C given by (9) and (10), respectively, are the appropriate ones in order to analyze $G(e, c)$ as a one-shot game of imperfect information, such analysis must focus on cases in which this net variation in welfare is strictly negative ($\Delta W < 0$). If not, C's deployment of a counter-espionage policy in its role as barrier to participation in the market would not be justified. The following subsection discusses when C's counter-espionage is justified, or not, in the framework considered by $G(e,c)$, showing that analysis of this general model would obscure the main objective of the paper.

4.2. From the general model represented by $G(e,c)$ to the benchmark case $G^b(e,c)$

Let us start with the following lemma (whose proof is presented in the Appendix) on when C's counter-espionage policy is justified or not according to the framework of the general model represented by $G(e,c)$.

Lemma 3. *The net variation in the aggregate welfare of C's participants in the international market due to the success of the espionage activities and the participation of F's firms in it, ΔW given by (15), is non-negative only if $\bar{\alpha} < \alpha \leq 1$ and $m \geq \bar{m}$, where*

$$\bar{\alpha} = \frac{2n}{1+2n} \tag{16}$$

and

$$\bar{m} = \frac{(4-2\alpha)\left(n^2+n\right)}{(1+2n)\,\alpha - 2n} \tag{17}$$

Following Lemma 3, there are two contexts in the framework considered by $G(e,c)$ that imply a negative expected variation in the aggregate welfare of C's participants in the market under F's potential success in its espionage activities[20] and, therefore, that justify C's counter-espionage policy. The first one is when C's consumers do not participate in the international market, $\alpha = 0$, or when they represent a relatively small proportion of the market demand, $\alpha \in \left]0, \bar{\alpha}\right]$. In the first case, C is only concerned about the surplus obtained by its domestic firms which, as stated above, is always negatively affected by the participation of F's firms in the market. In the second case, C also takes into account the positive effect of such participation on the surplus of its consumers. However, the proportion of the international demand they represent is so small

[20] Remember that this is the second part of C's payoff function as specified in (12).

that this positive effect never compensates the negative one seen on the surplus of C's firms.

This negative effect, furthermore, is not always compensated when C's consumers represent a relatively high proportion of the international demand, $\alpha \in]\bar{\alpha}, 1[$, or even when the product is demanded only by them, $\alpha = 1$. In fact, if the number of F's firms prepared to participate in the market is low enough, $m < \bar{m}$, their positive impact on the welfare of C's consumers will be relatively small and these two cases characterize the second context in which C's counter-espionage policy is justified. If not, the net variation in the aggregate welfare of C's market participants due to the participation of F's firms in the market is non-negative, and either C is indifferent to F's espionage activities or might be interested in sharing the secret technology.

Therefore, analysis of the interaction between economic espionage and counter-espionage in the framework considered by $G(e, c)$ must focus on the two contexts mentioned above in which $\Delta W < 0$. As stated in the Introduction, the main objective of the present paper is to study the most elemental effect of the initial level of market competition on the dynamics of this interaction. However, it would be difficult to identify this most elemental effect under the relatively high number of parameters implied by the general model. An additional complexity of the general model is that its two relevant contexts for the analysis, in which $\Delta W < 0$, also depend on this initial level of market competition, since the thresholds $\bar{\alpha}$ and $\bar{m}$ defining these contexts, given by (16) and (17) respectively, depend on n.

Moreover, it is clear to see from the analysis carried out in the previous subsection that under the characterization of the international market in $G(e, c)$, although suppliers' surpluses are decreasing with the initial level of competition, the aggregate surplus of all market participants is always increasing with it. This implies, however, that depending on the proportion α of the international demand C's consumers represent, this level of competition might not have such a positive effect on the aggregate surplus of C's market participants. This circumstance would complicate the aim of the present paper too much,[21] as a first approximation to the rationale for the influence of market competition in the dynamics of the interaction between espionage and counter-espionage.

Consequently, let us focus the analysis carried out in the remainder of the paper on the benchmark case in which the product commercialized in the market is only demanded by C's consumers ($\alpha = 1$), and there is only one F's firm prepared to participate in the market ($m = 1$). This benchmark case defines the most elemental model, the analysis of which enables us to achieve the objective of the paper. More precisely, it implies a reduction in the number of parameters compatible with an environment in which C is not only concerned about the surplus of its domestic firms. Such benchmark case also ensures that $\Delta W < 0$ regardless of the initial level of market competition and that this level of competition has a positive effect on the aggregate surplus of C's market participants in both scenarios considered by $G(e, c)$.[22]

Let $G^b(e, c)$ be this benchmark case of the general model represented by $G(e, c)$. Therefore, the payoff functions of F and C in $G^b(e, c)$, denoted by U_F^b and U_C^b respectively, are obtained by substituting $\alpha = 1$ (and therefore $\beta = 0$)

[21] Although it could move the analysis of counter-espionage even closer to the theoretical research, briefly presented in the section devoted to the related literature, studying the desirability of regulation of market entry. In this sense, this is one of the lines of interest for future research considered in the last section of the paper.

[22] As mentioned when defining the general model represented by $G(e, c)$ in Section 3, its market characterization is the same as in Kang and Lee's (2001) model except for its international conceptualization. In this sense, the above-defined benchmark case is structurally closer to their model than $G(e, c)$ since the government of C is concerned about the welfare of all the consumers in the market. Moreover, although Kang and Lee (2001) considered the existence of several potential market entrants, only one can succeed in obtaining the additional license that would characterize the market deregulation process. They found that such partial deregulation would harm market welfare regardless of the initial level of market competition due to rent-seeking by the incumbents and the potential entrants. However, although this benchmark case implies that entry also means a loss in welfare no matter the initial number of C's firms in the market, it is due to the foreign origin of the firm and represents an adequate context for analyzing counter-espionage.

and $m = 1$ in (9) and (10),

$$U_F^b = e(1-c)\frac{a^2}{(n+2)^2 b} - e^2 \tag{18}$$

$$U_C^b = (1-e+ec)\,\frac{na^2(n+2)}{2(n+1)^2 b} + e(1-c)\frac{\left(2n+(n+1)^2\right)a^2}{2(n+2)^2 b} - c^2 \tag{19}$$

This benchmark case has two relevant implications. Firstly, the aggregate surpluses of C's market participants taken into account by C in its payoff function, given by (19), are not only increasing (as stated above) but also concave with respect to the initial level of market competition. Secondly, the surplus taken into account by F in its payoff function, given by (18), namely the profit its firm will obtain from participating in the market if espionage activities are successful, is decreasing and convex with respect to this level of market competition. As shown later, these two implications have important consequences for the dynamics of the interaction between espionage and counter-espionage under variations in the initial level of competition. The next subsection deals with the equilibrium analysis of the benchmark case $G^b(e, c)$.

4.3. Espionage and counter-espionage efforts in the equilibrium of the benchmark case $G^b(e, c)$

As a benchmark case of the general model represented by $G(e, c)$, $G^b(e, c)$ can be analyzed as the one-shot game of imperfect information defined by the payoff functions of F and C given, respectively, by (18) and (19) in the previous subsection. The expressions for the espionage and counter-espionage efforts in the equilibrium of $G^b(e, c)$ are obtained in the present subsection by solving this one-shot game.

Firstly, the best effort of each country in response to the effort of the other country (namely, each country's best-response function) is derived. The best-response function of F defines the espionage effort, e, that maximizes its payoff U_F^b, given by (18), for each possible counter-espionage effort exerted by C. Similarly, the best-response function of C defines the counter-espionage effort,

c, that maximizes its payoff U_C^b, given by (19), for each possible espionage effort exerted by F.

Both countries' payoff functions, U_C^b and U_F^b, are continuous and differentiable. Equating to zero the first derivative of each one with respect to the corresponding country's decision variable (c in the case of C and e in the case of F) and solving for the decision variable, the unique critical point of each payoff function is obtained. Specifically, the critical point of U_C is given by:

$$\bar{c}(e) = \frac{a^2(-1+2n(1+n))}{4b(1+n)^2(2+n)^2}e \tag{20}$$

And the critical point of U_F by:

$$\bar{e}(c) = \frac{a^2}{2(n+2)^2 b}(1-c) \tag{21}$$

In addition, on the one hand, U_C^b is increasing if $c < \bar{c}(e)$ and decreasing if $c > \bar{c}(e)$, whereas U_F^b is increasing if $e < \bar{e}(c)$ and decreasing if $e > \bar{e}(c)$. On the other hand, both payoff functions are concave since their second derivative is strictly negative. Consequently, the unique critical point of each payoff function is a maximum.

Nevertheless, the domains of U_C^b and U_F^b are, respectively, $c \in [0,1]$ and $e \in [0,1]$. Therefore, $\bar{c}(e)$ is the maximum of U_C^b only if $\bar{c}(e) \in [0,1]$, which is satisfied for all $e \in [0,\gamma]$, where $\gamma = \frac{4b(1+n)^2(2+n)^2}{a^2(-1+2n(1+n))}$. Similarly, $\bar{e}(c)$ is the maximum of U_F^b only if $\bar{e}(c) \in [0,1]$. This is satisfied for all $c \in [\delta, 1]$, where $\delta = 1 - \frac{2(n+2)^2 b}{a^2}$. Note that $\gamma > 0$ and $\delta < 1$ for all $a, b > 0$ and $n \in \mathbb{Z}^+$.

The above discussion leads to the following corollary, which defines the best-response function of each country.

