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Corporate espionage

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Corporate Espionage¹

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Abstract

We consider a multimarket framework where a set of firms compete on two interrelated oligopolistic markets. Prior to competing in these markets, firms can spy on others in order to increase the quality of their product. We characterize the equilibrium espionage networks and networks that maximize social welfare under the most interesting scenario of diseconomies of scope. We find that in some situations firms may refrain from spying even if it is costless. Moreover, even though spying leads to increased product quality, there exist situations where it is detrimental to both consumer welfare and social welfare.

JEL classification: C70; L13; L20.

Keywords: Oligopoly, Multimarket, Networks.

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Introduction

Firms routinely collect and make use of business information about their rivals. With increasing competition at the global level, modern firms keep tabs on each other by engaging in competitive intelligence gathering activities. Competitive intelligence is the name given to the systematic and ethical approach for gathering, analyzing and managing information that can affect a firm's plans, decisions and operations. In 2002 for instance, *Business Week* reported that 90% of large companies have competitive intelligence staff, and many large US firms spend more than \$1 million annually on competitive intelligence. Moreover, several major multinational firms like GM, Kodak and BP have their own separate competitive intelligence units.

Of course firms also spy on each through more nefarious means. For instance the American Society of Industrial Security (ASIS) released a survey stating that economic espionage grew by 323% between 1992 and 1996.⁵ In fact realizing the enormity of this problem, in 1996 the US Congress passed the *Economic Espionage Act*, and by 2005 the US Department of Justice was engaged in prosecuting 45 cases under this act. There are also instances where the distinction between legal and illegal intelligence gathering activities is blurred. Crane (2005, [6]) is an interesting study of three cases that virtually cross the realm of competitive intelligence to being illegal. Probably the most notorious case listed in this study is Proctor and Gamble's attempt to find out more about Unilever's hair care business by hunting through their garbage bins. In fact numerous such tales about business spooks and their sordid activities can be found in the popular press demonstrating that firms attempt to access information about their competitors by hook or by crook.

Our reading of the literature in this area as well as the popular press suggests a number of stylized facts which we use in this paper. First, corporate espionage whether legal or illegal is

⁵Economic espionage is a broader term that includes, theft of proprietary information by firms, individuals or nations. The ASIS regularly carries out surveys and publishes the value of estimated loss to American businesses due to economic espionage. For a legal perspective on this and other related aspects of this topic see Nasheri (2005, [10]). The references listed therein also provide a wealth of information about all aspects of corporate espionage.

an issue of growing concern.⁶ Second, such activities are more likely in high-tech firms, the drug industry and the defense related sector. Typically it is also the case that such firms are involved in producing more than one product often with inter-related costs. Third, firms are aware that their competitors are attempting to obtain information about them and often take a variety of actions to curb it. Finally, despite protective measures, rival firms are often able to engage in successful spying.

We model corporate espionage as a two stage game and examine the interaction between spying activities and multimarket competition. In the first stage firms decide how much intelligence to gather. We use network theory to model this part of the game since it enables us to characterize the equilibrium in a succinct manner and also provides the tools for examining bi-lateral relationships between firms. So in stage 1 firms establish (directed) links with other firms which provides them information about these firms resulting in quality improvements.⁷ Link formation is costly capturing the fact that corporate espionage is a costly activity. In the second stage, firms play a Cournot game. Each firm in the model produces two different products with inter-related costs and is engaged in Cournot competition in two markets simultaneously. For much of the paper we focus on the more interesting case and assume that the cost function exhibits diseconomies of scope. Later in the paper we discuss the consequences of economies of scope.

To obtain insights about the role of information gathering when there are diseconomies of scope across markets, we begin by assuming that all firms engage in espionage in one market only. After solving for the Cournot equilibrium in the second stage, we look for the Nash equilibrium (a la Bala and Goyal, 2000, [1]) of the link formation, or intelligence gathering game. Clearly Nash equilibrium is the appropriate concept for this stage since espionage activities do not require mutual consent implicit in Jackson and Wolinsky's notion of pairwise stability (1996, [9]).

We begin by characterizing the equilibrium networks that emerge when firms have the op-

⁶Instead of focussing on the legal aspects of this issue in this paper we just consider the fact that firms engage in spying on each other.

⁷In our formulation firms are always successful in their spying efforts. Future work could relax this assumption by allowing links to succeed only with a positive probability.

portunity to spy on their competitors. We show that only certain types of networks, namely the complete network, the empty network and the k -all-or-nothing-networks can be equilibrium networks.⁸ We also characterize the networks that maximize social welfare and show that although the architectures of efficient networks are similar to the equilibrium networks, the two do not always coincide. This provides a clear rationale for public policy to regulate corporate intelligence gathering activities.

The paper also provides a number of other interesting insights. We show that spying activities do not always depend on the costs of these activities. Indeed, in some situations, firms will refrain from engaging in spying even if the costs of these activities are very low. Moreover, even though spying leads to improvements in product quality, there exist situations where these activities are detrimental to consumers as well as social welfare. Lastly, it is interesting to observe that in some situations competitors may indeed wish to be spied upon. In other words in multimarket competition, we may expect to observe situations where firms do not try to prevent competitors from doing intelligence gathering directed at them.

Next, the extension of espionage activities to both markets leads to an increase in the number of possible equilibrium configurations without altering the above observations. Finally, firms have always an incentive in engaging spying when there are economies of scope across markets with the equilibrium level of spying being determined only by the cost of spying. Thus in this case the multimarket competition leads to the same qualitative outcome as a competition in a single market.

Our paper intersects several existing literatures. It is related to the network formation models in an oligopolistic setting found in the work of Goyal and Joshi (GJ, 2003, [7]), and Billand and Bravard (BB, 2004, [3]). In GJ firms engage in link formation (requiring mutual consent) for R&D purposes. Of course these links are undirected and both firms involved in a link obtain resources from each other while incurring some costs. In the model of BB, as in this paper, link formation and resource flow are directed in nature and only the firm establishing the

⁸The k -all-or-nothing-networks are networks where k firms have formed a link with all firms while the others have not formed any link.

link incurs costs. Unlike our paper in both these formulations, link formation is cost reducing instead of quality enhancing. More importantly however, firms compete only on one market and this difference in formulation alters the results significantly in our model. In particular in BB, the complete network is the unique equilibrium and efficient network when the cost of forming links is zero. By contrast, in our model, there are cases where even with zero link costs the empty network is the only equilibrium network. Moreover, the complete network is not the only efficient network anymore.

Our paper is also related to the theory of multimarket competition, in particular to the work of Bulow, Geanakoplos, and Klemperer (1985, [5]) on multimarket oligopolies. These authors examine how a change in one market can have ramifications on a second market, even if demands in the two markets are unrelated. In the Bulow et al. (1985, [5]) model changes are exogenous. By contrast, in our model while costs are inter-related changes in quality are endogenous and depend on the choices firms make regarding their espionage activities. The paper also provides an interesting comparison with the traditional literature on multimarket competition where the focus is on mutual forbearance (see for instance Bernheim and Whinston, 1990, [2]). In our model, with diseconomies of scope we find that for certain parameters ranges firms may choose to spy on their rivals only on one market. This leads to a situation where every firm improves its quality and behaves aggressively on one market only allowing its competitors to do the same on the other market. This seemingly collusive behavior arises in equilibrium.

