On different modes of firms' cooperation

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A mi familia y a Jimmy

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Chapter 1

Introduction

A combination of factors, such as the increasing market liberalization and global competition, fast changing technology and the need for faster growth, have justified the wave of alliances, mergers and acquisitions in United States, Japan and Europe during the last decade.

Considering the world as a whole, mergers and acquisitions were valued at $2.4 trillion in 1998. In 1999, this figure increased to $3.4 trillion, and in 2000, the total value of the deals worldwide crossed $3.5 trillion. Although, in recent years, the economic instability and the lack of business confidence have produced a significant decline in M&A activity ($2.063 trillion in 2001 and $1.2 trillion in 2002, according to Thomson Financial Securities Data), merger mania is still truly alive. Clear examples are the Bank of America Corp.'s recent acquisition of FleetBoston Financial Corp. in a $47 billion stock deal, and health benefits insurer Anthem Inc.'s purchase of bigger rival Wellpoint Health networks Inc. for about $16.4 billion in cash and stock, that place this last October as the best month for M&A in more than two years.

While M&A activity has considerably declined during the last two years, there is no similar slump in alliance activity. Indeed, the value of alliances has increased over time. Until 1996, any deal valued at more than $100 million generated a lot of attention.

However, by 1997, the rules started to change and a significant number of new alliances were easily breaking the $100 million barrier. Since then, alliances have been increasing in value every year. In 2000, it was Vertex Pharmaceuticals' $815 million deal with Novartis. In 2001, it was CuraGen's $1.3 billion alliance with Bayer. 2002 has been also a good year for alliances, with an increase in biotech alliance activity of over 20%. Moreover, analysts predict that alliance activity will continue to rise in the next years.

The type of cooperation chosen by the firms strongly depends on the particular characteristics of the industry and the intended goal to be achieved by the participating firms. A firm that intends to increase its size or add new activities to its business should consider merger or acquisition. On the contrary, for a firm that wants access to another firm's knowledge in a particular area, without considering complicated restructuring and commitments for the very long run, an alliance or a research joint venture is the right option. Research joint ventures are specially useful for industries with high speed of technological change. They allow the access to another firm's knowledge and the sharing of resources on a big project, without restricting the freedom to look for other market opportunities once the project has been accomplished. In other words, while mergers are the corporate equivalence to *marriages*, alliances or research joint ventures are like *love affairs*. Indeed, Steve Heyer, president of Turner Broadcasting Services, thinks that one of the big arguments for alliances and research joint ventures is the freedom to be promiscuous. However, though alliances and research joint ventures offer the chance to move on if something better comes along, they may also involve important cooperation and free-riding problems.

The purpose of this thesis is to analyze different forms of firms' cooperation, studying the problems that may arise and the private incentives that firms have to start such cooperation, while providing some applications to regulation policy.

In this context, as different modes of firms' cooperation involve different characteristics, each chapter contains different approaches and industrial organization techniques.

Thus, in the second chapter, contract theory is used to find optimal menus of subsidies and monitoring to implement socially optimal efforts in a research joint venture, with both moral hazard and adverse selection problems. The third chapter shows a takeover situation with asymmetric information, introducing a general signaling model. In pure signaling models, agents do not change their type through signals (for example, in the model of Spence, 1973, agents invest in education to signal their type but agents do not improve their ability through education). In more recent signaling models, agents are assumed to change their type through signals (for example, Aoki and Reitman, 1992, analyze a simultaneous signaling model in which cost functions are privately known. Investing in R&D, firms signal their type and become efficient with probability 1). Both extremes and intermediate situations are considered in the signaling model proposed in the third chapter. The fourth chapter introduces different stability concepts to study mergers. Most of these stability notions differ in the way that firms are assumed to react following a deviation. Finally, in the fifth chapter, standard industrial organization techniques are used to study private and social profitability of mergers among limited liability firms.

The rest of the present introduction is devoted to explain more in detail the main insights of each chapter.

In the second chapter of this thesis, we consider two firms with complementary research capabilities deciding to start a collaborative project. Each firm has a comparative advantage in one part of the project, so the project is divided in two different tasks and each firm works in a separate laboratory. Firms' research efforts are not verifiable so the members of the research joint venture have incentives to free-ride.

We analyze the optimal technology policy to solve firms' free-riding problems. However, we assume that, when intervening, the Government suffers an additional adverse selection problem due to the fact that public authorities are not able to distinguish the value of the potential innovation. Although subsidies and monitoring may be considered as equivalent policy tools to solve firms' free-riding problem, they lead to different social losses if the Government is not able to perfectly distinguish the value of the potential innovation. The supremacy of monitoring tools over subsidies is proved to depend on which type of information the Government is able to obtain about firms' R&D performance. In particular, if only partial results can be observable, it is better to use subsidies rather than monitoring. However, if research efforts become verifiable, monitoring becomes socially dominant. Besides, if subsidies and monitoring were not equivalent policy tools to solve firms' free-riding problem in the absence of adverse selection, their combination might be the optimal solution. On the one hand, if partial results monitoring is cheaper than subsidies, low value innovators should be monitored more intensively than high value innovators, while high value innovators should receive higher subsidies. On the other hand, if subsidies are less costly than research effort monitoring, it is optimal to monitor more intensively the high value innovators and grant higher subsidies to low value ones.

In the third chapter of this thesis, as briefly described above, we analyze the effects that takeover threats have on target firms' incentives to invest in R&D. Critics of takeovers usually argue that takeover threats may reduce target firms' R&D intensity. However, it is found that under takeover threats, target firms may increase R&D investment in order to signal their compatibility with the acquiring firm. In particular, we consider three firms with different marginal costs competing in a homogenous output oligopoly. We assume that the most efficient firm makes bids to acquire one of the other two. Once the takeover has been performed, the acquiring firm must decide whether to close one of the plants, or transfer its technology to the acquired firm and operate both plants in competition with each other. The decision on whether to shut down or not the acquired plant will strongly depend on the compatibility of the target firm, which is privately known. Firms' compatibility also affects the profits of outsiders.

The identity of the acquired firm depends on the market size and target firms' efficiency and compatibility. Target firms may affect this result investing in R&D. Through R&D investments, firms signal potential outsiders the kind of competition they may face and force them to accept lower takeover offers.

The fourth chapter of this thesis highlights the importance of partners fitting well for a stable merger to arise. It is usually claimed that mergers are more likely to work when a company chooses a partner that fits well, rather than one that is merely available. However, as the empirical evidence suggests, it is not obvious that the less firms fit, the less they merge. Indeed, industries facing higher difficulties in bringing together their technologies and computer systems, such as banks, telecoms or computer industries, are the ones with higher number of mergers. We provide a simple model to explain this phenomenon. We consider three asymmetric firms competing in the market. Only mergers between two firms are analyzed. We assume that mergers profitability depends on how well firms fit. We prove that if all firms are perfectly compatible, it is impossible to reach an agreement to merge, no matter the definition of stability, since the outsider makes pressure and manages to break the agreement. On the contrary, if not all firms fit, stable mergers may arise, even if the strongest definition of stability is applied.