Corollary. *The unique best effort of each country in response to the effort of the other country is given by the following best-response functions. The best-response function of C is:*

$$c(e) = \begin{cases} \overline{c}(e) & \textit{if} \quad 0 < \gamma \leq 1 \textit{ and } 0 \leq e < \gamma \\ 1 & \textit{if} \quad 0 < \gamma \leq 1 \textit{ and } \gamma \leq e \leq 1 \\ \overline{c}(e) & \textit{if} \quad \gamma > 1, \forall e \in [0,1] \end{cases} \tag{22}$$

And the best-response function of F is:

$$e(c) = \begin{cases} \overline{e}(c) & \textit{if} \quad \delta < 0, \forall c \in [0,1] \\ 1 & \textit{if} \quad 0 \leq \delta < 1 \textit{ and } 0 \leq c \leq \delta \\ \overline{e}(c) & \textit{if} \quad 0 \leq \delta < 1 \textit{ and } \delta < c \leq 1 \end{cases} \tag{23}$$

Consequently, and as to be expected, in spite of the necessary constraints on efforts, $G^b(e,c)$ is an example of strategic asymmetry in the sense of Tombak (2006). In particular, F regards C's effort in its counter-espinage policy as a strategic substitute and C regards F's effort in espionage as a strategic complement.

The role of δ and γ in the best-response functions of F and C, respectively, is twofold. On the one hand, to establish the characterization of the market which justifies the cost carried by F and C in exerting the maximum effort in response to the effort exerted by the rival. On the other hand, to define the range of the rival's efforts for which such a cost is justified.

In the case of F, $\delta < 0$ implies a characterization of the market in which exerting the maximum effort in the espionage activities is never justified (not even as a response to a nonexistent counter-espionage policy) by the economic welfare generated through the participation of F's firm in the market. It is clear that such characterization of the market is defined, according to the market's willingness to pay for the product, by $a < \overline{a}_1$, where:

$$\overline{a}_1 = (2+n)\sqrt{2b}$$

Only the participation of F's firm in a market characterized by $a \geq \overline{a}_1$ generates a sufficiently high enough economic welfare to justify exerting the maximum effort in espionage activities as a response to sufficiently low enough efforts in the counter-espionage policy.[23] Consistently, $\delta < 1$ is the upper bound for the range of C's counter-espionage efforts for which F is prepared to exert the maximum effort in espionage ($0 \leq c \leq \delta$), and its increasing behavior with respect to a reflects that the higher the welfare implied by the characteristics of the market, the higher the range.

In the case of C, exerting the maximum effort in the counter-espionage policy would avoid for sure the negative effect of the participation of F's firm in the market on the aggregate welfare of C's domestic participants.[24] However, $\gamma > 1$ implies a characterization of the market in which exerting this maximum effort is never cost justified by this loss in welfare (not even as a response to the maximum effort in the espionage activities). This characterization is defined by $a < \overline{a}_2$, where:

$$\overline{a}_2 = (1+n)(2+n)\sqrt{\frac{4b}{-1+2n(1+n)}}$$

Therefore, C's maximum counter-espionage effort is only justified as a response to high enough efforts exerted in espionage[25] if the loss in welfare implied by the participation of F's firm in the market is sufficiently high enough, which is the case in a market in which $a \geq \overline{a}_2$. Consistently, $\gamma > 0$ is the lower bound for the range of strictly positive F's espionage efforts for which C is willing to exert the maximum effort in counter-espionage ($\gamma \leq e \leq 1$), and its decreasing behavior with respect to a reflects that the higher the loss is in the aggregate welfare of C's market participants, the higher is this range.

[23]Remember that exerting the maximum effort in the counter-espionage policy would imply that F's firm is prevented for sure from participating in the market, and therefore, F's best response is to exert zero effort in espionage, as refelected in its best-response function given by (23).

[24]Remember that, as stated in the previous subsection and according to Lemma 3, the benchmark case $G^b(e,c)$ ensures that this effect is strictly negative regardless of the initial level of market competition. Section 6 analyzes this negative effect in more detail.

[25]As specified in C's best-response function given by (22), the best response for C when there is no espionage activity is to deploy no counter-espionage policy.

Note that $\overline{a}_2 > \overline{a}_1$. This means that, even though the maximum effort in C's counter-espionage policy ensures F's firm is prevented from participating in the market and generating a loss in welfare to C's participants while F's maximum effort in espionage does not necessarily guarantee its firm's participation in the market, market characteristics justifying the former are more demanding than the ones justifying the latter. This reflects that, although the participation of F's firm in the market has a net negative effect on the aggregate welfare of C's participants, its effect on consumers' welfare is positive.

Following the discussion regarding δ and γ showing the influence of the characterization of the market in the specification of the best-response functions of F and C, three different characterizations with relevant consequences on this specification can be identified according to the market's willingness to pay for the product. The first characterization is defined by $0 < a \leq \overline{a}_1$, the second characterization is given by the case $\overline{a}_1 < a \leq \overline{a}_2$, while $a > \overline{a}_2$ defines the third characterization.

The role of δ and γ explained above would be better illustrated through a graphic representation of the specification of the best-response functions in each of these three market characterizations. Such a representation first requires the study of the intersection of these functions. Let us start with the intersection of $\overline{c}(e)$ and $\overline{e}(c)$, which is characterized in the following lemma.

Lemma 4. *(1) Both $\overline{c}(e)$ and $\overline{e}(c)$, given by expressions (20) and (21) respectively, intersect at the point $(\overline{c}, \overline{e})$, where,*

$$\overline{c} = \frac{a^4(-1+2n(1+n))}{8b^2(1+n)^2(2+n)^4 + a^4(-1+2n(1+n))} \tag{24}$$

$$\overline{e} = \frac{4a^2b(1+n)^2(2+n)^2}{8b^2(1+n)^2(2+n)^4 + a^4(-1+2n(1+n))} \tag{25}$$

(2) Both $\overline{c}$, given by (24), and $\overline{e}$, given by (25), respectively satisfy $\overline{c} \in]0,1[$ and $\overline{e} \in]0,1[$, for all $a, b > 0$ and $n \in \mathbb{Z}^+$.

Proof. See Appendix ∎

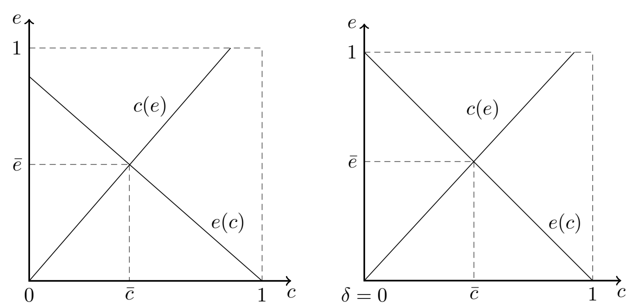
A crucial question is whether, in any of the three different market characterizations identified above, the intersection of the best-response functions of C

and F is not given by the intersection of $\overline{c}(e)$ and $\overline{e}(c)$. The following lemma sheds light on this aspect.

Lemma 5. *There is no case in terms of the parameters of the model, and therefore there is no market characterization such that the intersection of the best-response functions, defined in (22) and (23), is not given by the intersection of $\overline{c}(e)$ and $\overline{e}(c)$.*

Proof. See Appendix ☐

Therefore, although the specification of the best-response functions given by (22) and (23) is influenced by the market characterization, lemmas 4 and 5 state that their intersection is always given by the intersection of $\overline{c}(e)$ and $\overline{e}(c)$. This result, together with the above discussion regarding δ and γ, enables us to represent precisely the specification of the best-response functions and their intersection in each of the three market characterizations.

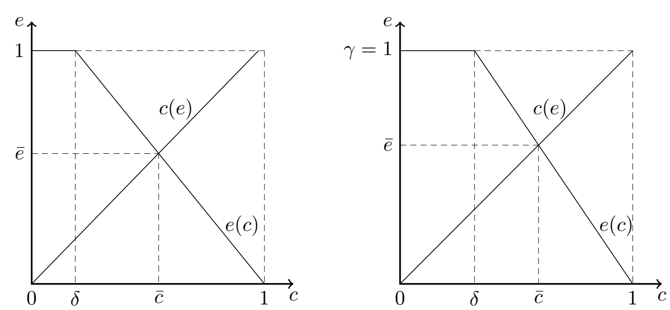


(a) $0 < a < \bar{a}_1$ (b) $a = \bar{a}_1$

Figure 1: Specifications of the best-response functions under the first market characterization

As shown in Figure 1(a), when $0 < a < \bar{a}_1$ (which implies that $\delta < 0$ and $\gamma > 1$) exerting the maximum effort is never cost justified either in F's espionage activities or in C's counter-espionage policy. Figure 1(b) shows that, under the first market characterization, just the participation of F's firm in a market characterized by $a = \bar{a}_1$ generates a high enough economic welfare to justify exertion of maximum effort in espionage activities, but only if C exerts zero effort in its counter-espionage policy. Accordingly, the upper bound for the range of C's counter-espionage efforts for which F is prepared to exert the maximum espionage effort ($0 \leq c \leq \delta$) is equal to zero ($\delta = 0$) when $a = \bar{a}_1$. However, such participation does not imply a high enough loss in the aggregate welfare of C's participants to justify the cost of exerting the maximum effort in the counter-espionage policy, not even as a response to maximum effort in espionage activities.

The higher the welfare generated by the participation of F's firm in the market, the higher the range of C's counter-espionage efforts for which F is prepared to shoulder the cost of exerting the maximum effort in its espionage activities. Nevertheless, maximum counter-espionage effort is not included in this range because it implies that F's firm is prevented for sure from participating in the market and, therefore, F's best response is to exert zero effort in espionage. As stated above, consistently, δ is increasing in a but always smaller than 1, as shown by Figures 2 and 3.