The rest of the paper is organized as follows. The model setup is presented in Section 2. In Section 3 we provide a characterization of equilibrium networks and Section 4 analyzes the efficient networks. Section 5 explores the implications of allowing firms to form links on both markets. In Section 6 we discuss how the introduction of economies of scope across markets can affect the results and Section 7 concludes.

1 The Model

In this section we introduce basic network concepts and describe the Cournot game played by the N firms in our setting.

1.1 Network Preliminaries

Let $N = \{1, \dots, n\}$, with $n \geq 3$, denote a set of *ex ante* identical firms. Each firm produces two products, and is simultaneously engaged in Cournot competition with all the other firms in both markets. We assume that each firm $i \in N$ can form links with the other firms before competing in both markets. For any $i, j \in N$, $g_{i,j} = 1$ implies that firm i has a directed link with firm j , while $g_{i,j} = 0$ denotes the absence of such a link. We denote the directed links vector of firm i by $\mathbf{g}_i = (g_{i,1}, \dots, g_{i,i-1}, 0, g_{i,i+1}, \dots, g_{i,n})$. We interpret the link from firm i to firm j as spying activity (or intelligence gathering) of i directed at j . A directed network $\mathbf{g} = \{(g_{i,j})_{i \in N, j \in N}\}$ is a formal description of the spying activities that exist between the firms. Let \mathcal{G} denote the set of all possible directed networks. Let $N_i(\mathbf{g}) = \{j \in N | g_{i,j} = 1\}$ be the set of firms j about whom i gathers information. Its cardinality is given by $n_i(\mathbf{g})$. We denote by $n_{-i}(\mathbf{g}) = \sum_{j \neq i} n_j(\mathbf{g})$ the number of links in the network excluding the links originating from firm i .

We now define the network architectures that are important for our analysis. In the *complete* network for every pair of firms i and j there is a link from i and j . A network \mathbf{g} is *empty* if no firm has formed links. Finally, a network is a *k-all-or-nothing-network* if k firms have formed links with all other firms, while the remaining $n - k$ firms have formed no links.

1.2 Links Formation and the Cournot Game

We consider two oligopoly markets labelled market 1 and market 2. Let q_i be the quantity produced by firm i on market 1 and Q_i be the quantity produced by firm i on market 2. Let $\mathbf{q} = (q_1, \dots, q_i, \dots, q_n)$ and $\mathbf{Q} = (Q_1, \dots, Q_i, \dots, Q_n)$ be the vectors of quantities produced by the n firms on market 1 and on market 2 respectively. Demand is assumed to be independent across markets.

We assume that consumers are identical and have the following quasi-linear aggregate utility function:

$$U(\mathbf{q}, \mathbf{Q}, I) = u(\mathbf{q}) + v(\mathbf{Q}) + I, \quad (1)$$

where,

$$u(\mathbf{q}) = \sum_{i=1}^n \alpha_i q_i - \frac{1}{2} \left(\sum_{i=1}^n q_i^2 + 2 \sum_{i=1}^n \sum_{j<i} q_i q_j \right),$$

and,

$$v(\mathbf{Q}) = \sum_{i=1}^n \beta_i Q_i - \frac{1}{2} \left(\sum_{i=1}^n Q_i^2 + 2 \sum_{i=1}^n \sum_{j<i} Q_i Q_j \right).$$

Consumers maximize utility on market 1 and on market 2, subject to the budget constraint $\sum_{i=1}^n p_i q_i + \sum_{i=1}^n P_i Q_i + I \leq R$, where R denotes income, p_i and P_i denote the prices set by firm i , on market 1 and on market 2 respectively.

Note that equation (1) is a quality augmented version of the standard quadratic utility function introduced by Vives (2000, [11]), when there are two independent markets and products are vertically differentiated. Thus, α_i and β_i represent the quality of the products sold by firm i on market 1 and market 2 respectively. This utility function implies that consumers spend only a small part of their income on the two products ensuring that an interior solution exists.

In the two stage game played by the firms, stage 1 involves intelligence gathering through link formation and stage 2 is quantity competition. For the time being in stage 1 we assume that firms can form links only on the first market.⁹ A link represents gathering information about competitors' products and costs $f > 0$. This in turn allows the firm gathering the information to increase the quality of its product to be sold on market 1. Observe that *ex ante* firms are symmetric in market 1. Consequently, firm i 's product quality is only a function of the number of firms with whom i has formed a link or spies on. More specifically, in the remainder of the paper, we assume the following specific form for the product quality function:¹⁰

⁹This is enough for obtaining the key insights. However in Section 4 we relax this assumption and examine how our results are affected if firms can spy on both markets.

¹⁰This is a natural adaptation of the marginal cost formulation used by Bloch (1995, [4]) to the quality production function.

$$\alpha_i = \gamma_0 + \gamma n_i(\mathbf{g}).$$

Further, as in BKG (1985, [5], pg. 490-491) in our model costs of firms are interrelated across markets in the following quadratic way:

$$\text{CT}(q_i, Q_i) = \frac{1}{2}(q_i + Q_i)^2.$$

Thus, the cost incurred by firm i depends on the quantities produced in both markets and there are joint diseconomies across markets. The impact of economies of scope is discussed in Section 5.

2 Equilibrium under Espionage

From the first order conditions, firm i 's inverse demand function in market 1 is given by

$$p_i(q_i, \sum_{j \neq i} q_j) = \alpha_i - q_i - \sum_{j \neq i} q_j, \forall i \in N.$$

Similarly, firm i 's inverse demand function for market 2 is given by:

$$P_i(Q_i, \sum_{j \neq i} Q_j) = \beta_i - Q_i - \sum_{j \neq i} Q_j, \forall i \in N.$$

This allows us to write firm i 's gross profit function as:

$$\begin{aligned} \Pi_i(q_i, \sum_{j \neq i} q_j, Q_i, \sum_{j \neq i} Q_j) &= \left(\gamma_0 + \gamma n_i - q_i - \sum_{j \neq i} q_j \right) q_i + \left(\beta_i - Q_i - \sum_{j \neq i} Q_j \right) Q_i \\ &\quad - \frac{1}{2}(q_i + Q_i)^2, \end{aligned}$$

From the first order conditions the equilibrium quantities produced by each firm $i \in N$ in the two markets can be written as:

$$\begin{aligned} q_i^* &= \left(\frac{1}{3(4n+3+n^2)} \right) \left(\gamma (2n^2 + 1 + 6n) n_i(\mathbf{g}) - \gamma (5 + 2n) \sum_{j \neq i} n_j(\mathbf{g}) \right. \\ &\quad \left. - (n^2 + 3n - 1) \beta_i + (n + 4) \sum_{j \neq i} \beta_j + 3\gamma_0 (n + 2) \right), \\ Q_i^* &= \left(\frac{1}{3(4n+3+n^2)} \right) \left(-\gamma (n^2 - 1 + 3n) n_i(\mathbf{g}) + \gamma (n + 4) \sum_{j \neq i} n_j(\mathbf{g}) \right. \\ &\quad \left. + (2n^2 + 1 + 6n) \beta_i - (5 + 2n) \sum_{j \neq i} \beta_j - 3\gamma_0 \right), \end{aligned} \tag{2}$$

We assume that the parameters γ_0, γ, β take values which ensure that the quantities are positive.