In the last chapter of this thesis, we analyze mergers in a homogenous product market with uncertainty over demand, fixed costs, and limited liability debt financing. We consider n firms that compete in a Cournot market with uncertainty over demand. All firms enjoy a limited liability situation, that is, if firms become insolvent, creditors are paid whatever operating profits are available. Output decisions are taken before the uncertainty over demand is realized. Limited liability firms only care about good states, so as debt raises, they compete more aggressively. This is what Brander and Lewis (1986) called the limited liability effect of debt financing.

On the one hand, given the limited liability effect, merging parties compete more aggressively and mergers that were unprofitable in absence of any debt obligation may become beneficial. On the other hand, socially advantageous mergers may be unprofitable for the colluding firms. In these cases, public intervention is needed. Policies promoting such mergers are quite common in Asian countries. A clear example is the Financial Institution Merger Law (FIML) implemented by the Chinese Government in 2000. One possible way of public intervention consists on subsidizing mergers. However, it is proved that the combination of limited liability debt financing and an appropriate antitrust policy leads to higher social welfare than subsidies, since the reduction of market quantity is mitigated.

Each chapter is self-contained, and therefore can be read independently.

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Chapter 2

Optimal technology policy: subsidies versus monitoring

2.1 Introduction

There is strong theoretical base and empirical evidence that the social benefit from R&D may be greater than the benefit available to the innovator. A variety of strategic and opportunistic reasons may cause a spread between private and social incentives to conduct R&D. One possible source of divergence is the existence of technological spillovers since firms conducting R&D do not take into account the positive effects that their own R&D investments have on the rest of the economy. As a result, the private investment in R&D is lower than the socially optimal.[1] Another reason for the gap between social and private returns to R&D is related with the problems of opportunism and asymmetric information faced by firms in collaborative projects, since important inputs of joint research activity cannot be contractible.[2] We focus on this latter issue. We consider a collaborative project that requires the complementary skills of two risk-

[1]For a related literature see, for example, D'Aspremont and Jacquemin (1988), Kamien, Muller and Zang (1992) or Kesteloot and Veugelers (1995).

[2]See, for example, Choi (1992) or Pérez-Castrillo and Sandonís (1996).

neutral firms. Research efforts are not verifiable and privately costly so firms have incentives to free-ride and the final provision of R&D is lower than the socially optimal (double-sided moral hazard problem).

The difference between private and social returns to R&D investments constitutes one of the main justifications for public intervention. Technology policy makers have a number of means of encouraging such investment, including subsidies and monitoring processes. Subsidized cooperative R&D projects have become an important tool of the industrial policy in the United States, Japan and Europe. Some examples of subsidized research corporations in the United States are the Microelectronics and Computer Consortium (MCC) or the ones sponsored by the Semiconductors Manufacturing Technology (SEMATECH). European governments have also agreed in sponsoring collaborative research through programs such as the European Research Coordination Agency (EUREKA), European Strategic Program for R&D in Information Technology (ESPRIT) or the Base Research in Industrial Technology for Europe (BRITE). Furthermore, Tripsas, Schrader and Sobrero (1995) point out that 80% of the research loans made by the Japanese Government are devoted to joint projects. Despite the extended application of subsidies as a policy tool some governments may prefer monitoring mechanisms in which more public control is combined with money incentives. Clear examples are the MITI in Japan, in which the Government assumes the role of an effective coordinator, or the Società di Ricerca Program in Italy, in which a manager is selected to supervise the execution of individual projects and coordinate the ongoing efforts of participating firms. Moreover, the Advanced Technology Program (ATP) in the United States combines initial subsidies with some monitoring tools, providing guidance in putting together a RJV and periodical evaluations of firms' R&D performance.

The literature examining R&D subsidies is rather sparse despite their extensive use as a policy tool.[3] Unfortunately, a policy relying on subsidies to correct R&D market failures has potentially serious shortcomings. Katz and Ordover (1990) argue that such policies may be subject to severe asymmetric information problems: firms reporting higher R&D expenditures or better potential innovations in order to collect higher subsidies.[4] As a result, some authors look at monitoring policies as a possible alternative. In particular, Tripsas, Schrader and Sobrero (1995) argue in their study of the Italian Società di Ricerca program that the Government may discourage opportunistic behavior on the part of RJV participants through improved monitoring (by formal auditing of the activities of the private sector members), through an ability to threaten reprisal (either explicitly if the RJV gives the Federal laboratory the legal power to discipline deviators or implicitly if the Federal laboratory is willing to exclude noncompliant firms from future collaborative activities), or through facilitating longer term relationships. However, there is not a general agreement about the effectiveness of any of these policy tools over the another to encourage R&D investments.

We analyze the optimal technology policy in a context of asymmetric information. A public regulator will try to solve firms' free-riding problems and restore their incentives to conduct R&D. However, it will be assumed that the regulator does not know precisely how much money firms will be able to obtain through patents. Therefore, the Government trying to solve the underprovision of efforts faces an additional adverse selection problem, given its inability to distinguish the value of the potential innovation.

There exist in the literature some papers designing optimal mechanisms to implement socially optimal efforts in the presence of both moral hazard and adverse selection problems (see Picard and Rey, 1990, or McAfee and McMillan, 1991). They find optimal

[3]See, for example, Spencer and Brander (1983), Pérez-Castrillo and Verdier (1993), Romano (1989), or Stenbacka and Tombak (1998)

[4]Indeed, Brown (1984) found that in response to the Economic Recovery Act of 1981 the increases in R&D expenditures reported with tax purposes greatly exceeded the growth in spending reported in *Business Week's* survey of R&D expenditures.

mechanisms such that imperfect observability of the contributions entails no additional welfare loss compared to the pure adverse selection case. Although these papers are important contributions from the theoretical point of view, they propose rather complex mechanisms hard to be empirically implemented by a social planner. The purpose of this paper is not the design of such theoretical mechanisms rarely applied by governments but the analysis and comparison of two extensively used policy tools: subsidies and monitoring.

Two possible monitoring systems are considered. In the first one, all the Government is able to verify is whether a firm has succeed or not in fulfilling its part of the project but nothing about real research efforts. This type of monitoring is more likely to be applied in high technology industries, in which verifying real efforts might become extremely hard. In the second monitoring system, the Government manages to verify the real research effort exerted by each of the participating firms. We consider as a benchmark a situation in which subsidies and both monitoring systems are equivalent to increase firms' incentives to conduct R&D if the Government is able to perfectly distinguish the value of the potential innovation. However, different policies induce different social losses if an additional adverse selection problem arises. Subsidies and monitoring are no longer equivalent to solve firms' moral hazard problem when the regulator faces an additional problem of adverse selection. It is proved that if only partial results can be observable, it is better to use subsidies rather than monitoring. However, if research efforts become verifiable monitoring is socially dominant. Therefore, the superiority of monitoring tools over subsidies depends on which type of information the Government is able to obtain about firms' R&D performance. It is also discussed the optimal combination of subsidies and monitoring if these policy tools are not ex-ante equivalent. On the one hand, if partial results monitoring is cheaper than subsidies, low value innovators should be monitored more intensively than high value innovators, while high value innovators should receive higher subsidies. On the other hand, if subsidies are less costly than research effort monitoring, it is optimal to monitor more the high value innovators and grant higher subsidies to low value ones.