(a) $\bar{a}_1 < a < \bar{a}_2$

(b) $a = \bar{a}_2$

Figure 2: Specifications of the best-response functions under the second market characterization

Although the loss in welfare of C's participants implied by the participation of F's firm in the market is also increasing in a, this increasing behavior is softened by the positive effect of such participation on the welfare of C's consumers, as explained before. Consequently, just the participation of F's firm in a market characterized by $a = \bar{a}_2$ generates a high enough loss in welfare to justify exerting the maximum effort in the counter-espionage policy, but only if F exerts the maximum effort in its espionage activities. Accordingly, as shown by Figure 2(b), the lower bound for the range of strictly positive F's espionage efforts for which C is willing to exert the maximum counter-espionage effort ($\gamma \leq e \leq 1$) is equal to 1 ($\gamma = 1$) when $a = \bar{a}_2$.

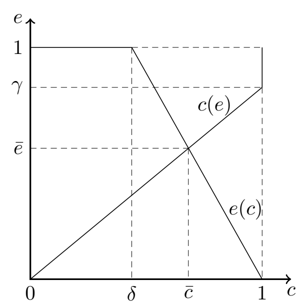


Figure 3: Specifications of the best-response functions under the third market characterization ($a > \bar{a}_2$)

So, on the one hand, as shown by Figure 2(a), an intermediate characterization of the market exists ($\overline{a}_1 < a < \overline{a}_2$) in which F is prepared to exert the maximum effort in espionage even in the context of an active counter-espionage policy, but exerting the maximum effort in this counter-espionage policy is still never cost justified. On the other hand, as Figure 3 shows, only under the third market characterization ($a > \overline{a}_2$) does the participation of F's firm imply a high enough loss in the aggregate welfare of C's participants such that C is willing to exert its maximum effort when the effort exerted in the espionage activities is not necessarily the maximum but high enough. As stated above, the decreasing behavior of γ with respect to a captures the increasing loss in welfare mentioned previously, and the fact that it is always strictly positive is consistent with C's best response to no espionage activity, to deploy no counter-espionage policy.

A Nash equilibrium of $G^b(e, c)$ is given by the espionage and counter-espionage efforts such that each country's effort is the best response to the effort of the other country. Technically, this Nash equilibrium is given by the intersection of the best-response functions defined by (22) and (23). Therefore, lemmas 4 and 5 enable characterization of the equilibrium espionage and counter-espionage efforts in $G^b(e,c)$, which is done through the following proposition.

Proposition 1. *(1) The game represented by the benchmark case $G^b(e,c)$ has a unique Nash equilibrium in pure strategies and is characterized by e^* and c^* such that $e^* = \bar{e}$ and $c^* = \bar{c}$, where $\bar{c}$ and $\bar{e}$ are given by (24) and (25) respectively.*

(2) This equilibrium exists for all the parameters that characterize $G^b(e,c)$, $a, b > 0$ and $n \in \mathbb{Z}^+$, and satisfies $c^* \in]0,1[$ and $e^* \in]0,1[$.

Before analyzing the effect of the initial level of market competition, the equilibrium espionage and counter-espionage efforts are discussed in the following section.

5. Discussion of the espionage and counter-espionage efforts in the equilibrium of the benchmark case $G^b(e,c)$

As stated by Proposition 1 in the previous section, the unique stable situation in the strategic interaction between F and C described by $G^b(e,c)$ is one in which both countries exert some strictly positive effort in their respective espionage and counter-espionage activities, but smaller than the maximum. This is true regardless of the specific market characteristics in terms of consumers' maximum willingness to pay for the product, price-elasticity of demand and initial level of competition.

In response to these results, the explanation is clear as to why there exists no particular specification of the benchmark case represented by $G^b(e,c)$ such that F and C exert zero effort in their respective espionage and counter-espionage activities in equilibrium. In a hypothetical situation in which C exerted zero effort in counter-espionage, and therefore, there was no external impediment for F to obtain the information to replicate the secret technology, F would always be able to find a strictly positive effort for its espionage activities such that the expected economic welfare from the participation of its firm in the market compensated for the cost of that effort.[26]

As discussed in the previous section, only a market characterized by $a \geq \overline{a}_1$ justifies exerting the maximum effort in the espionage activities in this hypothetical situation of no counter-espionage policy, as shown by the corresponding specifications of F's best-response function in Figures 1(b), 2 and 3. However, scenarios characterized by no counter-espionage policy by C but F exerting some positive effort in its espionage activities (including the maximum one) are not stable either. Note that, in such a situation, C would always be able to define an active counter-espionage policy (even one characterized by a relatively small effort) whose costs would be justified by the decrease in the expected loss in welfare of its domestic market participants implied by the potential participation of F's firm in the market.[27]

Also, as Figures 2 and 3 show, if $a > \overline{a}_1$, F is willing to exert its maximum effort as a response to strictly positive but sufficiently low enough efforts in the counter-espionage policy. Moreover, C is willing to exert the maximum effort in the counter-espionage policy as a response to high enough efforts in the espionage activities if the market is characterized by $a \geq \overline{a}_2$ (see Figures 2(b) and 3). However, although an intermediate characterization of the market exists in which the maximum counter-espionage effort is never justified but F is prepared to exert her maximum effort even as a response to an active counter-

[26] Only if the cost structure of the espionage activities was characterized by a sufficiently high fixed cost could the scenario in which both F and C exert zero effort emerge as an equilibrium outcome. However, we assume that fixed costs implied not only by F's espionage activities but also by C's counter-espionage policy are equal to zero to avoid an unreasonable number of parameters, and to focus on the case of interest in which espionage activities are sufficiently profitable and counter-espionage policy is sufficiently affordable.

[27] Only if C's counter-espionage policy implied a sufficiently high fixed cost could the scenario in which F exerts some strictly positive effort in espionage under no counter-espionage policy emerge as an equilibrium outcome.

espionage policy (see Figure 2(a)), a scenario in which $e = 1$ and $c \in]0, 1[$ never emerges as an equilibrium outcome either. The reason is that the effort exerted by C in such a scenario is sufficiently high enough to weaken the expected welfare from the participation of F's firm in the market such that F is better off reducing the effort in espionage.

This would not be the case if F were sufficiently more cost-efficient in its espionage activities (and/or C's counter-espionage policy sufficiently more costly) than assumed in $G^b(e, c)$, or in the hypothetical context in which espionage activities had zero marginal cost. In this hypothetical context, exerting the maximum effort would be the dominant strategy for F, implying that the maximum counter-espionage effort would also be exerted in equilibrium when the market is characterized by $a \geq \overline{a}_2$ (or if the marginal cost of the counter-espionage policy were also equal to zero). Such equilibrium, or one in which F exerts not the maximum but a strictly positive effort, does not emerge when F's espionage activities have a positive marginal cost, as in the present model, and regardless of the level of cost efficiency. This is because, under the maximum counter-espionage effort, F's firm is prevented for sure from participating in the market and F is better off exerting no effort in espionage.

This scenario, in which $e = 0$ and $c = 1$, would emerge as an equilibrium outcome regardless of the characteristics of the market only if the marginal cost of the counter-espionage policy (but not the marginal cost of the espionage activities) were equal to zero. However, when both marginal costs are positive, as in $G^b(e, c)$, the best for C when there is no espionage activity is to deploy no counter-espionage policy, implying that every scenario in which C deploys an active counter-espionage policy when F carries out no espionage is not stable. Furthermore, as explained at the beginning of this discussion, in $G^b(e, c)$ the best for F under no counter-espionage policy is to exert some positive effort in its espionage activities. Consequently, as stated by Proposition 1, the unique stable scenario of $G^b(e, c)$ is one in which both F and C exert some smaller than the maximum but strictly positive effort in their respective espionage and counter-espionage activities. This facilitates the study of the effect of the initial level of market competition on the dynamics of this interaction between F's espionage activities and C's counter-espionage policy, as outlined in the following section.

6. The effects of the level of market competition on espionage and counter-espionage efforts

The present section discusses the effect of the initial level of competition in the market determined by the initial number n of firms operating in it on the efforts exerted by the governments of F and C in their respective espionage and counter-espionage activities in the equilibrium of the benchmark case $G^b(e, c)$ characterized in Proposition 1. This discussion also sheds light on the role played by market demand in the complex relationship between F's espionage effort in equilibrium and this initial level of competition.

6.1. Espionage and counter-espionage efforts in the equilibrium of the benchmark case $G^b(e, c)$ in response to variations in the initial level of market competition

This analysis of the effects of the initial level of market competition begins with the relationship between this initial level of competition and the effort the government of C exerts in its counter-espionage policy in the equilibrium of the benchmark case $G^b(e, c)$. The following proposition summarizes this relationship.

Proposition 2. *The counter-espionage effort exerted by the government of C in the equilibrium of $G^b(e, c)$, c^*, is decreasing with the initial level of market competition (defined by the initial number n of C's firms operating in the market).*

Proof. It follows from Proposition 1, according to which $c^* = \overline{c}$ where $\overline{c}$ is given by (24), and the fact that the degree in n of the polynomial $8b^2(1+n)^2(2+n)^4$ is higher than the degree in n of $a^4(-1+2n(1+n))$. □

According to Proposition 2, regardless of the parameters a and b defining the demand in the market, the higher the initial number, n, of firms competing in it, the lower the effort exerted by the government of C in the counter-espionage policy. As the following discussion shows, the effect of the success of F's espionage activities (and the participation of its firm in the market) on the aggregate welfare of C's participants, for the different initial levels of market competition, is behind this result.