The stage 1 profit function can now be rewritten as:

$$\begin{aligned} \Pi_i^*(n_i(\mathbf{g}), n_{-i}(\mathbf{g})) = & \Lambda n_i(\mathbf{g})^2 + \Delta \left(\sum_{j \neq i} n_j(\mathbf{g}) \right)^2 + \Phi n_i(\mathbf{g}) \sum_{j \neq i} n_j(\mathbf{g}) \\ & + \Omega_i n_i(\mathbf{g}) + \Gamma \sum_{j \neq i} n_j(\mathbf{g}) + \Psi - n_i(\mathbf{g})f, \end{aligned} \quad (3)$$

where $\Lambda > 0, \Delta > 0, \Phi < 0, \Gamma \in \mathbb{R}, \Psi \in \mathbb{R}$.¹¹ Note that $\Omega_i = \Omega_i(\beta_i, \sum_{j \neq i} \beta_j)$ is decreasing in its first argument and increasing in its second argument. We now characterize equilibrium espionage networks in this setting. Let $\Pi_i^*(n_i(\mathbf{g}), n_{-i}(\mathbf{g}))$ be the equilibrium profit of firm $i \in N$ in the network \mathbf{g} .

The network \mathbf{g} is an *equilibrium espionage network* if, for all $i \in N$, we have:

$$\Pi_i^*(n_i(\mathbf{g}), n_{-i}(\mathbf{g})) \geq \Pi_i^*(n_i(\mathbf{g}'), n_{-i}(\mathbf{g}')), \text{ for all } \mathbf{g}' \in \mathcal{G}, \text{ with } n_{-i}(\mathbf{g}') = n_{-i}(\mathbf{g}).$$

It follows that firm i forms an additional espionage link only if it allows i for strictly greater profits. We now provide a complete characterization of the architecture of equilibrium networks. We start by noting a convexity property of the firm's profits with respect to the number of links it establishes, then we state a proposition that uses this property.

Lemma 1 *Let the payoff function satisfy (3). In an equilibrium network \mathbf{g} , firms will establish either 0 links or $n - 1$ links.*

Proof To prove the lemma, let $\Pi_i^*(n_i(\mathbf{g})) = \Pi_i^*(n_i(\mathbf{g}), \hat{n}_{-i}(\mathbf{g}))$ where $\hat{n}_{-i}(\mathbf{g})$ is a fixed vector. Now we compare $\Pi_i^*(n_i(\mathbf{g}) + 1)$ with $\Pi_i^*(n_i(\mathbf{g}))$.

$$\Pi_i^*(n_i(\mathbf{g}) + 1) - \Pi_i^*(n_i(\mathbf{g})) = (2n_i(\mathbf{g}) + 1) \Lambda + \Phi \sum_{j \neq i} n_j(\mathbf{g}) + \Omega - f.$$

If $n_i(\mathbf{g}) \geq \left(-\Omega - \Lambda - \Phi \sum_{j \neq i} n_j(\mathbf{g}) + f \right) / 2\Lambda$, then $\Pi_i^*(n_i(\mathbf{g}) + 1) - \Pi_i^*(n_i(\mathbf{g})) \geq 0$ and the function increases with $n_i(\mathbf{g})$. If $n_i(\mathbf{g}) \leq \left(-\Omega - \Lambda + \Phi \sum_{j \neq i} n_j(\mathbf{g}) + f \right) / 2\Lambda$, then $\Pi_i^*(n_i(\mathbf{g}) + 1) - \Pi_i^*(n_i(\mathbf{g})) \leq 0$ and the function decreases with $n_i(\mathbf{g})$. It follows that there are two cases:

¹¹The values of these parameters are given in Appendix A.

1. If $f \leq \Omega + \Lambda - \Phi \sum_{j \neq i} n_j(\mathbf{g})$, then profit increases with $n_i(\mathbf{g})$ and firm i will establish $(n - 1)$ links.
2. If $f > \Omega + \Lambda - \Phi \sum_{j \neq i} n_j(\mathbf{g})$, then there exists x such that the function decreases for $n_i(\mathbf{g}) \leq x$ and increases for $n_i(\mathbf{g}) > x$. Therefore, profits are maximized either at $n_i(\mathbf{g}) = 0$ or $n_i(\mathbf{g}) = n - 1$.

□

Proposition 1 *Let the payoff function satisfy (3).*

1. *If for all $i \in N$, $f \leq \Lambda(n - 1) + \Omega_i + \Phi(n - 1)^2$, then the complete network is the unique equilibrium espionage network;*
2. *If for all $i \in N$, $f \in (\Lambda(n - 1) + \Omega_i, \Lambda(n - 1) + \Omega_i + \Phi(n - 1)^2)$, then an equilibrium espionage network is a k -all-or-nothing-network;*
3. *If for all $i \in N$, $f \geq \Lambda(n - 1) + \Omega_i$, then the empty network is the unique equilibrium espionage network.*

Proof See Appendix.

□

Few remarks are in order here.

Remark 1. *In equilibrium intelligence activities can lead to asymmetric espionage networks among ex ante symmetric firms.* Note that for a range of parameters, asymmetric networks where some firms have $n - 1$ links and other firms have no links at all, are equilibrium networks. In fact, Proposition 1 is true even if $\beta_i = \beta$ for all $i \in N$, that is if firms are *ex ante* identical. Hence this result illustrates how intelligence activities can generate substantial asymmetries among firms with regard to the quality of their products and profits.

Remark 2. *Higher quality product in market 2 results in trade-off with intelligence gathering.* The intuition for this result is as follows. It is easily checked that the price-elasticity of demand for the product sold by firm i in market 2 is increasing in the quality of its product, β_i . In this framework when firm i establishes an additional link in market 1, it has an incentive to increase

the quantity produced on the first market (“*output effect*”) and due to diseconomies of scope across markets, decrease the quantity of its product sold on the second market (“*cost effect*”). A higher β_i implies a greater loss of revenue resulting from the decrease in Q_i .

Remark 3. *In equilibrium, firms selling the higher quality goods in market 2 may be the ones that engage in intelligence gathering.* Even if ceteris paribus the better quality sold by a firm on market 2 lowers the incentive for this firm to establish links (Remark 2), it is not necessarily the firms with the lowest quality products on market 2 that will do so. This counterintuitive result can be explained as follows. Recall that when the number of firms who have formed $n - 1$ links increases, the marginal payoff of a firm from spying decreases. In some situations, where this (latter) negative effect outweighs the positive effect resulting from differences in product quality on market 2, we can observe equilibrium networks where only the firms with higher quality products on market 2 have formed links. The following example illustrates this situation.