The paper is organized as follows. Section 2.2 presents the model, firms' free-riding problem and the additional adverse selection problem for the regulator. In section 2.3, we analyze the welfare losses induced by each policy tool when the Government is unable to distinguish the type of the project and discuss the optimal policy choice. Section 2.4 concludes.

2.2 The model

Let us consider two risk neutral firms with complementary research capabilities that decide to start a collaborative project. For the sake of simplicity, we consider that each firm has a comparative advantage in a part of the project so research is divided in two different tasks and firms work in separated laboratories. Once both firms have successfully completed its corresponding task, results are combined to obtain an innovation of value $V \in \{\overline{V}, \underline{V}\}$ with $\overline{V} > \underline{V}$. The value of the innovation is common knowledge for both firms at the beginning of the collaborative agreement. If one firm fails in fulfilling its part of the project, the innovation is not obtained.[5] We assume it is not possible for a firm to verify that it has succeeded in solving its part but its partner has not, that is, it is not possible for firms to sign contracts based on individual success.

Even if the innovation is not finally achieved, a successful firm learns new technical methods and procedures that may be applied in future research. We assume firms obtain

[5] These kind of collaborative projects are quite common in high technology industries. For example, Sandonís (1993) points out that, when developing the aircraft Boeing 767, a consortium of Japanese firms made the fuselage, Aeritalia designed and produced the tail and the rudder and Boeing took charge of the wings, cabin and final assembling. Another example is the production of the "V. 2500 turbofan jet engine" motor by Pratt & Whitney and Rolls Royce with a clear division of the project based on the comparative avantage of each firm.

some particular utility w if they manage to successfully finish their task, independently of whether its partner has succeeded or not.[6] The private benefit w can be interpreted as the value of the know-how firms learn when fulfilling their task and it is assumed to be strictly smaller than the innovation value, $\underline{V} > w > 0$. This assumption ensures that we obtain an interior solution both in the cooperative and noncooperative game without introducing complex functional forms.

Firms decide about the amount of real R&D investments, called efforts, which affect the success of their part of the project. For the sake of simplicity, assume that the effort e_i that firm i exerts in fulfilling its task represents the probability of it being successful, which is independent of the probability of success of its partner. R&D efforts are not observable and hence not contractible. The cost of research effort is assumed to be quadratic, implying the existence of decreasing returns to R&D expenditures.[7] In particular, the cost of firm i's R&D investment is assumed to be $\theta e_i^2/2$, where θ is inversely related to the efficiency of firms' innovation process. Given our interpretation of R&D efforts as the probabilities of success, assuming $\theta > 2\overline{V}$ is sufficient to guarantee that equilibrium efforts belong to the interval $[0, 1]$.

The timing of the game is as follows: First, Nature determines whether the project has a high value $\overline{V}$ or a low value $\underline{V}$. The final innovation value will strongly depend on the characteristics of the market in which it will be introduced such as the level of demand and competition, innovator's ability to price discriminate or degree of technological spillovers. The realization of the innovation value is perfectly observed by both firms. Secondly, firms specify the collaborative agreement including the division

[6] Dasgupta and Tao (1998) also consider that a collaborative project may generate some exclusive benefits for the two firms but they only take them into account if firms have succeeded in developing the targeted products.

[7] The assumption of quadratic cost for R&D investments is usually applied in the cooperative and noncooperative R&D literature. Some examples are Beath, Poyago-Theotoky and Ulph (1998), D'Aspremont and Jacquemin (1988), Kesteloot and Veugelers (1995) and Sandonís (1993).

of tasks and share of profits α_i. Each firm is responsible just for a part of the project and it simultaneously and noncooperatively undertakes an unobservable effort that is privately costly. Finally, firms obtain their payoffs: If firm i is successful in performing its assignment, it obtains w if its partner fails and $(\alpha_i V + w)$ if its partner succeeds. If firm i does not succeed, it receives nothing, independently of whether its partner has succeeded or not. This assumption is justified by the fact that firms carry out their research in separate laboratories. The expected profit for firm i is given by the following expression:

$$\Pi_i(e_i, e_j, \alpha_i) = e_i e_j \alpha_i V + e_i w - \theta \frac{e_i^2}{2}, \tag{2.1}$$

with $V \in \{\overline{V}, \underline{V}\}$, $\alpha_i \in [0, 1 - \alpha_j]$, $i \neq j$ and $i, j = 1, 2$.

2.2.1 Equilibrium in efforts

Once the project has been divided in two independent tasks and the sharing rule has been fixed, RJV participants are assumed to behave noncooperatively. Firm i maximizes the expected profits given by expression (2.1), choosing its research effort while taking its partner's effort as given. The non-cooperative Nash equilibrium efforts are given by:

$$e_i^{nc}(V) = \frac{w\theta + \alpha_i w V}{\theta^2 - \alpha_i(1-\alpha_i)V^2} \text{ with } V \in \{\overline{V}, \underline{V}\}, i \neq j \text{ and } i, j = 1, 2.$$

When acting in a noncooperative way, firms only take into account their private benefits disregarding that their research decisions will have an effect in its partner's profits. As a result, the choice of R&D investments may not be optimal from the social point of view. We will consider as the first-best equilibrium the research efforts resulting from internalizing the effects that a firm may generate to the another, that is, from cooperating in the choice of efforts. As defined before, the first-best equilibrium R&D efforts for every project $V \in \{\overline{V}, \underline{V}\}$ are the solution of the following maximization problem:

$$\underset{e_1, e_2}{Max} \left\{ e_1 e_2 V + e_1 w + e_2 w - \theta \frac{e_1^2}{2} - \theta \frac{e_2^2}{2} \right\},$$

that is $e_i^*(V) = \frac{w(\theta+V)}{\theta^2 - V^2}$ with $i \neq j$ and $i, j = 1, 2$.

Comparing the cooperative and noncooperative approach, it is straightforward to show that the resulting equilibrium efforts will be different, no matter firms' agreement on how to share innovating profits. This is a well-known result in team theory due to Holmstrom (1982) and it is formally stated in the following lemma.[8]

Lemma 2.1. *There does not exist any sharing rule* $\alpha_i \in [0, 1 - \alpha_j]$ *such that for every firm* i *of type* V *the non-cooperative Nash equilibrium effort* $e_i^{nc}(V)$ *coincides with its first-best* $e_i^*(V)$.

Since both firms are symmetric, it is optimal to equally split innovation profits and the noncooperative solution yields to lower research effort than the first-best optimum. Given that firms equally share the innovation profits but efforts are privately costly and not verifiable, RJV participants have incentives to free-ride. The problems of opportunism and asymmetric information reduce the incentives to exert research effort and lead to an insufficient investment in R&D (double-sided moral hazard problem). This is formally summarized in Lemma 2.2.