Let ΔCS^b be the variation in the surplus of C's consumers, ΔSS^{Cb} be the variation in the surplus of C's firms and $\Delta W^b = \Delta CS^b + \Delta SS^{Cb}$ be the variation in the aggregate welfare of C's market participants due to the success of F's espionage activities in $G^b(e, c)$. By substituting $m = 1$ in (13), given that in this benchmark case all the consumers are from C ($\alpha = 1$), it is clear that ΔCS^b, although always strictly positive, exhibits decreasing returns with respect to the initial level of market competition. This reflects that, the higher the initial number of C's firms competing in the market, the lower the marginal impact of F's firm participation on market price and quantities sold of the product. Moreover, it is also clear that by substituting $m = 1$ in (14) ΔSS^{Cb} shows the diametrically opposite behavior. Not only is it always strictly negative but it also exhibits increasing returns with respect to the initial level of market competition. These increasing returns reflect that the higher the initial number of C's firms competing in the market, the smaller the market price and the quantity sold by each of them prior to F's firm participation in it and, therefore, the lower its negative marginal impact.

If ΔW^b is considered, obtained by substituting $\alpha = 1$ and $m = 1$ in (15), it is clear that this total variation in welfare is always strictly negative (as stated in Subsection 4.2, and in accordance with Lemma 3) but is increasing with respect to the initial level of market competition. This means that, in $G^b(e, c)$, the effect of F's firm participation in the market on the surplus of C's domestic firms dominates its effect on consumers' surplus. More precisely, the increase in the latter does not compensate the negative effect for domestic firms implied by the reduction in market price and in the quantity of product sold by each of them. This negative net variation in the aggregate welfare of C's participants in the market regardless of its initial level of competition is behind the fact that the equilibrium effort exerted by C in the counter-espionage policy is always strictly positive. Nevertheless, given that this net reduction in welfare is smaller the higher the initial level of market competition, the optimal counter-espionage effort in equilibrium is also decreasing with the initial number of C's firms competing in the market.

Moreover, although C wants to avoid this reduction in welfare, according to Proposition 1 and as stated in the previous section, a scenario in which C exerts the maximum effort in its counter-espionage policy is not stable. Following Proposition 2, this would only be possible in the case that the market is intially dominated by a monopoly ($n = 1$). However, even in this case, the best for F, when the counter-espionage policy prevents for sure the acquisition of the information required to replicate the secret technology, is to conduct no espionage activity and, consequently, C would be better off deploying no counter-espionage policy, as explained in the previous section.

These dynamics in the aggregate welfare of C's market participants explains that the equilibrium effort exerted by C in the counter-espionage policy is decreasing with the initial level of market competition even in cases in which the equilibrium espionage effort exerted by F is not. In order to shed more light on this result, let us discuss the implications of the behavior of C's and F's best-response functions, given by (22) and (23), when this initial level of competition increases. It is clear that, according to these best-response functions, an increase in the initial level of competition implies that both C and F are better off reducing their levels of effort for a given effort of the rival. On the one hand, in the case of C, this reduction in the effort exerted in the counter-espionage policy is a reflection of the weakening effect, discussed above, of competition on the decrease in the aggregate welfare of C's market participants that would imply F's firm participation in the market. On the other hand, the higher the initial number of firms operating in the market, the smaller the profits F's firm obtains from participating in it, and therefore, F is better off reducing the effort in espionage.

Consequently, given the strategic asymmetry between C and F implied by their best-response functions and mentioned in Subsection 4.3, an increase in the initial level of competition would imply a reduction in the equilibrium effort exerted by C in its counter-espionage policy, as shown by Proposition 2. However, the implication is not the same for the espionage effort exerted by F in the new equilibrium. In fact, given this strategic asymmetry, this equilibrium espionage effort can be higher, smaller or equal to the one exerted with a smaller level of competition. This depends on whether, due to an increase in the initial level of competition, the reduction in the espionage effort exerted by F, given the counter-espionage effort of C, is small or high in terms of the reduction in the counter-espionage effort exerted by C given F's espionage effort. Actually, this relationship between both reductions is also behind the degree of reduction in the equilibrium counter-espionage effort.

The discussion in the following subsection helps to explain the role of market demand in this relationship. Furthermore, it shows that, whereas the degree of reduction in the equilibrium counter-espionage effort due to an increase in the initial level of market competition is relatively steady, the behavior of the equilibrium espionage effort with respect to this level of competition is substantially complex.

6.2. The role of market demand

The objective of the analysis carried out in the present subsection is twofold. On the one hand, it deals with the behavior of F's equilibrium espionage effort with respect to the initial level of market competition and the influence of demand characteristics on it. And, on the other hand, this helps shed light on the degree of reduction in C's equilibrium counter-espionage effort due to an increase in this level of competition.

Let us first highlight the influence of price elasticity of demand (inversely related to parameter b in the model) on the relationship, discussed in the previous subsection, between the reductions in C's and F's levels of effort given the effort of the rival due to an increase in the initial level of market competition, focusing on how it determines the sign of the variation in the equilibrium espionage effort. Note that, given the strategic asymmetry between C and F, the important aspect in this relationship is whether the reduction in the espionage effort exerted by F given the counter-espionage effort of C is small or high in terms of the reduction in the counter-espionage effort exerted by C given F's espionage effort. Here, the role of price elasticity of demand in each reduction considered individually is behind its influence on their relationship.

In the case of C, the increase in the welfare of its domestic market participants due to a higher initial level of competition is potentiated by a sufficiently elastic demand (b relatively small). Note that both consumers' and suppliers' surpluses are decreasing in b (see Lemma 1), reflecting the fact that under a sufficiently elastic demand, the decrease in the market price due to a higher level of competition implies a proportionally higher increase in the quantities sold in the market. This potentiates the positive effect of a higher competition on consumers' surplus and reduces the decrease in the profits of the suppliers that were already in the market, weakening the negative effect of this higher competition on their surplus. Consequently, C will reduce the counter-espionage effort more if the market demand is sufficiently elastic enough than if it is not.

In the case of F, the reduction in its firm's profits from participating in the market due to a higher initial level of competition will be smaller under a sufficiently elastic demand than under a not so elastic one. The reason is the same as stated above: under a relatively elastic demand the decrease in the market price due to a higher level of competition implies a proportionally higher increase in the quantities sold in the market. Consequently, F will reduce the espionage effort less if the market demand is sufficiently elastic than if it is not.

Therefore, the influence of price elasticity of demand on the relationship between the reductions in C's and F's levels of effort, given the effort of the rival, due to an increase in the initial level of competition, and consequently on the sign of the variation in the equilibrium espionage effort, is clear. If the market demand is sufficiently elastic (b sufficiently small), the reduction in F's espionage effort given the counter-espionage effort exerted by C will be relatively small, in the sense that the necessary reduction in the counter-espionage effort in order for F to keep its previous equilibrium espionage effort is smaller than C's reduction in the counter-espionage effort given the previous equilibrium espionage effort. In this situation, the counter-espionage effort that C would exert in response to the previous equilibrium espionage under the higher initial level of competition is so low that F is better off increasing the espionage effort, and in the new equilibrium with a higher initial level of competition F will exert a higher espionage effort than before.

Thus, a sufficiently elastic demand can more than compensate for the negative effect of a higher initial level of competition in F's espionage effort. However, a sufficiently inelastic market demand potentiates this negative effect. In particular, if market demand is sufficiently inelastic (b sufficiently high) the reduction in F's espionage effort given the counter-espionage effort exerted by C will be relatively high, in the sense that the necessary reduction in the counter-espionage effort for F to keep its previous equilibrium espionage effort is higher than C's reduction in the counter-espionage effort given the previous equilibrium espionage effort. In this situation, under this relatively small reduction in C's counter-espionage effort in response to the previous equilibrium espionage given the higher initial level of competition, F is better off decreasing the espionage effort and, in the new equilibrium with a higher initial level of competition, F will exert a smaller espionage effort than before.

Therefore, in between these two characterizations, there exists an intermediate level of price elasticity of demand (an intermediate value of b) such that the reduction in F's espionage effort given the counter-espionage effort exerted by C will imply that the necessary reduction in the counter-espionage effort for F to keep its previous equilibrium espionage effort is exactly C's reduction in the counter-espionage effort given the previous equilibrium espionage effort. In other words, the previous equilibrium espionage effort is F's best response, under the higher initial level of competition, to C's counter-espionage effort in response to the previous equilibrium espionage given this higher initial level of competition. Consequently, in the equilibrium under a higher initial level of competition in a market characterized by this intermediate level of price elasticity, F will exert the same espionage effort as before.

The pair of initial number of C's firms competing in the market $\{y, z\}$, where $y, z \in \mathbb{Z}^+$ and $y < z$, considered to define the increase in the initial level of market competition, determines the threshold, in terms of the value of b and denoted by $\overline{b}_{y,z}$, to define the demand as sufficiently elastic/inelastic. More precisely, $\overline{b}_{y,z}$ is the value of b such that $e^*_y = e^*_z$, where e^*_y and e^*_z are, respectively, the equilibrium espionage efforts under the initial number y and z of C's firms competing in the market. The relationship among these thresholds $\overline{b}_{y,z}$, together with the above-discussed influence of price elasticity of demand, is behind the behavior of the equilibrium espionage effort with respect to the initial level of competition.