Example 1 Assume $n = 10$, $\gamma_0 = 7$, $\gamma = 0.2$, $\beta_i = 6.1$, for five firms, $\beta_i = 6$ for five other firms and $f = 0.16$. We can check that the network where firms having the higher product quality in market 2 have formed $n - 1$ links on market 1 and the firms having the lower quality product on market 2 have formed no links on market 1 is an equilibrium network.

Remark 4. *Firms may have an incentive to be spied upon.* It is interesting to note that in some situations firms do not have an incentive to protect themselves from spying by competitors, as the following example illustrates.

Example 2 Assume $n = 3$, $\gamma_0 = 7$, $\gamma = 0.5$, $\beta_i = 22$, for all $i = 1, 2, 3$, and $f = 0$. Consider a network g where two firms have formed 2 links each and one firm has formed no links. We can check that if the latter firm forms links, the profits of her competitors increase.

The intuition of this result stems from the interplay between the “*output effect*” and the “*cost effect*”. The example shows that when the “*cost effect*” (which increases profits) dominates the “*output effect*” (which decreases profits) firms have an incentive to be spied upon. Although this result seems relatively strange, we find such behavior in a case study about US minimill steel

producers (von Hippel, 1987, [8]). We now establish that, under some conditions, the complete network is not an equilibrium espionage network when the cost of spying is zero.

Corollary 1 *Suppose the payoff function satisfies (3) and the cost of forming links is zero. Then, there exist parameters, γ , γ_0 , $(\beta_i)_{i \in N}$, such that the empty network, and the k -all-or-nothing-networks are equilibrium espionage networks.*

Proof The proof is straightforward and is omitted. □

This result suggests that even if there are no costs of spying, due to the two effects mentioned above there are instances when firms have no incentive to gather information about other firms, i.e., *the set of equilibrium espionage networks does not include the complete network*. Note that this result differs from rest of networks literature where zero link costs always lead to the complete network in equilibrium. This is also true when espionage occurs in the absence of spillovers across markets as in BB (Proposition 1, pg. 598).

3 Welfare under Espionage

In this section we identify different types of efficient espionage networks when firms are involved in intelligence gathering. For a network \mathbf{g} , aggregate welfare $W(\mathbf{g})$ is defined as the sum of consumers' surplus and firms' aggregate profits.

We define a network \mathbf{g} as *efficient* if $W(\mathbf{g}) \geq W(\mathbf{g}')$ for all $\mathbf{g}' \in \mathcal{G}$. Moreover, we say that a network \mathbf{g} is efficient for firms (consumers) if this network maximizes the aggregate profits of firms (surplus of consumers).

3.1 Consumer Welfare

In this section, we show that the total surplus of consumers is maximized either for the complete network or for the empty network. We begin by showing that consumers' welfare does not depend on the number of links established by specific firms. In other words consumers surplus

does not depend on intelligence gathering activities of specific firms but on the total amount of spying that takes place in the industry.

Lemma 2 *Suppose that the utility function satisfies (1) and the quantities produced satisfy (2). The total surplus of consumers depends on the total amount of spying in the industry and not on the distribution of the spying activity.*

Proof The aggregate surplus of consumers is given by:

$$S_C(\mathbf{q}^*(\mathbf{g}), \mathbf{Q}_i^*(\mathbf{g})) = \frac{1}{2} (\sum_{i=1}^n q_i^*(\mathbf{g}))^2 + \frac{1}{2} (\sum_{i=1}^n Q_i^*(\mathbf{g}))^2$$

where

$$\sum_{i \in N} q_i^*(\mathbf{g}) = \frac{\gamma(n+2) \sum_{i=1}^n n_i(\mathbf{g}) - \sum_{i=1}^n \beta_i + n\gamma_0(2+n)}{4n+3+n^2}.$$

and

$$\sum_{i \in N} Q_i^*(\mathbf{g}) = \frac{-\gamma \sum_{i=1}^n n_i(\mathbf{g}) + (2+n) \sum_{i=1}^n \beta_i - n\gamma_0}{4n+3+n^2}.$$

Since $\sum_{i=1}^n q_i^*(\mathbf{g})$ and $\sum_{i=1}^n Q_i^*(\mathbf{g})$ depend only on the total number of links, the total surplus of consumers does not depend on the pattern of spying activity; it depends only on the aggregate spying level. \square

Proposition 2 *Suppose that the utility function satisfies (1) and the quantities produced satisfy (2). The efficient espionage network for consumers is either the empty network or the complete network.*

Proof Let $S_C(T)$ denote the the total surplus of consumers in a network \mathbf{g} , where the total number of links formed by the firms is $\sum_{i=1}^n n_i(\mathbf{g}) = T$. We have:

$$S_C(T+1) + S_C(T-1) - 2S_C(T) = \frac{1}{9}\gamma^2 \left(\frac{n^2 + 4n + 5}{(n^2 + 4n + 3)^2} \right) > 0$$

Observe that the total surplus of consumers exhibits increasing returns with respect to the number of links formed by firms. Hence the efficient network for consumers is either the empty

network or the complete network, depending on the sign of the expression $S_C((n-1)^2) - S_C(0)$. □

Note that consumers may be negatively affected by corporate espionage even if it leads to an increase in product quality in market 1. This can be explained in the following way. Link formation in market 1 has two opposite effects on consumers welfare. First, firms offer a better quality product in market 1 and as a whole have an incentive to sell more in this market. This behavior is clearly beneficial to consumers. Second, due to diseconomies of scope, as firms sell more in market 1, they have an incentive to sell less in market 2. This leads to higher prices in market 2 and is harmful for consumers. The above proposition establishes that this latter effect may outweigh the gains from the higher quality in market 1.

3.2 Social Welfare

In this section, we examine the profits of firms as well as total welfare.

Lemma 3 *Let the payoff function satisfy (3).*

1. *There are at least $n - 1$ firms which have formed either 0 or $n - 1$ links in an efficient espionage network for firms.*
2. *There are at least $n - 1$ firms which have formed either 0 or $n - 1$ links in an efficient espionage network.*

Proof See appendix. □

Proposition 3 *Let the payoff function satisfy (3).*

1. *A network \mathbf{g} is an efficient espionage network for firms if it is the empty network, the complete network, or a k -all-or-nothing network.*
2. *A network \mathbf{g} is an efficient espionage network if it is the empty network, the complete network, or a k -all-or-nothing network.*

Proof See Appendix. □

Our analysis shows that as with equilibrium networks, only three architectures can arise here: the empty network, the complete network, and the k -all-or-nothing networks.

Remark 5. *Conflict between Nash and efficient espionage networks, and policy implication.* While efficient espionage networks and Nash networks have the same architectures they do not always coincide. Below is a simple example where such a conflict between efficiency and equilibrium exists.