Lemma 2.2. *The optimal sharing rule is* $\alpha_i = \frac{1}{2}$ *,* $i \neq j$ *and* $i, j = 1, 2$*. Moreover, for every firm of type* V *the noncooperative Nash equilibrium effort* $e^{nc}(V)$ *is strictly smaller than its first-best* $e^*(V)$.

A benevolent social planner would surely be interested in solving firms' coordination problems and restore their incentives to conduct R&D. However, the Government is in general less informed about market conditions than firms and it will be extremely hard for it to distinguish whether the innovation value is high or low. All the regulator knows is the proportion $p \in [0, 1]$ of high value innovations. The Government trying to solve the moral hazard problem within a RJV will run into an additional problem of adverse

[8] See Gandal and Scotchmer (1993), Morasch(1995), Radner (1991) and Vislie (1994) for exceptions to this result. These exceptions do not apply here.

selection, because of its inability to distinguish the type of the project and the potential strategic behavior of innovators. We will show in next section that the choice of the optimal policy is not trivial at all.

2.3 Policy tools

Several policies may be used to alleviate firms' incentives to free ride and encourage R&D investment, such as subsidies or monitoring. The literature examining R&D subsidies is rather sparse despite their extensive use as a policy tool and there is still not a general agreement about its effectiveness to correct R&D market failures. Instead some economists claim that a monitoring policy could be more appropriate to encourage R&D investments since it combines money incentives with public control on firms' activities. In this section, we will consider as benchmark a situation in which both policy tools are equivalent to increase firms' incentives to cooperate. This result agrees with Holmstrom (1982) and McAfee and McMillan (1991) in maintaining that in presence of subsidies, monitoring is not needed to reduce the incentives to free-ride of the members of a team.

Although subsidies and monitoring may be equivalent policy tools to mitigate the moral hazard problem, they will not be longer equivalent if an adverse selection problem is added. If the Government is unable to identify the type of the project, it will have to look for the best way to, not only encourage firms to cooperate, but also discourage firms to lie about the value of their future innovation. Therefore the choice of the best way of intervention becomes more complex.

There are, roughly, two essential ways to give subsidies. One is through cost subsidies when the Government pays some of the expenditures undertaken during the innovation process. The other is through the patent system and consists of granting an additional prize to the innovator. Pérez-Castrillo and Verdier (1993) proved that under severe moral hazard problems it is not optimal for technology policy makers to use cost subsidies. Probably that is why the patent subsidy system has been largely employed in United

States and Germany in high technology industries, such as the biotechnology sector. (See Adelberger (1999) and Abramson *et al.* (1997)). Since as a benchmark we are considering equivalent policy tools to solve a moral hazard problem, we will focus on patent subsidies.

An alternative technology policy to alleviate the problem of free-riding consists of monitoring firms' actions. By monitoring we will mean all those mechanisms used in order to obtain information about firms' research effort and decrease their incentives to behave in an opportunistic way. Recall that, though they are engaged in a collaborative project, RJV participants are rivals in other markets. Therefore, firms will not allow their partners to monitor their actions, since other strategic information may be revealed during the evaluating processes. However, the Government, in its role as an "honest broker", can strongly discourage firms' strategic behavior and increase their incentives to innovate.[9] The Government sends some research experts to firms' laboratories to judge and evaluate their R&D performance. The monitoring mechanism includes direct supervision and money incentives. Depending on the efficacy of the evaluating process, we will distinguish two possible cases. In the first case, Federal advisers are only able to identify whether a firm has individually succeeded or not but they learn nothing about research efforts. We refer to this as partial results monitoring. In the second case, scientific experts, after an arduous and costly auditing process, are able to verify the real effort exerted by each RJV member when fulfilling their corresponding task. We refer to this as research efforts monitoring.

[9]Leyden and Link (1999) argue that it is precisely this role of an "honest broker" what induces some RJV to invite a public partner to participate. Moreover, they argue that governments embody unique human and technical capital that is rarely available in the private sector and thus they may be able to monitor firms at a lower cost than RJV participants. These authors provide empirical evidence that larger collaborative research relationships have a greater incentive to include a Federal laboratory as a member than smaller ones, since free-riding problems become significantly more important in large RJV.

We will assume, as it is usual in regulation models (Laffont and Tirole, 1993), that public funds are obtained through distortionary taxation. The distortion costs λ are identical for all means of intervention. In all cases, firms behave noncooperatively so socially optimal efforts must be implemented as a noncooperative Nash equilibrium. We will prove that regulator's inability to identify each type of project affects the optimal results attained by each policy tool in a different manner and the choice of the optimal technology policy is not trivial.

2.3.1 Patent subsidies

Let S_i represent the patent subsidy received by firm i, that is, the added prize that it will obtain once the innovation is discovered. Since we are considering symmetric firms, both RJV members receive the same subsidy in case of joint success, that is $S_1 = S_2 = S$. However, the level of the subsidy may differ for different types of projects. Let us denote by $\overline{S}$ and $\underline{S}$ the patent subsidies received by each of the participating firms of a high value and low value project, respectively.

If the Government were able to perfectly distinguish each type of project and distortionary costs were not excessive, it would be socially optimal to spend more resources in the high value innovation project than in the low one. Obviously, if the distortionary cost of public funds were too high it would be better not to intervene or, in some cases, to subsidize just the high value project. On the other hand, if there were not distortion costs for public funds, $\lambda = 0$, and the Government could anticipate the innovation value of every project, first-best equilibrium efforts could be attained in both type of projects. This is no longer true if the regulator faces an adverse selection problem as it is stated in the following proposition.

Proposition 2.1. *If the Government is unable to distinguish the type of the project, the optimal menu of subsidies* $\left\{\overline{S}; \underline{S}\right\}$ *satisfies the following properties:*

a) The optimal subsidy coincides for both types of projects, that is $\overline{S} = \underline{S} = \widetilde{S}$.

b) *There exists an upper bound for the distortion cost* λ^S *such that the optimal subsidy is zero above it. Below* λ^S*, the optimal subsidy* $\widetilde{S}$ *is a strictly decreasing and convex function of* λ*. Moreover, below* λ^S *the maximum social benefit* $W(\widetilde{S},\overline{V},\underline{V})$ *is also a strictly decreasing and convex function of* λ.

c) *First-best equilibrium effort is never attained for the high value project while the effort implemented for the low value project may be excessive.*

We know that it is socially optimal to devote more public funds to a high value innovation project than to a low one. However, if the Government is unable to distinguish the type of the project, low value innovators have few incentives to reveal their true type and the policy maker will be forced to establish the same subsidy for both types of projects. Moreover, Proposition 1 shows that the first-best equilibrium effort is never obtained for the high value projects while R&D investment may be higher than the socially optimal for the low ones. The main results of Proposition 2.1 are summarized in Figure 2.1. The social benefit for different values of the distortion cost λ is plotted. As it is shown in the figure, the social benefit is strictly concave in S and strictly decreasing in λ. The darker curve corresponds to the maximum social benefit for every possible value of the distortion cost, a strictly decreasing and convex function of λ. If the distortionary cost is higher than λ^S, it is optimal for the Government not to intervene and the maximum social benefit is just the one without intervention, $W(0,\overline{V},\underline{V})$. Below λ^S, the optimal subsidy is always below $\overline{V}/2$ (so first-best effort is never attained for high value projects) while it is higher than $\underline{V}/2$ if the distortion cost is below λ_S (so the effort implemented for the low value project turns out to be excessive).