Note that, according to Proposition 1, the espionage effort exerted by F in equilibrium, e^*, satisfies $e^* = \overline{e}$, where $\overline{e}$ is given by (25). The proposition below summarizes the main aspects in the behavior of e^* with respect to the initial level of market competition, abstracting from some specific cases which are considered in more detail in the discussion that follows. According to the proof of the proposition (in the Appendix), the most relevant thresholds $\overline{b}_{y,z}$ for this behavior are the following (ordered from smallest to largest),

$$\overline{b}_{4,5} = \frac{\sqrt{109/26}}{210} a^2 \approx 0.009a^2, \quad \overline{b}_{1,2} = \frac{1}{24\sqrt{14}} a^2 \approx 0.011a^2,$$

$$\overline{b}_{3,4} = \frac{\sqrt{17/66}}{40} a^2 \approx 0.012a^2, \quad \overline{b}_{2,3} = \frac{\sqrt{17/2}}{180} a^2 \approx 0.016a^2.$$

Proposition 3. *Consider the espionage effort exerted by the government of F in the equilibrium of $G^b(e, c)$, e^*. The following are the main aspects in the behavior of e^* with respect to the initial level of market competition (defined by the initial number n of C's firms operating in the market).*

(1) Let $e^*_{\bar{n}}$ and $e^*_{\tilde{n}}$ be the equilibrium espionage efforts under the initial number of C's firms competing in the market $\bar{n}$ and $\tilde{n}$ respectively, where $\bar{n} < \tilde{n}$. Given $a, b > 0$, $\exists n^*$, $n^* \leq \bar{n}$, such that $e^*_{\bar{n}} > e^*_{\tilde{n}}$ for all $\bar{n} \in [n^*, \tilde{n}[$.

(2) n^* *is decreasing in* b.

(3) If $0 < b < \bar{b}_{1,2}$*, then* $n^* \geq 4$ *and* e^* *increases with* n *for* $1 \leq n < n^*$ *and decreases for* $n > n^*$.

(4) If $\bar{b}_{1,2} < b < \bar{b}_{2,3}$*, then* $n^* \in \{3, 4\}$*, and* e^*

(4.1) decreases from $n = 1$ *to* $n = 2$,

(4.2) increases from $n = 2$ *to* $n = n^*$*, and*

(4.3) decreases for $n > n^*$.

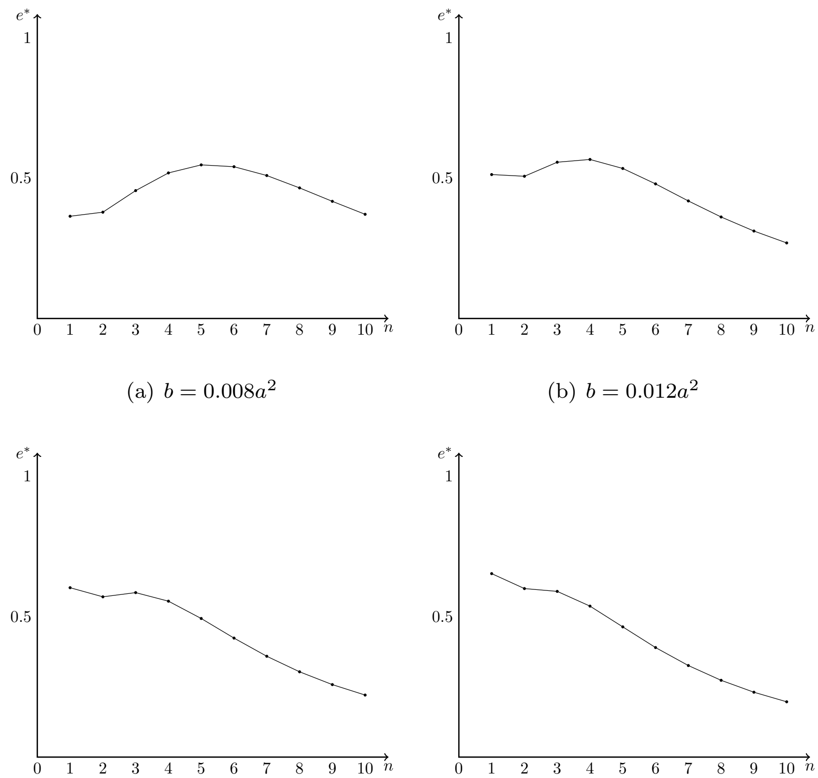
(5) If $b > \bar{b}_{2,3}$*, then* $n^* = 1$ *and* e^* *decreases with* n *for all* $n \in \mathbb{Z}^+$.

Proof. See Appendix □

Figure 4 depicts the behavior of the espionage effort exerted by F in equilibrium summarized in Proposition 3 through four representative particular cases in terms of parameter b and for the competitive intensities defined by $n \in \{1, \ldots, 10\}$. Although $n \in \mathbb{Z}^+$ and e^* is a discrete function, by using a straight line to connect the plotted points, it is easier to show its behavior with respect to the initial level of market competition.

According to part (1) of Proposition 3 and as shown in Figure 4, regardless of how high elasticity of demand is, there always exists a critical initial number n^* of C's firms competing in the market from which the equilibrium espionage effort e^* is non-increasing[28] with the initial level of market of competition. In order to understand this, it is important to remember the two relevant implications of $G^b(e, c)$ stated at the end of Subsection 4.2. According to these implications, given the characteristics of market demand, the larger the initial number of C's firms in the market, the smaller both the increase in the aggregate welfare of C's market participants and the decrease in the profits of F's firm from participating in it due to a higher initial level of competition and, therefore, the smaller the reductions will be in the efforts exerted by C and F given the effort of the rival.

[28]As shown in the present discussion, it is not strictly decreasing only in one particular case.



(a) $b = 0.008a^2$ (b) $b = 0.012a^2$

(c) $b = 0.015a^2$ (d) $b = 0.017a^2$

Figure 4: Four representative particular cases of the behavior of e^*

Following the discussion above regarding the influence of elasticity of demand, the implication is that the decreasing behavior of e^* for $n \geq n^*$ reflects that there always exists some initial number n^* of C's firms in the market such that, no matter how elastic the demand is, the reduction in C's effort due to an increase in the initial level of competition is never high relative to the reduction in F's effort. In other words, a critical initial number n^* of firms exists such that there is no sufficiently elastic demand which more than compensates[29] the negative effect of a higher initial level of competition in F's espionage effort.

[29]In the sense considered when discussing above the influence of price elasticity of demand.

More technically, no matter how small and close to zero b is, no pair of initial number of firms $\{\bar{n}, \tilde{n}\}$ exists, where $n^* \leq \bar{n} < \tilde{n}$, such that, according to its corresponding threshold $\overline{b}_{\bar{n},\tilde{n}}$, the demand can be considered sufficiently elastic (that is, there is no $\overline{b}_{\bar{n},\tilde{n}}$ such that $b < \overline{b}_{\bar{n},\tilde{n}}$).

Therefore, and coherently with the influence of elasticity of demand discussed above, the behavior of e^* with respect to the initial level of competition for $1 \leq n < n^*$ is not necessarily decreasing. Moreover, as shown by Figure 4, when the elasticity of demand increases, this behavior becomes strictly increasing at the same time as n^* becomes larger (as according to part (2) of Proposition 3). The reason for this is that the smaller b and the closer it is to zero, the more thresholds there are associated with pairs of initial number of firms with respect to which the demand is sufficiently elastic. As stated by part (3) of Proposition 3, when the demand is elastic enough ($0 < b < \overline{b}_{1,2}$), the critical number of firms n^* is relatively high and e^* is strictly increasing for $1 \leq n < n^*$. Namely, there is no pair of initial number of firms in $[1, n^*]$ such that, according to its corresponding threshold, the demand can be considered sufficiently inelastic.

Consistent with this, $\overline{b}_{1,2} < \overline{b}_{3,4} < \overline{b}_{2,3}$ as stated above, and therefore $n^* > 3$ when $0 < b < \overline{b}_{1,2}$. More precisely, given that $\overline{b}_{4,5} < \overline{b}_{1,2}$, $n^* = 4$ when $\overline{b}_{4,5} < b < \overline{b}_{1,2}$ and, coherently with the increasing behavior of n^* with respect to price elasticity of demand, $n^* > 4$ when $0 < b < \overline{b}_{4,5}$ (a particular example of this last case is represented by Figure 4(a)). The particularity of the case $b = \overline{b}_{4,5}$ is that $e_4^* = e_5^*$, representing an example of the intermediate level of price elasticity of demand discussed above. Note that another example of this is represented by the case $b = \overline{b}_{1,2}$, the only particularity of which, with respect to the considerations in the case $0 < b < \overline{b}_{1,2}$, is that $e_1^* = e_2^*$.

In line with the above reasoning, the higher b is (the smaller the price elasticity of demand) the less thresholds exist associated with pairs of initial number of firms with respect to which the demand is sufficiently elastic, and therefore, the smaller the critical number of firms n^*, as stated by part (2) of Proposition 3. Moreover, according to part (5) of the proposition, there exists a low enough elasticity of demand ($b > \overline{b}_{2,3}$) such that there is no threshold with respect to which the demand can be considered sufficiently elastic. Consequently, $n^* = 1$ and e^* decreases with the initial level of market competition regardless of the initial number of firms competing in the market (Figure 4(d) represents a particular example of this case). Note that the particularity of the case $b = \bar{b}_{2,3}$ with respect to these considerations in the case $b > \bar{b}_{2,3}$ is that $e_2^* = e_3^*$.

When the level of price elasticity of demand is in between the above two extreme cases, $\bar{b}_{1,2} < b < \bar{b}_{2,3}$, the behavior of e^* for $1 \leq n < n^*$, as stated by part (4) of Proposition 3, is not as stable as when $0 < b < \bar{b}_{1,2}$. The reason behind this is that, although the equilibrium espionage effort still increases from $n = 2$ to $n = 3$ under this level of price elasticity, the demand is not sufficiently elastic relative to the pair of initial number of firms $\{1, 2\}$ and it decreases from $n = 1$ to $n = 2$. Regarding the critical number of firms in this case, $n^* \in \{3, 4\}$ since $\bar{b}_{4,5} < \bar{b}_{1,2}$ and $\bar{b}_{3,4} \in]\bar{b}_{1,2}, \bar{b}_{2,3}[$. More precisely, when $\bar{b}_{1,2} < b < \bar{b}_{3,4}$, $n^* = 4$ and e^* increases from $n = 3$ to $n^* = 4$. However, $n^* = 3$ when $\bar{b}_{3,4} < b < \bar{b}_{2,3}$, which is consistent with the decreasing behavior of n^* with respect to b. Figures 4(b) and (c) represent, respectively, concrete examples of these two cases. Note that the only particularity of the case $b = \bar{b}_{3,4}$ is that $e_3^* = e_4^*$.