Example 3 Assume $n = 3$, $\gamma_0 = 20$, $\gamma = 2$, $\beta_i = 22$, for all $i = 1, 2, 3$, and $f = 6$.

It can be checked that the complete network is an equilibrium espionage network, but not an efficient espionage network. For instance, the network where 2 firms have established 2 links each and one firm has no links is more efficient than the complete network. Thus, equilibrium espionage networks can be over-connected with respect to social welfare leading to over-investment in spying activities in equilibrium. This provides a strong argument for policy intervention with regard to business related espionage, as the US Industrial Espionage Act of 1996.

4 Intelligence Gathering in Both Markets

We now extend our basic model by allowing firms to engage in espionage activities in both markets. While the basic insights remain the same, we show that the possible range of equilibrium espionage networks increases dramatically since the two markets allow for a richer set of outcomes.¹²

In the following we denote by $n_{i\ell}(\mathbf{g})$ the number of links formed by firm i on market ℓ , where $\ell = 1, 2$. We assume that the qualities of the products sold by firm i on market 1, α_i , and on market 2, β_i , depend on the number of links established, or the amount of intelligence gathered by the firm in each market in the following way:

$$\alpha_i = \alpha_0 + \alpha n_{i1}(\mathbf{g}).$$

¹²Here we only provide the main results and a sketch of the proofs. Detailed results and proofs are available from the authors on request.

$$\beta_i = \beta_0 + \beta n_{i2}(\mathbf{g}).$$

The profits of firm i are given by:

$$\Pi_i(q_i, \sum_{j \neq i} q_j, Q_i, \sum_{j \neq i} Q_j) = (\alpha_i - q)q_i + (\beta_i - Q)Q_i - \frac{1}{2}(q_i + Q_i)^2, \quad (4)$$

where $q = q_i + \sum_{j \neq i} q_j$ and $Q = Q_i + \sum_{j \neq i} Q_j$.

Since equilibrium quantities ultimately depend on the number of links in stage 1 of the game, the equilibrium profit function of firm i can be written as $\Pi_i^*(n_{i1}, \sum_{j \neq i} n_{j1}, n_{i2}, \sum_{j \neq i} n_{j2})$.

Lemma 4 *Let the payoff function satisfy (4). In an equilibrium espionage network \mathbf{g} , firms form either zero or $n - 1$ links.*

Proof Let $\Delta \Pi_{i\ell}^*(\mathbf{g})$ denote the marginal payoff of a firm i from forming an additional link in market ℓ . Using the same arguments as in Section 2 and with straightforward computations, we find that for a given network \mathbf{g} , $\Delta \Pi_{i\ell}^*(\mathbf{g})$ is increasing in $n_{i\ell}(\mathbf{g})$. Consequently, in equilibrium, each firm either forms no links or $n - 1$ links on each market. \square

Observe that the above lemma allows for a large number of possible equilibrium architectures. To present results in a succinct manner we define some additional notations. Let n_A be the number of firms who form 0 links in both markets. Let n_B be the number of firms who form 0 links in market 1 and $n - 1$ links in market 2. Let n_C be the number of firms who form $n - 1$ links in market 1 and 0 links in market 2. Let n_D be the number of firms who form $n - 1$ links in both markets.

Just as in the case of link formation in one market, here we can identify parameters $\Gamma_1, \Gamma_2, \Gamma_3, T, \omega_0, \tau_0, \tilde{\omega}$ and $\tilde{\tau}$ (with $\tilde{\omega} > \omega_0$ and $\tilde{\tau} > \tau_0$ and $\Gamma_1, \Gamma_2, \Gamma_3, T > 0$) such that we get the following result.¹³

Proposition 4 *Let the payoff function satisfy (4).*

1. *If $f \leq \min[\omega_0, \tau_0] - \frac{\alpha\beta(\Gamma_1 + \Gamma_3)(n - 1)}{T} = \Sigma_1$, then the complete network is the unique equilibrium espionage network.*

¹³The values of these parameters are given in Appendix C.

2. *If for all $i \in N$, $f \geq \max[\tilde{\omega}, \tilde{\tau}] + \frac{\Gamma_2(n-1)}{T} \max[\alpha^2, \beta^2] = \Sigma_2$, then the empty network is the unique equilibrium espionage network.*
3. *A network \mathbf{g} , where some firms spy on all other firms in both markets while other firms do not spy at all, (namely $n_A > 0$ and $n_D > 0$ simultaneously) cannot be an equilibrium espionage network.*
4. *If $f \in (\Sigma_1, \Sigma_2)$, then an equilibrium espionage network is characterized by some combination of n_A, n_B, n_C, n_D with $0 \leq n_i \leq n$ ($i = A, B, C, D$) such that we do not have $n_A > 0$ and $n_D > 0$ simultaneously.*

The table below furnishes sufficient conditions for a certain network to be an equilibrium network. Namely, if the parameters in question lie in the relevant range in the left column, an equilibrium described by the right column exists provided of course that the parameters values are such that the range is a non-empty interval.

Parameters ranges	Equilibrium Configurations
$\max(\tilde{\tau}, \tilde{\omega}) \leq f \leq \tau_0 + \frac{\Gamma_2(n-1)\beta^2}{T}$	$n_A > 0$ and $n_B > 0$
$\max(\tilde{\tau}, \tilde{\omega}) \leq f \leq \omega_0 + \frac{\Gamma_2(n-1)\alpha^2}{T}$	$n_A > 0$ and $n_C > 0$
$\max(\tilde{\tau}, \tilde{\omega}) \leq f \leq \min(\omega_0, \tau_0) + \frac{\Gamma_2(n-1) \min[\alpha^2, \beta^2]}{T}$	$n_A > 0, n_B > 0$ and $n_C > 0$
$\max(\tilde{\tau}, \tilde{\omega}) - \frac{\alpha\beta \cdot \Gamma_3 \cdot (n-1)}{T} \leq f \leq \min(\omega_0, \tau_0) + \frac{\Gamma_2(n-1) \min[\alpha^2, \beta^2]}{T}$	$n_B > 0$ and $n_C > 0$
$\max(\tilde{\tau}, \tilde{\omega}) - \frac{\alpha\beta \cdot \Gamma_3 \cdot (n-1)}{T} \leq f \leq \min(\omega_0, \tau_0) + \frac{\Gamma_2(n-1) \min[\alpha^2, \beta^2]}{T} - \frac{\alpha\beta(\Gamma_1 + \Gamma_3)(n-1)}{T}$	$n_B > 0, n_C > 0$ and $n_D > 0$
$\tilde{\tau} - \frac{\alpha\beta \cdot \Gamma_3 \cdot (n-1)}{T} \leq f \leq \min(\omega_0, \tau_0) + \frac{\Gamma_2(n-1) \min[\alpha^2, \beta^2]}{T} - \frac{\alpha\beta(\Gamma_1 + \Gamma_3)(n-1)}{T}$	$n_C > 0$ and $n_D > 0$
$\tilde{\omega} - \frac{\alpha\beta \cdot \Gamma_3 \cdot (n-1)}{T} \leq f \leq \min(\omega_0, \tau_0) + \frac{\Gamma_2(n-1) \min[\alpha^2, \beta^2]}{T} - \frac{\alpha\beta(\Gamma_1 + \Gamma_3)(n-1)}{T}$	$n_B > 0$ and $n_D > 0$

To give some insights into the proof of Proposition 4, it works in the same way as the proof of Proposition 1. Namely, given that a firm can either form 0 or $n - 1$ links in equilibrium, we compare the profits in these two scenarios and identify conditions in which one is weakly greater than the other.