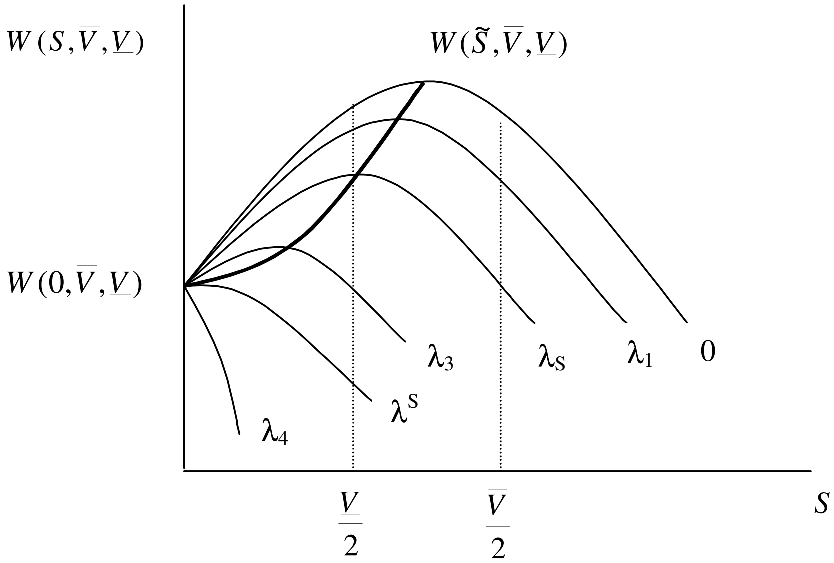

Figure 2.1: Optimal subsidy if the Government cannot distinguish the type of the project, with $0 < \lambda_1 < \lambda_S < \lambda_3 < \lambda^S < \lambda_4$.

2.3.2 Partial results monitoring

In this case, Federal experts are sent to each RJV member's laboratory in order to gather any kind of information about firms' research effort and evaluate their innovation process. However, there are many situations in which it may become especially difficult for experts to verify real research efforts. For example, it could be really hard to verify whether researchers are thinking of how to go through the project or how to organize their weekend. In this subsection we assume that experts are unable to verify efforts but they have the specialized knowledge and advanced methods to unequivocally identify partial success in a costless way.[10] Let m_i be the monetary transfer that the regulator makes to firm i if it is individually successful, independently of whether its partner has

[10] Assuming no additional costs to the partial results monitoring process is irrelevant to the main results of the paper.

succeeded or not. Since both firms are symmetric, they receive the same amount of transfer in case of individual success, $m_1 = m_2 = m$. However, the amount of monetary transfers that each firm receives may depend on the type of the project they are working on. Let us denote by $\overline{m}$ and $\underline{m}$ the monetary transfer that each participating firm obtains in case of individual success in a high value and low value project, respectively.

If the Government could unequivocally identify each type of project and distortionary costs were low enough, it would be socially optimal to spend more resources in the high value innovation project than in the low one. However, as with subsidies, if the distortionary cost of public funds were excessive it would be better not to intervene or, in some cases, to reward just high value innovators. Again, if there were no distortion costs for public funds, $\lambda = 0$, first-best equilibrium efforts could be achieved in both types of projects. How this policy changes when the Government suffers an additional adverse selection problem is formally stated in the following proposition.

Proposition 2.2. *If the Government is unable to distinguish the type of the project, the optimal menu of monetary transfers associated to partial results monitoring* $\{\overline{m}; \underline{m}\}$ *satisfies the following properties:*

a) The optimal monetary transfer coincides for both types of projects, that is $\overline{m} = \underline{m} = \widetilde{m}$.

b) There exits an upper bound λ^m *such that the optimal transfer is zero above it. Below* λ^m*, the optimal transfer* $\widetilde{m}$ *is a strictly decreasing and convex function of* λ*. Moreover, below* λ^m *the maximum social benefit* $W(\widetilde{m}, \overline{V}, \underline{V})$ *is also a strictly decreasing and convex function of* λ.

c) First-best equilibrium effort is never attained for the high value project while the effort implemented for the low value project may be excessive.

If the Government is unable to distinguish the type of the project and Federal experts are just able to identify partial success, policy makers will be forced to establish the same reward for both types given that low value innovators will act strategically and pretend to be high value. Moreover, as it happens with a subsidy policy, the first-best equilibrium effort is never attained for the high value projects while research investments may be excessive from a social point of view for the low ones.

2.3.3 Patent subsidies versus partial results monitoring

In this section we will compare optimal solutions obtained through patent subsidies and monitoring, when all Federal experts are able to learn from firms' innovation processes is their potential partial success. If the Government can perfectly distinguish the value of the potential innovation, patent subsidies and partial results monitoring are equivalent policy tools to increase firms' incentives to conduct R&D. They induce the same level of research effort and social expected costs. Although the optimal subsidy for each type is higher than the optimal monetary transfer associated with partial results monitoring, the former is less likely to be paid.

Nevertheless, both policy tools are no longer equivalent if the Government is unable to distinguish the value of the potential innovation. In particular, the unfavorable effects of the adverse selection problem are more intense in monitoring than in the case of subsidies, as it will be formally proved in next proposition.

Proposition 2.3. *If the Government is unable to distinguish the type of the project, patent subsidies socially dominate partial results monitoring in the sense that they induce higher social benefits.*

Given the additional adverse selection problem the Government is facing, patent subsidies provoke lower social losses than rewards to partial success.[11] The explanation of this result is related with the way each particular policy affects efforts. We know, given their inability to distinguish the type of the project, policy makers are forced to

[11] This result is even stronger if we assume a cost associated with the partial results monitoring process.

reward both types in the same manner. For both policy tools, high (low) value firms will be rewarded less (more) than the socially optimal and, as a result, high innovators will exert less effort than their first-best while low type's effort may be excessive. Social losses can be measured as the difference between the effort exerted by high value and low value innovators: The higher this difference, the lower the social loss. Monitoring affects efforts more directly than patent subsidies, so making mistakes in setting the right reward for each type of firm has more drastic consequences for the monitoring case. Hence, both type's efforts are closer and social losses higher if a monitoring policy is applied. The result of Proposition 2.3 is depicted in Figure 2.2. We plot, for every possible value of the distortion cost λ, the maximum social benefit obtained by subsidies and monitoring, respectively. From Propositions 2.1 and 2.2 we know that, for both policy tools, the maximum social benefit is a strictly decreasing and convex function of the distortion cost. However, as it is shown in the figure, the maximum social benefit if monitoring is used, $W(\widetilde{m}, \overline{V}, \underline{V})$, is smaller than or equal to (in case of no intervention) the maximum social benefit obtained through patent subsidies, $W(\widetilde{S}, \overline{V}, \underline{V})$, so patent subsidies are socially dominant.