The influence of market's willingness to pay for the product, represented by parameter a, comes through in its effect on the most relevant thresholds considered above for the behavior of the equilibrium espionage effort with respect to the initial level of competition. It is clear that they are similarly increasing in a, which means that the higher a, the broader the spectrum of values of b for which the demand is considered sufficiently elastic according to these thresholds. This reflects the positive effect of a higher willingness to pay on both the welfare generated by the market to C's domestic participants and the profits F's firm will obtain from participating in it.

Following on from the discussion above, the most important implications of a higher willingness to pay are twofold. On the one hand, there is a broader spectrum of demand elasticities for which there exists a non-empty range of initial number of firms in which the equilibrium espionage effort is strictly increasing with the initial level of competition. On the other hand, it becomes harder to consider the demand as sufficiently inelastic such that the equilibrium espionage becomes strictly decreasing for every intial number of firms in the market.

Finally, let us examine the influence of market demand characteristics on the degree of reduction in the equilibrium counter-espionage effort under an increase in the initial level of market competition. As stated in the previous subsection, given the strategic asymmetry between C and F, the relationship between the reductions in C's and F's levels of effort given the effort of the rival is also behind the degree of reduction in the equilibrium counter-espionage effort due to an increase in the initial level of market competition. Furthermore, as explained at the beginning of the present subsection, price elasticity of demand influences this relationship and, therefore, the sign of the variation in the equilibrium espionage effort. In particular, if the demand is sufficiently inelastic (elastic), the reduction in C's counter-espionage effort is small (high) relative to F's reduction, and F is better off decreasing (increasing) its effort leading to a smaller (higher) espionage effort in equilibrium.

However, note that C's reaction to this behavior of F goes in the same direction, since C regards F's effort as a strategic complement, diluting the influence of price elasticity on the degree of reduction in the equilibrium counter-espionage effort. Moreover, if the level of demand elasticity is intermediate in the sense that the previous equilibrium espionage effort is F's best response under C's reduction in its counter-espionage effort, the latter has no incentive to change its effort. Consequently, given that market's willingness to pay influences when considering the demand as sufficiently elastic or inelastic, the strategic asymmetry between C and F implies that the degree of reduction in the equilibrium counter-espionage effort due to an increase in the initial level of competition is more or less stable regardless of the characteristics of market demand.

7. Conclusions and lines for future research

The governments of advanced economies are concerned about the recent significant negative impact economic espionage is having on their economies recently. In retaliation, they are increasing their efforts to counter such economic espionage, a move which is quickly becoming one of their priorities. The present paper attempts to advance the scarce theoretical literature analyzing the interaction between economic espionage and counter-espionage. The analysis carried out and the results obtained represent a first approximation towards the rationale for the effect of market level of competition on the dynamics of this interaction. Given that countries establish counter-espionage measures for their entire economy (characterized by the interrelation of markets), the general model proposed in the present paper considers that the economy of the country countering espionage consists of one market although open to international trade.

This study assumes that the product commercialized in this international market is initially supplied only by firms from this country (C), while other firms from a foreign country (F) are interested in participating in this market by supplying the product from their country, although a secret technology is needed for such participation. In this context, the government of F decides what effort to exert in espionage activities in an attempt to acquire the necessary information to replicate this technology, taking into account that the probability of acquiring it also depends on the counter-espionage policy that might be deployed by the government of C. At the same time, considering this possibility of economic espionage and knowing that the participation of F's firms in the market is harmful for the aggregate welfare of C's market participants, the government of C decides what effort to exert in deploying a counter-espionage policy (considered in its role as market entry barrier), taking into account that the failure of economic espionage activities also depends on the unobservable effort exerted in them.

With the aim of highlighting the most elemental effect of the initial level of market competition on the dynamics of this interaction, the analysis carried out in the present paper focuses on a benchmark case in which the product is only demanded by C's consumers and there is only one F's firm willing to participate in the market. By using this benchmark case the complexity implied by the possible negative effect of the initial level of competition on the aggregate welfare of C's market participants can be avoided. Moreover, both F and C are considered sufficiently efficient in exerting their respective espionage and counter-espionage efforts. However, despite the relative simplicity of the benchmark case, the results obtained from its analysis suggest that the most elemental effect mentioned above is characterized by a non-trivial relationship between economic espionage and the initial level of competition.

Furthermore, the price elasticity of demand is shown to play an important role in this relationship, influenced by the market's willingness to pay for the product and contingent to the initial number of firms in the market. Specifically, this relationship is defined by the existence of a critical initial number of firms in the market, which decreases together with elasticity of demand, from which the espionage effort is decreasing with the initial level of competition. If the elasticity of demand is low enough, the espionage effort is decreasing regardless of the initial number of firms competing in the market. However, when the elasticity of demand increases, the critical number of firms becomes larger and the behavior of the espionage effort, for competitive intensities lower than the one defined by this critical number of firms, is not necessarily decreasing, becoming strictly increasing when demand elasticity is high enough. The effort exerted in the counter-espionage policy is always strictly positive but smaller than the maximum (as the espionage effort) and decreasing with the initial level of market competition regardless of this complex behavior of the espionage effort and the characteristics of market demand.

These interesting results obtained from analysis of the benchmark case also serve as a baseline for future research dealing with the analysis of the general model. Such an analysis, on the one hand, could show the effect of the international fragmentation of demand and the number of foreign firms willing to participate in the market on these results. On the other hand, considering the initial level of market competition as given, it will enable the study of the effect of this number of foreign firms on the dynamics of the interaction between economic espionage and counter-espionage and, therefore, how this effect is influenced by the international fragmentation of demand and the initial level of market competition. Moreover, analysis of the general model will allow the influence of such fragmentation of demand on the dynamics of this interaction to be studied under joint variations in the initial level of competition in the market and the number of foreign firms willing to participate in it.

As mentioned above, counter-espionage measures are established for the entire country's economy, in which different markets are interrelated. The general model, and therefore the benchmark case, proposed in the present paper allows to isolate the effect of the level of competition in a particular spied market on the effort exerted in a country's counter-espionage policy. However, the potential use of the results provided by the present paper to empirically evaluate the evolution of the resources devoted by a country (such as, for instance, the United States) to their counter-espionage policy is not straightforward, given that other factors apart from the level of competition in the market being spied on (for example, a pharmaceutical market in the case of the United States, as mentioned in the Introduction) might be influencing that evolution.

Moreover, on the one hand, this effect of the level of competition in a particular market being spied on as considered in the present paper is very specific since the general model focuses on counter-espionage policy in its role of protecting market welfare and, therefore, such effect comes through in the impact of competition on this welfare. On the other hand, as mentioned above, in the analyzed benchmark case the initial level of market competition always has a positive effect on the aggregate welfare of C's market participants. But, as pointed out by the theoretical literature studying the desirability of market entry regulation briefly presented in Section 2, there are market circumstances under which competition might not have such a positive effect. In this sense, the analysis of the general model considered above (which contemplates cases in which the aggregate welfare of C's participants in the market decreases with its initial level of competition) would also move the analysis of counter-espionage even closer to this strand of research.

Nevertheless, evaluation according to theoretical results, such as the ones obtained in this paper, of the increase in the efforts exerted by governments of advanced economies in their counter-espionage policies in recent years is a very interesting line for future research, contributing to the empirical analysis of economic espionage topics (see recent contibutions by Glitz and Meyersson, 2020). In this sense, more theoretical research is needed in addition to analysis of the general model proposed in the present paper which, taking into account that a counter-espionage policy also includes penalty-enhancing measures, could be extended in different ways. For instance, it could be extended to a general equilibrium framework considering the markets related to the value chain of the product commercialized in the market being spied on. Furthermore, a general equilibrium framework could be employed to capture the economy-wide nature of a country's counter-espionage measures. Future theoretical research can also study in detail the complexities and implications of considering that the effectiveness of both espionage and counter-espionage activities may depend not only on the efforts exerted in them (as assumed in the present paper), but also on the initial number of firms in the market being spied on (in the sense that information about the secret technology may be obtained more easily the higher this number of firms is).

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Appendix

Proof of Lemma 1: Under the characterization of the international market and the aspects related to the product value chain in $G(e,c)$ (see Section 3 in the main text), it can be shown that market equilibrium in *Scenario 1* is defined by

$$p^* = \frac{a}{(n+1)} \tag{A1}$$

$$q_i^* = \frac{a}{(n+1)b}$$

$$Q^* = \frac{na}{(n+1)b} \tag{A2}$$

Let us denote by Π_n^* the equilibrium profit of each firm in this scenario in which only the n firms of C are competing in the market. Such equilibrium profit is given by

$$\Pi_n^* = \frac{a^2}{(n+1)^2 b} \tag{A3}$$

Given that production and export costs are assumed to be zero, the sum of the n equilibrium profits coincides with the suppliers' surplus of the C's domestic firms (SS_n). With respect to the surplus of all the consumers in the international market in this first scenario (CS_n), it is easily obtained from the market demand, defined by (1) in the main text, and the market price and quantity in equilibrium, given by (A1) and (A2), respectively.