The possibility of equilibrium espionage networks where some firms have formed $n - 1$ links on market 1 and no links on market 2, while other firms have formed no links on market 1 and

$n - 1$ links on market 2 can be easily explained. Indeed, straightforward calculations show that the marginal payoff of firm i , $\Delta\Pi_{il}^*(\mathbf{g})$, satisfies the three following properties.

Property 1: $\Delta\Pi_{i1}^*(\mathbf{g})$ is decreasing in β_i , and hence in $n_{i2}(\mathbf{g})$. Similarly, $\Delta\Pi_{i2}^*(\mathbf{g})$ is decreasing in α_i , and hence in $n_{i1}(\mathbf{g})$. Consequently, each link formed in one of the two markets reduces the marginal profitability of a link formed in the other market.

Property 2: $\Delta\Pi_{i1}^*(\mathbf{g})$ is decreasing in α_j where $j \neq i$ and hence in $n_{j1}(\mathbf{g})$. Similarly, $\Delta\Pi_{i2}^*(\mathbf{g})$ is decreasing in β_j where $j \neq i$ and hence in $n_{j2}(\mathbf{g})$.

Property 3: $\Delta\Pi_{i1}^*(\mathbf{g})$ is increasing in β_j where $j \neq i$ and hence in $n_{j2}(\mathbf{g})$. Similarly, $\Delta\Pi_{i2}^*(\mathbf{g})$ is increasing in α_j where $j \neq i$ and hence in $n_{j1}(\mathbf{g})$.

Properties 2 and 3 mean that the marginal payoff of a firm in a particular market decreases when other firms step up intelligence activities in that market, but increases when they increase the level of such activities in the other market.

Note that it is more difficult to explain why the networks with firms that have formed $n - 1$ links on both markets and firms that have formed no links on both markets cannot be equilibrium espionage network. Indeed in such networks the three properties have opposing effects. However, it is interesting to note that the difference of marginal profits from forming $n - 1$ links on one market, between a firm, say i , which has already formed links on both markets and a firm, say j , which has formed no links at all, can be split into three terms. Each of these terms assesses the difference of strength of the effect associated with one property. As expected, property 1 as well as property 3 work in favor of marginal profits of firm j while property 2 works in favor of marginal profits of firm i . Moreover through tedious algebra it can be checked that the total effect of properties 1 and 3 always outweighs the effect of property 2. This explains the result. Further it is also worth noting that in some equilibria we get a kind of mutual forbearance result involving no spying in both markets.

Next, we focus on aspects that is most important from a policy perspective: the conflict between efficiency and equilibrium. This conflict continues to be present when we introduce the

possibility of firms spying in both markets. In particular, the following example illustrates how firms can over-invest in spying links with regard to social welfare.

Example 4 This is similar to Example 3 and exploits continuity by making β sufficiently small. Assume $n = 3$, $\alpha_0 = 20$, $\alpha = 2$, $\beta_0 = 22$, $\beta = 0.000001$ and $f = 6$. The network in which all firms form two links in market 1 and no links in market 2 is an equilibrium but not efficient network. Indeed the network in which two firms form two links each and the remaining firm forms no links in market 1, and no firm forms any links in market 2 is more efficient than the earlier network.

5 Economies of Scope versus Diseconomies of Scope

We now explain what happens when the cost function exhibits economies of scope. We show that in this case there is no tension across markets anymore and firms have always an incentive to form links and spy, provided these costs are low enough. For simplicity we assume that firms spy in only one market, though as before the insights can be generalized to allow for spying on multiple markets. In equilibrium we have:

$$\frac{d\pi_i^*}{d\alpha_i} = \sum_{j \neq i} \left(\frac{\partial \pi_i^*}{\partial q_j^*} \right) \left(\frac{dq_j^*}{d\alpha_i} \right) + \sum_{j \neq i} \left(\frac{\partial \pi_i^*}{\partial Q_j^*} \right) \left(\frac{dQ_j^*}{d\alpha_i} \right) + \frac{\partial \pi_i^*}{\partial \alpha_i},$$

where π_i^* is equilibrium profit, and q_j^*, Q_j^* , are equilibrium quantities.

Unlike the case with diseconomies of scope across markets, in this situation $\frac{\partial Q_j^*}{\partial \alpha_i}$ is positive. Since the three terms in the above expression have a positive sign, firms have always an incentive to spy in order to increase the quality of their products. The intuition behind this result is as follows: when firm i forms a link and increases the quality of its product on a market, then it adopts a more aggressive strategy not only on this market but on the other market too due to economies of scope. Since competitors regard their product as a strategic substitute for the products of firm i on each market, they sell less on both markets and this behavior is beneficial to firm i . Hence the complete network is the only possible equilibrium espionage network with zero costs of spying. When costs of spying are positive, then the equilibrium architecture is

dependent only on the value of f and not on the spillovers across markets, making economies of scope rather uninteresting in the multimarket context.

It is also important to note that the introduction of economies of scope across markets does not put an end to the conflict between equilibrium espionage networks and total welfare. More precisely, the following example shows that there exist situations where firms may over-invest in espionage with respect to social welfare.

Example 5 Suppose that the cost function of all firms $i = 1, \dots, n$ is given by:

$$CT(q_i, Q_i) = (q_i)^2 + (Q_i)^2 - \frac{1}{128}(q_i + Q_i)^2.$$

The cost incurred by firm i depends on the quantities produced in both markets and there are joint economies across markets. In this example we let γ take different values in market 1 and market 2 denoted by α_1 and β_1 respectively. Assume $n = 3$, $\alpha_0 = 3$, $\alpha_1 = 1$, $\beta_0 = 10$, $\beta_1 = 0.1$, and $f = 0.6177$. It can be checked that the situation where all firms have established two links on market 1 and no links on market 2 is an equilibrium network, whereas social welfare increases if one of the firms deletes its links.

Conclusion

In this paper we study the incentives of firms to spy on other firms in order to increase the quality of their products, in a multimarket setting where competitors regard their products as strategic substitutes. A significant finding is that under diseconomies of scope firms may have no incentive to spy even if the cost of intelligence activities is zero. Moreover, in some situations firms might even prefer other firms to spy on them. We find that although intelligence activities lead to increased quality products, they may lead to a reduction of social welfare as well as consumers welfare. Furthermore, in some cases equilibrium level of spying by firms can exceed the socially optimal level, making a strong case for regulatory intervention.