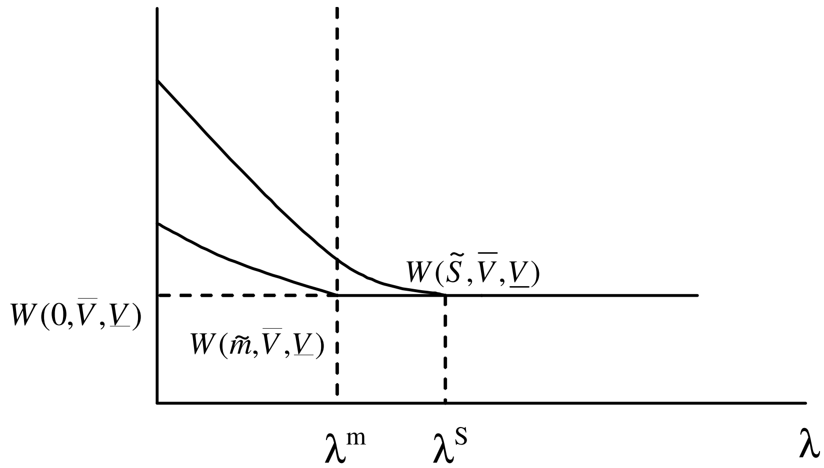

Figure 2.2: If the Government cannot distinguish the type of the project, patent subsidies dominate partial results monitoring.

Proposition 2.3 states that if an additional adverse selection arises and the Government can only choose a policy tool to regulate RJV participants and alleviate their free-riding problems, it is socially optimal to use patent subsidies instead of partial results monitoring. However, could policy makers do better if they were able to combine both means of intervention? The answer is no. Through the combination of subsidies and monitoring, the Government has still to prevent firms to lie about their type. Regulator cannot encourage high type firms to innovate without providing the suitable incentives to low value innovators. As a result, research efforts are identical to the case in which only patent subsidies are applied.[12]

Proposition 2.4. *The Government can do no better when it combines patent subsidies and partial results monitoring than when it simply uses patent subsidies.*

2.3.4 Research efforts monitoring

In this last case, Federal experts are sent to firm's research laboratories and they start a laborious and costly auditing process in order to verify the R&D investment made by RJV participants. We assume after such exhaustive audits, Federal specialists are able to perfectly observe the research effort exerted in each laboratory. However, the auditing process is too complex and the Government will only send Federal experts to firms' facilities with some probability $q \in [0, 1]$, identical for both members of the RJV. If Federal experts are sent to research laboratories, the true results of the audits will be published in public documents and noncompliant firms will suffer an adverse publicity and loss of prestige.[13] This shame-based sanction may be particularly efficient in RJV

[12] Notice that we are assuming the same distortion cost λ for all means of intervention. If these costs were different, it could be optimal to combine both policy tools. This possibility will be considered in the last subsection.

[13] There are several criticisms to the use of monetary fines to corporate offenders. Instead of this, French (1984) proposes a shame-based sanction in which noncompliant firms will suffer bad publicity.

since image and reputation are at the very heart of this business, given the usual need to form research partnerships and obtain external funds.[14] Little sustained success has ever been enjoyed by research laboratories with a bad reputation. Let P denote the expected monetary losses suffered by adverse publicity.[15] The exogenous penalty P is assumed to be identical for both types of projects since negative effects of bad reputation are independent of the value of the current innovation.

Given the shame-based sanction P, the Government must choose the socially optimal audit probability for each type of project, anticipating that RJV participants will behave noncooperatively. Let $q((e,e),V)$ represent the minimum probability of auditing a project of type V to implement (e,e) as a noncooperative Nash equilibrium effort. The following lemma provides some insights about the characteristics of this minimum audit probability.

Lemma 2.3. *The minimum audit probability for a type V project $q((e,e),V)$ is a strictly increasing function of e and strictly decreasing of P and V.*

Audits imply a fastidious and socially costly process so that Government will set the minimum probability of auditing necessary to implement its research policy. For the sake of simplicity and in order to favour further comparisons with other policy tools, we will assume linear audit costs, $C(q) = kq$, where k is inversely related to the efficiency of Federal experts during the auditing process. Finally, notice that there is a

He called it the "Hester Prynne Sanction", derived from the punishment inflicted in the novel *The Scarlett Letter*.

[14] As an example of the relevance of image and reputation, we can refer to the ATP case. The ATP frequently elaborates "an independent, objective and confidential evaluation" of the strength of firms' R&D performance. Many firms have reported that ATP support was an important factor in securing additional funding.

[15] This sanction P may reach really high values. In a study of 17 major corporations that have suffered adverse publicity over an offense or serious incident, executives at the middle and higher levels of management reported that loss of corporate prestige was regarded as more serious than the payment of a stiff fine (French, 1984).

positive relationship between the research effort chosen by the social planer e and its corresponding audit probability $q((e,e),V)$. Hence, it is equivalent for the Government to look for the optimal audit probability or the maximum research effort.

If the Government does not face any asymmetric information on the side of the innovation value, it implements higher efforts for the high type project. It is obvious that the monitoring policy has no effect on firms' incentives to innovate if the auditing process is not connected to any real sanction. Shame-based sanctions are designed to threaten prestige and image but they can only be effective if the noncompliant firm does regard social stigmatization as a matter of importance. If this is not the case, the monitoring policy is completely useless and the probability of auditing becomes a vain threat. However, whenever researchers care for a good reputation and prestige the monitoring policy will yield to higher R&D investments than without intervention. In particular, if the auditing process is totally costless, first-best equilibrium efforts are implemented for each type of project. Next proposition shows that all these results continue to hold even if the Government becomes unable to distinguish whether an innovation is high or not.

Proposition 2.5. *The optimal menu of efforts and audit probabilities* $\{[(\overline{e},\overline{e}), q((\overline{e},\overline{e}),\overline{V})]$*;* $[(\underline{e},\underline{e}), q((\underline{e},\underline{e}),\underline{V})]\}$ *coincides for the case in which the Government can and cannot distinguish the type of the project .*

Proposition 2.5 states that the adverse selection problem does not have any effect on the optimal monitoring policy if real research efforts can be perfectly observed through an auditing process. Firms' incentives to behave opportunistically and untruthfully reveal their type disappear if Federal auditors can verify efforts and force them to exert the effort of the revealed type. The main difference with other policy tools is that efforts are verifiable and hence firms are obliged to exert the research effort they announced. On the contrary, with patent subsidies and partial results monitoring, firms receive the monetary transfers corresponding to the type they announce but they exert the effort corresponding to their true type. Low value innovators are willing to receive as much money as high value innovators but they do not want to exert as much research effort as high value firms do. As a result, if efforts are perfectly observable the incentives for low value researchers to lie about their type entirely disappear.