The equilibrium analysis of *Scenario 2* and the derivation of the surpluses generated by the market to its participants in this scenario follow immediately from the previous analysis of *Scenario 1* since product expenses for F's firms are also assumed to be zero. Taking into account that there are $n+m$ firms competing in the international market in *Scenario 2*, the equilibrium profit of each firm is easily obtained by substituting n for $n+m$ in (A3):

$$\Pi_{n+m}^* = \frac{a^2}{(n+m+1)^2 b}$$

The surplus obtained by F's firms from participating in the market (SS_{n+m}^F) is the sum of their m individual equilibrium profits given the assumption that their expenses related to the product value chain are equal to zero. With respect to the suppliers' surplus of C's domestic firms in this second scenario (SS_{n+m}^C), as in *Scenario 1*, this is the sum of their n individual equilibrium profits. Finally, the surplus of all the consumers in the international market (CS_{n+m}) can be easily obtained by substituting n for $n+m$ in CS_n, previously derived. □

Proof of Lemma 2: With respect to U_F, this takes into account, on the one hand, that F's firms obtain zero surplus with probability $1-e+ec$, the occurrence probability of *Scenario 1*. Nevertheless, F's consumers, representing the proportion β of the whole demand in the international market, obtain a surplus equal to βCS_n, where CS_n is given by (3) in the main text, in this *Scenario 1*.[30] On the other hand, U_F also takes into account the surplus obtained by F's firms and consumers in *Scenario 2*, which happens with probability $e(1-c)$. The surplus of the m firms from F is SS^F_{n+m}, which is given by (4), and F's consumers obtain the surplus βCS_{n+m}, where CS_{n+m} is given by (6). Therefore:

$$U_F = (1-e+ec)\,\beta CS_n + e(1-c)\left(SS^F_{n+m} + \beta CS_{n+m}\right) - e^2$$

Note that the last element, e^2, is the cost of espionage effort. Equivalently:

$$U_F = (1-e+ec)\,\frac{\beta}{2b}\left(\frac{na}{n+1}\right)^2 + e(1-c)\frac{\left(2m+\beta(n+m)^2\right)a^2}{2\left(n+m+1\right)^2 b} - e^2$$

Regarding U_C, this takes into account the surplus obtained by C's consumers, who represent the proportion α of the whole demand in the international market, and the surplus of the n firms from C in these two possible scenarios with their respective occurrence probabilities. Specifically:

$$U_C = (1-e+ec)\left(SS_n + \alpha CS_n\right) + e(1-c)\left(SS^C_{n+m} + \alpha CS_{n+m}\right) - c^2 \quad \text{(A4)}$$

where the last element, c^2, is the cost of counter-espionage effort. Substituting in (A4), on the one hand, SS_n and CS_n by their expressions given by (2) and (3) respectively in the main text, and on the other hand, SS^C_{n+m} and CS_{n+m} by (5) and (6), respectively, also in the main text and simplifying we have:

$$U_C = (1-e+ec)\,\frac{na^2(\alpha n+2)}{2(n+1)^2 b} + e(1-c)\frac{\left(2n+\alpha(n+m)^2\right)a^2}{2(n+m+1)^2 b} - c^2$$

[30] Note that this way of obtaining the surplus of consumers from a particular country (in this case F) directly follows from the assumption of the general model according to which all the consumers in the international market have identical preferences (see Section 3 in the main text).

□

Proof of Lemma 3: On the one hand, note that $\bar{\alpha} \in]0,1[$ for all $n \geq 1$, and $\bar{m} > 1$ for all $\alpha \in [0,1]$ and $n \geq 1$. On the other hand, since the denominator in (15), in the main text, is strictly positive for all $n, m \geq 1$ and $b > 0$, the sign of ΔW depends only on its numerator. Therefore, given that $(4-2\alpha)n(n+1)m > 0$ for all $\alpha \in [0,1]$ and $n, m \geq 1$, $(1+2n)\alpha - 2n > 0$ and $\Delta W \geq 0$ only if $\alpha \in]\bar{\alpha}, 1]$ and $m \geq \bar{m}$. □

Proof of Lemma 4: Part (1) of the lemma is straightforward first plugging (21) into (20) in the main text and solving for c, obtaining as a result $\bar{c}$ and then substituting $\bar{c}$ into (21).

With respect to part (2) of the lemma, the proof of $\bar{c} \in]0,1[$ immediately follows from the fact that:

$$a^4(-1 + 2n(1+n)) > 0$$

and

$$8b^2(1+n)^2(2+n)^4 > 0$$

for all $n \in \mathbb{Z}^+$ and $a, b > 0$.

Similarly, it can be easily proved that $\bar{e} > 0$ given that both the numerator and the denominator in (25), in the main text, are strictly positive for all $n \in \mathbb{Z}^+$ and $a, b > 0$. However, the proof of $\bar{e} < 1$ is not that straightforward.

Note that, according to (25), $\bar{e} \leq 1$ is equivalent to:

$$-8b^2(1+n)^2(2+n)^4 + 4a^2b(1+n)^2(2+n)^2 - a^4(-1 + 2n(1+n)) \leq 0$$

which is a quadratic inequality with respect to parameter b. Let us redefine the quadratic equation in the last inequality as follows:

$$\pi b^2 + \lambda b + \sigma \tag{A5}$$

where

$$\pi = -8(1+n)^2(2+n)^4 < 0$$

$$\lambda = 4a^2(1+n)^2(2+n)^2 > 0$$

$$\sigma = -a^4(-1 + 2n(1 + n)) < 0$$

for all $n \geq 1$ and $a > 0$. It can be shown that (A5) has no real root given that $\lambda^2 - 4\pi\sigma < 0$ for all $n \in \mathbb{Z}^+$ and $a > 0$. More precisely:

$$\lambda^2 - 4\pi\sigma < 0$$

$$\left(4a^2(1+n)^2(2+n)^2\right)^2 - 4\left(8(1+n)^2(2+n)^4\right)\left(a^4(-1+2n(1+n))\right) < 0$$

which is equivalent to:

$$16a^4(1+n)^4(2+n)^4 < 32\left((1+n)^2(2+n)^4\right)\left(a^4(-1+2n(1+n))\right)$$

$$(1+n)^2 < 2\left(-1+2n(1+n)\right)$$

$$-3n^2 - 2n + 3 < 0$$

which is satisfied for all $n \in \mathbb{Z}^+$.

Therefore, (A5) is always negative since its quadratic coefficient, π, is negative. And this implies that $\bar{e}$, as defined by (25), is strictly smaller than 1 for all $n \in \mathbb{Z}^+$ and $a, b > 0$. □

Proof of Lemma 5: In the first market characterization ($0 < a \leq \bar{a}_1$), in which $\delta \leq 0$ and $\gamma > 1$, the proof is straightforward.

In the second market characterization ($\bar{a}_1 < a \leq \bar{a}_2$), in which $0 < \delta < 1$ and $\gamma \geq 1$, the proof follows from the fact that the intersection of both best-response functions would not be given by the intersection of $\bar{c}(e)$ and $\bar{e}(c)$ only if $\bar{e} \geq 1$, which is a contradiction according to the second part of Lemma 4.

Finally, in the third market characterization ($a > \bar{a}_2$), $0 < \delta < 1$ and $0 < \gamma < 1$. Therefore, the intersection of both best-response functions would not be given by the intersection of $\bar{c}(e)$ and $\bar{e}(c)$ only if $\bar{c} > 1$, which is also a contradiction according to the second part of Lemma 4. □

Proof of Proposition 3: Part (1) of the proposition immediately follows from, on the one hand, the fact that F's equilibrium espionage effort, e^*, satisfies $e^* = \bar{e} > 0$ (where $\bar{e}$ is given by (25) in the main text) for all $n \in \mathbb{Z}^+$ and $a, b > 0$ (see part (2) of Lemma 4 and Proposition 1), and on the other hand, $e^* \to 0$ when $n \to \infty$.

Next, parts (2)-(5) of the proposition are jointly proven. First of all, given that $n \in \mathbb{Z}^+$ and in order to better understand the behavior of e^* with respect to the initial level of market competition (defined by the initial number n of firms in the market), let us make a change of variable and define the following positive, continuous and differentiable function by substituting n for $x \in [1, \infty[$ in (25):

$$e(x) = \frac{4(1+x)^2(2+x)^2}{8\eta(1+x)^2(2+x)^4 + \frac{1}{\eta}(-1+2x(1+x))} \tag{A6}$$

where $\eta = b/a^2$. Let κ be the number of critical points of this function $e(x)$ given by (A6) and with domain $[1, \infty[$, and consider the following lemma.

Lemma A1. *(1) There exists some $x^* \geq 1$ from which $e(x)$ is strictly decreasing in x.*

(2) Counted with multiplicity, $\kappa \in \{0, \ldots, 7\}$. However, if $\kappa \neq 0$, no critical point of $e(x)$ can be obtained analytically.

Proof. Part (1) of the lemma directly follows from part (1) of the proposition and the fact that $e(x)$ comes from substituting $n \in \mathbb{Z}^+$ for $x \in [1, \infty[$ in e^*.

With respect to part (2) of the lemma, it is relatively easy to show that the first derivative of $e(x)$ is given by

$$e'(x) = -\frac{8\eta(1+x)(2+x)\left(5 + 8\eta^2(1+x)^3(2+x)^4 + x\left(3 - x(3+2x)\right)\right)}{\left(-1 + 2x(1+x) + 8\eta^2(1+x)^2(2+x)^4\right)^2}$$

Therefore, the κ critical points of $e(x)$ are given by the real roots of:

$$5 + 8\eta^2(1+x)^3(2+x)^4 + x\left(3 - x(3+2x)\right) = 0 \tag{A7}$$

belonging to the domain of $e(x)$, $[1, \infty[$.

Note first that, according to basic Algebra, no real root of a polynomial of degree higher than five, as the one given by (A7), can be obtained analytically.