Our paper is the first formal analysis of competitive intelligence type activities which are becoming increasingly important in modern economies. We briefly discuss some issues that could

be explored in future work. First we take up the issue of spying activities. In our model spying is always successful. However in future work spying need only be successful with a certain probability. Another extension would be to introduce a spatial dimension where the identity of the firms being spied upon would matter. The second issue is the impact of spying activities. An important question would be to examine the consequences of spying for future product development and its impact on social welfare. It might also be interesting to examine the impact of spying activities when firms play a price game. Third, from a network perspective we need to examine multimarket competition with inter-related costs where firms make collaborative R &D decisions. In this case it would be necessary to modify the equilibrium concept to allow for consent. This would enable us to consider other stability notions like pairwise stability.

Appendix A: Values of profit parameters

We give the values of Λ, Φ, Ω which play an important role in the marginal payoff from links. Let $d = (18(n^2 + 4n + 3))^2$. We have:

$$\begin{aligned}
\Lambda &= d\gamma^2(11n^4 + 66n^3 + 107n^2 + 24n + 8), \\
\Phi &= -2d\gamma^2(11n^3 + 62n^2 + 91n + 4), \\
\Omega_i &= 2d\gamma(3\gamma_0(5n^3 + 26n^2 + 37n + 4) \\
&\quad - (7n^4 + 42n^3 + 55n^2 - 24n - 8)\beta_i) \\
&\quad + (n + 4)(7n^2 + 18n - 1)\sum_{j \neq i} \beta_j)
\end{aligned}$$

We now give the value of other parameters.

$$\begin{aligned}
\Psi &= d(n\gamma_0(6\sum_{j\neq i}\beta_j(n+14) - 6\beta_i(10n+n^2+17) + 9\gamma_0(10+3n)) \\
&\quad -\beta_i\sum_{j\neq i}\beta_j(124n^2+22n^3+182n+8) + \gamma_0(99\gamma_0+150\sum_{j\neq i}\beta_j) \\
&\quad +\beta_i(n\beta_i(3+n)(11n^2+33n+8) + 8\beta_i - 8\sum_{j\neq i}\beta_j + 24\gamma_0) \\
&\quad +n(\sum_{j\neq i}\beta_j)^2(58+11n)). \\
\Gamma &= 2d\gamma(\gamma_0(n-1)(11n^2+58n+83) + \beta_i(n+4)(7n^2+18n-1) \\
&\quad -(7n^2+50n+79)(\sum_{j\neq i}\beta_j)). \\
\Delta &= d(\gamma^2(11n^2+58n+83))
\end{aligned}$$

Appendix B: Proofs.

Proof of Proposition 1 By Lemma 1 firm i either forms 0 links or $n-1$ links in an equilibrium espionage network. We compare the profits of firm i in these two cases. Let $\hat{n}_{-i}(\mathbf{g})$ be a fixed number of links formed by all the other firms. The network \mathbf{g} where i forms $n-1$ links is an equilibrium espionage network if for all firms i :

$$\Pi_i^*(n-1, \hat{n}_{-i}(\mathbf{g})) - \Pi_i^*(0, \hat{n}_{-i}(\mathbf{g})) \geq 0,$$

that is:

$$\Lambda(n-1)^2 + \Omega_i(n-1) + \Phi(n-1) \sum_{j\neq i} n_j(\mathbf{g}) - f(n-1) \geq 0. \quad (5)$$

(1) We now prove the first part of the proposition. The complete network is an equilibrium espionage network if inequality (5) is verified for $n_j = n-1$ for all $j \neq i$, that is $\sum_{j\neq i} n_j(\mathbf{g}) = (n-1)^2$. Therefore, the complete network is an equilibrium espionage network if for all firms i

$$f \leq \Lambda(n-1) + \Omega_i + \Phi(n-1)^2.$$

Next we show that under this condition, a network where at least one firm has set zero links is not an equilibrium espionage network. Assume an equilibrium network \mathbf{g} where k firms belonging

to $K \subset N$ have formed no links and $f \leq \Lambda(n-1) + \Omega_i + \Phi(n-1)^2$ for all firms i .¹⁴ Since \mathbf{g} is an equilibrium espionage network, we have for all $i \in K$:

$$\Pi_i^*(0, \hat{n}_{-i}(\mathbf{g})) - \Pi_i^*(n-1, \hat{n}_{-i}(\mathbf{g})) \geq 0,$$

that is:

$$\Lambda(n-1)^2 + \Omega_i(n-1) + \Phi(n-1) \sum_{j \neq i} n_j(\mathbf{g}) - f(n-1) \leq 0.$$

Since $\sum_{j \neq i} n_j(\mathbf{g}) = (n-k)(n-1)$, for all $i \in K$ we obtain

$$\Lambda(n-1) + \Omega_i + \Phi(n-1)(n-k) \leq f.$$

Hence, for all $i \in K$, $f \leq \Lambda(n-1) + \Omega_i + \Phi(n-1)^2$ and $\Lambda(n-1) + \Omega_i + \Phi(n-1)(n-k) \leq f$. Since $\Phi < 0$, this gives us the desired contradiction.

(2) We now prove the second part of the proposition. First, the empty network is an equilibrium espionage network if for all firms inequality (5) is not verified for $n_j = 0$ for all $j \neq i$, or,

$$f \geq \Lambda(n-1) + \Omega_i.$$

Next, we show that under this condition a network where at least one firm has formed $n-1$ links is not an equilibrium espionage network. Again assume an equilibrium network \mathbf{g} where k firms which belong to $K' \subset N$ have formed $n-1$ links, and for all $i \in K'$, $f \geq \Lambda(n-1) + \Omega_i$.¹⁵ Since \mathbf{g} is an equilibrium espionage network, we have for all $i \in K'$

$$\Pi_i^*(n-1, \hat{n}_{-i}(\mathbf{g})) - \Pi_i^*(0, \hat{n}_{-i}(\mathbf{g})) \geq 0,$$

that is:

$$\Lambda(n-1)^2 + \Omega_i(n-1) + \Phi(n-1) \sum_{j \neq i} n_j(\mathbf{g}) - f(n-1) \geq 0$$

Substituting the fact that $\sum_{j \neq i} n_j(\mathbf{g}) = (k-1)(n-1)$, we obtain

$$\Lambda(n-1) + \Omega_i + \Phi(n-1)(k-1) \geq f.$$

¹⁴Note that K may be a singleton set.

¹⁵Again note that K' may be a singleton.

Hence, we have $f \geq \Lambda(n-1) + \Omega_i$ and $\Lambda(n-1) + \Omega_i + \Phi(n-1)(k-1) \geq f$. Since $\Phi < 0$, we get the desired contradiction.

(3) The third part of the proposition follows in a straightforward manner from the first two parts of the proposition and the Lemma 1.