2.3.5 Patent subsidies versus research effort monitoring

Now we will compare patent subsidies and monitoring when Federal experts are able to verify firms' research efforts through an auditing process. Recall it is not in the interest of low value innovators to truthfully reveal their type in a patent subsidy policy and the adverse selection problem negatively affects optimal results. On the other hand, if firms are monitored the adverse selection problem vanishes as it was proved in Proposition 2.5 and monitoring may socially dominate patent subsidies. This is formally stated in the following proposition.

Proposition 2.6. *If patent subsidies and research effort monitoring are equivalent policy tools to alleviate firms' free-riding problem when the Government can distinguish the type of the project, in the sense that they yield the same level of research effort or social benefit, patent subsidies are socially dominated by effort monitoring when the Government cannot distinguish the type of the project.*

Once again we should wonder whether the Government can improve social benefit combining both monitoring and patent subsidies. The answer is still negative if the shamed-based sanction is sufficiently high. The reason is that though patent subsidies and monitoring may be equally effective to solve the moral hazard problem, the former implies a higher social cost than research effort monitoring. Then, it is not sensible for the social planner to combine both policy tools.

Proposition 2.7. *If P is sufficiently high and λ small enough and patent subsidies and research effort monitoring implement the same level of research effort when the*

Government can distinguish the type of the project, the Government can do no better when it combines patent subsidies and effort monitoring than when it simply uses effort monitoring.

2.3.6 Optimal combination if subsidies and monitoring are not ex-ante equivalent

Finally, we should briefly comment when it is optimal to combine patent subsidies and monitoring tools. Along the paper, we have considered equivalent policy tools in the absence of any adverse selection problem and we have argued that it is not sensible for regulators to combine patent subsidies and monitoring. Obviously this is not longer true if policy tools are not ex-ante equivalent, that is, if they are associated with different social costs before the adverse selection problem arises. There are two ways in which policies can differ in these social costs. On the one hand, we have assumed that public funds are obtained through distortionary taxation and distortion costs are identical for all means of intervention. However, policies may differ in the distortion cost. The distortion cost of public funds depends on the specific characteristics of the fiscal program, such as the kind of tax instruments used. We know patent subsidies require the Government to spend more public resources than partial results monitoring (though they are less likely to be paid). Thus, patent subsidies may involve more tax instruments than partial results monitoring and induce higher distortion costs.[16] On the other hand, policies may differ in how expensive are the processes they imply. In this sense, the auditing process necessary to verify real research efforts may result extremely costly to be performed in both types of projects and the Government may be interested

[16] Hansson and Stuart (1985), in a study of the Swedish fiscal program, conclude that taxes on capital are more distortionary than taxes on labor. Hence if, for example, partial results monitoring is financed just through taxes on labor but patent subsidies require both taxes on capital and taxes on labor, the latter would induce higher distortion costs than the former.

in combining this policy with patent subsidies.

It is optimal to combine patent subsidies and monitoring if the most effective policy tool turns out to be also the most expensive. The optimal combination of subsidies and monitoring goes through applying more intensively the most effective policy tool to high value innovators, that is, patent subsidies if only partial results can be observable or monitoring if research efforts become verifiable. However, the Government should provide low value innovators the right incentives to tell the truth while encouraging high value innovators to increase their research efforts.

Corollary 2.1. *If the Government is unable to distinguish the type of the project, it may be optimal to combine patent subsidies and monitoring. In particular, if partial results monitoring implies lower social costs than patent subsidies, it is optimal to monitor more the low value innovators* $\overline{m} \leq \underline{m}$ *and give higher subsidies to high value firms* $\overline{S} \geq \underline{S}$*. On the other hand, if patent subsidies are less costly than research effort monitoring, it is socially optimal to monitor more the high value innovators* $\overline{e} \geq \underline{e}$ *and give higher subsidies to low value firms* $\overline{S} \leq \underline{S}$*.*

From Corollary 2.1 we can conclude that a combination of subsidies and monitoring may be socially optimal if both means of intervention imply different social costs. In all cases, the Government should apply more intensively to high value innovators the most effective, though most expensive, policy tool. To be precise, if partial results monitoring is comparatively cheaper than patent subsidies it is optimal to monitor more the low value innovators and give higher subsidies to high value firms. Obviously, if partial results monitoring is more expensive than patent subsidies, combination has no sense since the former is also more inefficient. On the other hand, if patent subsidies are less costly than research effort monitoring, it is socially optimal to monitor more the high value firms and give higher subsidies to low value projects.[17] Again, no combination is sensible if research efforts monitoring is cheaper than patent subsidies, since it is also

[17] Similar conclusion can be found in Caballero (1999).

more efficient.

2.4 Conclusions

It is usually the case that when a third party tries to solve a problem between two agents, it is unable to find out all the relevant information. Although some tools may be equivalent to solve the initial problem of agents, they are no longer equivalent if some information is missing. We provide a clear application of this fact related with firms' incentives to invest in R&D in collaborative projects.

In R&D collaborative projects where firms' actions are not verifiable, the problems of opportunism and asymmetric information reduce the incentives to exert research effort and lead to an insufficient investment in R&D. The Government trying to solve the underprovision of efforts faces an additional adverse selection problem, given its inability to distinguish precisely how much money innovators will be able to make from patents.

We focus on two different means of public intervention, patent subsidies and monitoring, because of their extensive use as policy tools. We assume two possible monitoring systems, one where the Government is able to observe just partial results and one where the Government is able to observe the real research effort exerted by firms. The first monitoring system may correspond to high technology industries in which observing research efforts may result specially hard.

We consider as benchmark a situation in which patent subsidies and both monitoring systems are equivalent policies to increase firms' incentives to conduct R&D. Although subsidies and monitoring are ex-ante equivalent, they imply different social losses if an additional adverse selection problem arises. In particular, if the Government cannot observe research efforts, patent subsidies must be applied while monitoring is the optimal policy if efforts become verifiable. Therefore, the supremacy of monitoring tools over patent subsidies is clearly dependent on which type of information the Government can obtain about firms' R&D performance. Moreover, if subsidies and monitoring are not ex-ante equivalent and differ in their costs, it might be optimal to combine them. Combination is only sensible if the most effective policy tool is also the most expensive. In each case, it is optimal to apply more intensively the most effective, though most expensive, policy tool to high value innovators. To be more precise, if partial results monitoring is cheaper than patent subsidies, it is optimal to give higher subsidies to high value innovators and monitor more the low value ones. However, if patent subsidies are less costly than research effort monitoring, it is better to monitor more the high value projects and give higher subsidies to low value ones.