Assuming next that $x \in \mathbb{R}$, then, according to the Fundamental Theorem of Algebra, the polynomial given by (A7) would have, counted with multiplicity, seven roots and, since (A7) has real coefficients and odd degree, at least one root is real. This, together with the fact that the domain of $e(x)$ is $[1, \infty[$, directly leads to $\kappa \in \{0, \dots, 7\}$. □

Lemma A1 directly leads to the following corollary.

Corollary A1. *Consider the function $e(x)$ given by (A6).*

(1) Suppose that $\kappa \in \{1, \dots, 7\}$ and let $\bar{x}^*$ and $\tilde{x}^*$ be the smallest and the largest critical points of $e(x)$ respectively. Consider that $\tilde{x}^* > 1$, which includes the case in which $\kappa = 1$ and $\tilde{x}^* > 1$. Then,

(1.1) following part (1) of Lemma A1, $x^* = \tilde{x}^*$ and $e(x)$ is decreasing for $x \in]\tilde{x}^*, \infty[$;

(1.2) following part (2) of Lemma A1, it is not possible to know analytically whether a particular critical point of $e(x)$ is a maximum, a minimum or an inflection point, and therefore, the behavior of $e(x)$ for $x \in [1, \tilde{x}^*[$ cannot be analytically characterized.

(2) Suppose that $\kappa = 1$ and $\tilde{x}^* = 1$, then following part (1) of Lemma A1 $x^* = 1$ and $e(x)$ is decreasing for all $x \in [1, \infty[$. This is also the case if it is assumed that $\kappa = 0$.

The analytical intractability of $e(x)$ highlighted by part (2) of Lemma A1 and part (1.2) of Corollary A1 forces us to study it numerically. The following figure shows the results of such a study through a geometrical succession of parameters $\eta_j = 1/10^j$, where $j \in \{0, \dots, 100\}$.

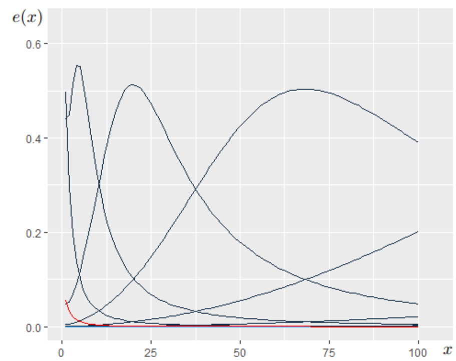

Figure A1: Numerical study of $e(x)$

In particular, Figure A1 depicts the behavior of $e(x)$ for different values of η, showing that the local maximum of $e(x)$ moves to the left as η increases. But this is only one aspect of the results obtained from the numerical study of $e(x)$. The following corollary summarizes more precisely its most relevant conclusions.

Corollary A2. *Consider the function* $e(x)$ *given by (A6) and let* $\bar{\eta} \in]0.17, 0.18[$.

(1) If $0 < \eta < \bar{\eta}$, $\kappa = 2$. *More precisely,*

(1.1) $\bar{x}^*$ *is a local minimum of* $e(x)$, $\bar{x}^* \in]1, 2[$ *and it is increasing in* η*;*

(1.2) $\tilde{x}^*$ *is a local maximum of* $e(x)$ *and it is decreasing in* η*, in particular* $\tilde{x}^* \to \infty$ *when* $\eta \to 0$*. Moreover,* $\tilde{x}^* \in]2, 3[$ *when* $\eta \in]0.16, \bar{\eta}[$.

Then, following part (1.1) of Corollary A1, when $0 < \eta < \bar{\eta}$, $x^* = \tilde{x}^*$ *and* $e(x)$ *is decreasing for* $x \in]\tilde{x}^*, \infty[$.

(2) If $\eta > \bar{\eta}$, $\kappa = 0$ *and therefore, following part (2) of Corollary A1,* $x^* = 1$ *and* $e(x)$ *is decreasing for all* $x \in [1, \infty[$.

The following claim is required in order to use Corollary A2 to study the behavior of e^* with respect to $n \in \mathbb{Z}^+$.

Claim A1. *Let* e^*_ν *be the equilibrium espionage effort under the initial number* ν *of C's firms operating in the market, where* $\nu \in \{1, 2, 3, 4, 5\}$*. Then,*

(1) $e^*_1 \leq e^*_2$ *only if* $\eta \leq \frac{1}{24\sqrt{14}} \equiv \bar{\eta}_{1,2} \approx 0.011$.

(2) $e_2^* \leq e_3^*$ *only if* $\eta \leq \frac{\sqrt{17/2}}{180} \equiv \overline{\eta}_{2,3} \approx 0.016$.

(3) $e_3^* \leq e_4^*$ *only if* $\eta \leq \frac{\sqrt{17/66}}{40} \equiv \overline{\eta}_{3,4} \approx 0.012$.

(4) $e_4^* \leq e_5^*$ *only if* $\eta \leq \frac{\sqrt{109/26}}{210} \equiv \overline{\eta}_{4,5} \approx 0.009$.

Proof. Straightforward □

Given that $e(x)$ comes from substituting $n \in \mathbb{Z}^+$ for $x \in [1, \infty[$ in e^*, Corollary A2 together with Claim A1 allows characterization of the behavior of e^* with respect to $n \in \mathbb{Z}^+$. Since according to Corollary A2 $\bar{\eta} > \overline{\eta}_{2,3}$, and given the behavior of $e(x)$ summarized in this corollary and the relationship among the thresholds stated in Claim A1, such characterization must be done analyzing the following relevant cases.

Case 1: Consider the case in which $0 < \eta \leq \overline{\eta}_{1,2}$. Note that when $0 < \eta < \overline{\eta}_{1,2}$, according to part (1) of Claim A1, $e_1^* < e_2^*$. Consequently, on the one hand, the local minimum of $e(x)$, $\bar{x}^* \in]1, 2[$ (see part (1.1) of Corollary A2), is not relevant for e^* since $n \in \mathbb{Z}^+$. On the other hand, given that $e(x)$ is increasing for $x \in]\bar{x}^*, \tilde{x}^*[$ (as implied by part (1) of Corollary A2) and following part (1) of the proposition, e^* increases with n for $1 \leq n < n^*$ and decreases for $n > n^*$, where n^* is relatively close to the local maximum of $e(x)$, $\tilde{x}^*$, which is decreasing in η (see part (1.2) of Corollary A2).

In particular, note that, according to part (3) of Claim A1, $e_4^* > e_3^*$ in this case. Moreover, according to part (4) of Claim A1, if $\overline{\eta}_{4,5} < \eta \leq \overline{\eta}_{1,2}$, $e_4^* > e_5^*$ and therefore $n^* = 4$. If $0 < \eta < \overline{\eta}_{4,5}$, then $n^* > 4$. Note that the only particularity of the case $\eta = \overline{\eta}_{4,5}$ is that $e_4^* = e_5^*$, as implied by part (4) of Claim A1.

Finally, the only particularity of the case $\eta = \overline{\eta}_{1,2}$ with respect to these considerations is that $e_1^* = e_2^*$, as implied by part (1) of Claim A1.

Case 2: Consider the case in which $\overline{\eta}_{1,2} < \eta < \overline{\eta}_{2,3}$. In this case, according to parts (1) and (2) of Claim A1, $e_1^* > e_2^*$ and $e_2^* < e_3^*$. Therefore, given that $e(x)$ is decreasing for $x \in [1, \bar{x}^*[$ and increasing for $x \in]\bar{x}^*, \tilde{x}^*[$ (as implied by part (1) of Corollary A2), and following part (1) of the proposition, e^* decreases from $n = 1$ to $n = 2$, increases from $n = 2$ to $n = n^*$ and decreases for $n > n^*$, where n^* is relatively close to the local maximum of $e(x)$, $\tilde{x}^*$, which is decreasing in η (see part (1.2) of Corollary A2).

In particular, note that, according to part (4) of Claim A1, $e_4^* > e_5^*$ in this case. According to part (3) of Claim A1, if $\overline{\eta}_{1,2} < \eta < \overline{\eta}_{3,4}$, $e_3^* < e_4^*$ and therefore $n^* = 4$. If $\overline{\eta}_{3,4} < \eta < \overline{\eta}_{2,3}$, $e_3^* > e_4^*$ and then $n^* = 3$. Note that the only particularity of the case $\eta = \overline{\eta}_{3,4}$ is that $e_3^* = e_4^*$, as implied by part (3) of Claim A1.

Case 3: Consider the case in which $\overline{\eta}_{2,3} \leq \eta \leq \bar{\eta}$. Let us consider first the case $\overline{\eta}_{2,3} < \eta \leq \bar{\eta}$. Note that in this case, on the one hand, following part (1.2) of Corollary A2, the local maximum of $e(x)$ satisfies $\tilde{x}^* \in]2, 3[$, and on the other hand, according to part (2) of Claim A1, $e_2^* > e_3^*$. Therefore, the local maximum of $e(x)$ is not relevant for e^* since $n \in \mathbb{Z}^+$. This together with the fact that, according to part (1) of Claim A1, $e_1^* > e_2^*$ in this case and $e(x)$ decreases for $x > \tilde{x}^*$ (see part (1) of Corollary A2), implies that $n^* = 1$ and e^* decreases in n for all $n \in \mathbb{Z}^+$. Note that the only particularity of the case $\eta = \overline{\eta}_{2,3}$ with respect to these considerations is that $e_2^* = e_3^*$, as implied by part (2) of Claim A1.

Case 4: Consider the case in which $\eta > \bar{\eta}$. According to part (2) of Corollary A2, $e(x)$ is decreasing for all $x \in [1, \infty[$ and therefore $n^* = 1$ and e^* decreases in n for all $n \in \mathbb{Z}^+$.

The analysis of these four cases, together with the fact that $b = \eta a^2$, proves parts (2)-(5) of the proposition. $\square$