□

Proof of Lemma 3.1 Let \mathbf{g} be an efficient network for multimarket firms. Assume there are two firms, say i and ℓ , such that $n_i(\mathbf{g}) \in \{1, \dots, n-2\}$ and $n_\ell(\mathbf{g}) \in \{1, \dots, n-2\}$. Without loss of generality let $n_i(\mathbf{g}) \geq n_\ell(\mathbf{g})$. Let \mathbf{g}' be the network where all firms except i and ℓ do not change their links. Suppose ℓ deletes k links and i adds k links giving us: $n_i(\mathbf{g}') = n_i(\mathbf{g}) + k$ and $n_\ell(\mathbf{g}') = n_\ell(\mathbf{g}) - k$. We assume that there are x firms which have formed $n-2$ links, and so $n-2-x$ firms have formed no links. The difference in total profit between \mathbf{g} and \mathbf{g}' , denoted by Z_m , is

$$\begin{aligned} Z_m &= 2\Lambda k(n_i(\mathbf{g}) - n_\ell(\mathbf{g}) + k) + 2\Phi k(n_\ell(\mathbf{g}) - n_i(\mathbf{g}) - k) \\ &\quad + 2\Delta k(n_i(\mathbf{g}) - n_\ell(\mathbf{g}) + k) \\ &= 2k(n_i(\mathbf{g}) - n_\ell(\mathbf{g}) + k)(\Lambda - \Phi + \Delta). \end{aligned}$$

Since, $k > 0$, $\Lambda > 0$, $\Phi < 0$ and $\Delta > 0$, we have $Z_m > 0$.

Thus, \mathbf{g} cannot be efficient for multimarket firms, giving us a contradiction.

□

Proof of Lemma 3.2 This lemma is straightforward from Lemma 2 and Lemma 3.1.

□

Proof of Proposition 3.1 We know by Lemma 3 that a network \mathbf{g} is an efficient network if there is at most one firm i which has formed $n_i(\mathbf{g}) \in \{1, \dots, n-2\}$ links. We now show that a network \mathbf{g} , where a firm i has formed $n_i(\mathbf{g}) \in \{1, \dots, n-2\}$ links, is not an efficient espionage network. To introduce a contradiction let us assume an efficient espionage network \mathbf{g} where a firm, say i , has formed $n_i(\mathbf{g}) \in \{1, \dots, n-2\}$ links and $g_{i,j} = 1, g_{i,k} = 0$. Let \mathbf{g}' be the network with the same set of links as in \mathbf{g} except that i has not formed a link with j . Let x be the number of firms which have formed $n-1$ links. Since \mathbf{g} is an efficient espionage network, we have:

$$\begin{aligned} \sum_{i \in N} \Pi_i^*(\mathbf{g}) - \sum_{i \in N} \Pi_i^*(\mathbf{g}') &= \Omega_i - f + \Gamma (n-1) + 2 \Phi x (n-1) + \Lambda (2 n_i(\mathbf{g}) - 1) \\ &\quad + (1 + n(-1 - 6 x + 2 n_i(\mathbf{g}) + 2 n x) \\ &\quad + 4 x - 2 n_i(\mathbf{g})) \Delta \\ &= \mathcal{X} > 0. \end{aligned}$$

Let \mathbf{g}'' be the network where all firms except i have the same links as in \mathbf{g} , and i forms the same links as in \mathbf{g} except that it has formed a link with k . Since \mathbf{g} is efficient, we have:

$$\begin{aligned} \sum_{i \in N} \Pi_i^*(\mathbf{g}'') - \sum_{i \in N} \Pi_i^*(\mathbf{g}) &= \Omega_i - f + \Gamma (n-1) + 2 \Phi x (n-1) + \Lambda (2 n_i(\mathbf{g}) + 1) \\ &\quad + (n + 4 x - 6 n x - 2 n_i(\mathbf{g}) + 2 n n_i(\mathbf{g}) \\ &\quad + 2 n^2 x - 1) \Delta \\ &= \mathcal{Y} < 0. \end{aligned}$$

We now compare \mathcal{X} and \mathcal{Y} , we get:

$$\mathcal{X} - \mathcal{Y} = -2((n-1)\Delta + \Lambda) < 0.$$

This gives us the desired contradiction.

□

Proof of Proposition 3.2 We know by Lemma 4 that there is at most one firm i which has formed $n_i(\mathbf{g}) \notin \{0, n-1\}$ links in an efficient espionage network. We now show that this firm cannot exist in an efficient espionage network.

Denote by $f(n_i, \sum_{j \neq i} n_j)$ the profit of a firm with n_i links while the other firms have $\sum_{j \neq i} n_j$ links. Consider a network where x firms have formed $n-1$ links, $n-x-1$ firms have formed 0 links and one firm, say i , which has formed t links, $t \in \{1, \dots, n-2\}$.

Aggregate profit of all firms, Π , is given by:

$$xf(n-1, (x-1)(n-1) + t) + (n-x-1)f(0, x(n-1) + t) + f(t, x(n-1)) = g(t).$$

Also denote by $h(t)$ the total consumers' surplus when $x(n-1) + t$ links have been formed. Hence, the total surplus is: $s(t) = g(t) + h(t)$. We have

$$s(t+1) + s(t-1) - 2s(t) = \frac{(11n^4 + 77n^3 + 154n^2 + 49n - 75)\gamma^2}{9(8n+13)^2} > 0.$$

The total gross surplus increases with the number of links firm i has formed with others. Therefore, an efficient espionage network cannot contain a firm which has formed $n_i(\mathbf{g}) \notin \{0, n-1\}$ links.

□

Appendix C: Intelligence gathering in both markets.

Parameters values in terms of model primitives for Proposition 4. are

$$\begin{aligned} T &= 18(1+n)^2(3+n)^2, & \Gamma_1 &= (110n^2 + 84n^3 + 14n^4 - 16 - 48n), \\ \Gamma_2 &= (8 + 182n + 124n^2 + 22n^3), & \Gamma_3 &= (142n + 92n^2 + 14n^3 - 8), \end{aligned}$$

$$\begin{aligned}
\tau_0 &= (\beta/T)[\Gamma_0(2\beta_0 + (n-1)\beta) - \Gamma_1\alpha_0 - \Gamma_2(n(\beta_0 + (n-1)\beta) - \beta_0) \\
&\quad + \Gamma_3(n-1)\alpha_0], \\
\tilde{\tau} &= (\beta/T)[\Gamma_0(2\beta_0 + (n-1)\beta) - \Gamma_1\alpha_0 - \Gamma_2(n-1)\beta_0 \\
&\quad + \Gamma_3(n(\alpha_0 + (n-1)\alpha) - \alpha_0)], \\
\omega_0 &= (\alpha/T)[\Gamma_0(2\alpha_0 + (n-1)\alpha) - \Gamma_1\beta_0 - \Gamma_2(n(\alpha_0 + (n-1)\alpha) - \alpha_0) \\
&\quad + \Gamma_3(n-1)\beta_0], \\
\tilde{\omega} &= (\alpha/T)[\Gamma_0(2\alpha_0 + (n-1)\alpha) - \Gamma_1\beta_0 - \Gamma_2(n-1)\alpha_0 \\
&\quad + \Gamma_3(n(\beta_0 + (n-1)\beta) - \beta_0)].
\end{aligned}$$

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