Finally, it is worth highlighting that the main conclusions can be extended to other economic areas, such as environmental economics. As an example, consider two pollutant firms along a river whose property rights belong to fishermen. Each pollutant firm makes independent emissions that may damage the quality of the water and whose combination may produce an environmental disaster. If independent emissions pollute the river each firm i has to pay w_i to fishermen and if an environmental disaster occurs they have to jointly compensate fishermen with an amount $V \in \left\{\overline{V}, \underline{V}\right\}$ strictly higher than w_i for every firm i. The degree of the potential disaster is common knowledge for both firms but neither the fishermen nor the regulator are able to precisely anticipate the nature of such a disaster. All they know is the probability $p \in [0,1]$ of a great environmental calamity, $\overline{V} > \underline{V}$. Finally, assume firms may be able to reduce their emissions and decrease the probability of polluting the river. This abatement effort is not verifiable and privately costly so firms suffer a double-sided moral hazard problem. The Government may be interested in raising firms' incentives to abate but it would face an additional adverse selection problem, given its inability to anticipate the degree of the potential environmental disaster. In this case the relevant policy tools are monitoring and sanctions in case of disaster and the optimal policy choice will again depend on how informative is the monitoring process.

2.5 Appendix

Proof of Lemma 2.2. It is not difficult to see that the sum of noncooperative research efforts $e_1^{nc}(V) + e_2^{nc}(V)$ is maximal for an egalitarian sharing rule. For $\alpha_i = 1/2$, it can be easily obtained that $e^*(V) = w/(\theta - V)$ which is strictly larger than $e^{nc}(V) = w/(\theta - V/2)$, as we wanted to prove. ■

Proof of Proposition 2.1. The Government solves the following maximization program:

$$\underset{\overline{S},\,\underline{S}}{Max}\left\{\begin{array}{c} 2p[\Pi(e(\overline{S},\overline{V}),\overline{S},\overline{V}) - (1+\lambda)e^2(\overline{S},\overline{V})\overline{S}]+ \\ 2(1-p)[\Pi(e(\underline{S},\underline{V}),\underline{S},\underline{V}) - (1+\lambda)e^2(\underline{S},\underline{V})\underline{S}] \end{array}\right\}$$

subject to

(1) $\Pi(e(\overline{S},\overline{V}),\overline{S},\overline{V}) \geq \Pi(e(\underline{S},\overline{V}),\underline{S},\overline{V})$

(2) $\Pi(e(\underline{S},\underline{V}),\underline{S},\underline{V}) \geq \Pi(e(\overline{S},\underline{V}),\overline{S},\underline{V})$

(3) $\Pi(e(\overline{S},\overline{V}),\overline{S},\overline{V}) \geq \Pi(e(0,\overline{V}),0,\overline{V})$

(4) $\Pi(e(\underline{S},\underline{V}),\underline{S},\underline{V}) \geq \Pi(e(0,\underline{V}),0,\underline{V})$

(5) $\overline{S} \geq 0$

(6) $\underline{S} \geq 0$,

where $e(S,V)$ is the noncooperative Nash equilibrium effort given the patent subsidy S, that is, $e(S,V) = \frac{w}{\theta - \frac{V}{2} - S}$.

Expressions (1) and (2) represent the incentive compatibility constraints for each type of project and they imply that no type wants to lie. For both constraints to be satisfied it is easy to show that if there exists a solution it must satisfy that $\overline{S} = \underline{S} = \widetilde{S}$. Expressions (3) and (4) represent the participation constraints for each type of project and they imply that no one is worse off than without intervention. They are satisfied if expressions (5) and (6) are satisfied. Then, the regulator's program can be rewritten as:

$$\underset{S}{Max}\left\{W(S,\overline{V},\underline{V}) = 2pf(S,\overline{V}) + 2(1-p)f(S,\underline{V})\right\}$$

subject to $S \geq 0$,

where $f(S,V) = \frac{w^2}{(\theta - \frac{V}{2} - S)^2}\left[\frac{\theta}{2} - (1+\lambda)S\right]$ with $V \in \{\overline{V},\underline{V}\}$.

The following steps can simply be obtained by computing the derivatives of $W(S,\overline{V},\underline{V})$ with respect to S and λ.

Step 1.1 If $\theta > 2\overline{V}$, the social objective function $W(S,\overline{V},\underline{V})$ is strictly concave in S for every $S \geq 0$ and strictly decreasing in S for every $S \geq \overline{V}/2$.

Step 1.2 If $\theta > 2\overline{V}$, the social objective function $W(S,\overline{V},\underline{V})$ and its first derivative with respect to S are strictly decreasing in λ for every $S > 0$.

Step 1.3 If $\theta > 2\overline{V}$, the second derivative of $W(S,\overline{V},\underline{V})$ with respect to S is strictly decreasing in λ and its first derivative with respect to S is linear in λ.

Step 1.4 $\frac{\partial W}{\partial S}(0,\overline{V},\underline{V}) = 0$ if and only if $\lambda = \lambda^S > 0$.

From steps 1.2 and 1.4 we can conclude that the optimal subsidy is zero above λ^S and strictly positive below it. For every $\lambda \in \left[0,\lambda^S\right)$, $\frac{\partial W}{\partial S}(\widetilde{S},\overline{V},\underline{V}) = 0$ defines $\widetilde{S}$ implicitly as a function of λ. Applying the implicit function theorem, the envelope theorem and previous steps, it is not difficult to prove that the optimal subsidy and the maximum social benefit are strictly decreasing and convex functions of λ. Finally, we should prove that the optimal subsidy is never above $\overline{V}/2$ but there always exists a lower bound λ_S such that below it $\widetilde{S} > \underline{V}/2$. From step 1.1 we can deduce that the optimal subsidy is never above $\overline{V}/2$. To prove that there exists a lower bound λ_S such that below it $\widetilde{S} > \underline{V}/2$, it is sufficient to verify that $\frac{\partial W}{\partial S}(\frac{\underline{V}}{2},\overline{V},\underline{V}) > 0$ for $\lambda = 0$. ■

Proof of Proposition 2.2. The Government solves the following maximization program:

$$\underset{\overline{m},\,\underline{m}}{Max}\left\{\begin{array}{c} 2p[\Pi(e(\overline{m},\overline{V}),\overline{m},\overline{V}) - (1+\lambda)e(\overline{m},\overline{V})\overline{m}] \\ +2(1-p)[\Pi(e(\underline{m},\underline{V}),\underline{m},\underline{V}) - (1+\lambda)e(\underline{m},\underline{V})\underline{m}] \end{array}\right\}$$

subject to

$$(1)\ \Pi(e(\overline{m},\overline{V}),\overline{m},\overline{V}) \geq \Pi(e(\underline{m},\overline{V}),\underline{m},\overline{V})$$

$$(2)\ \Pi(e(\underline{m},\underline{V}),\underline{m},\underline{V}) \geq \Pi(e(\overline{m},\underline{V}),\overline{m},\underline{V})$$

$$(3)\ \Pi(e(\overline{m},\overline{V}),\overline{m},\overline{V}) \geq \Pi(e(0,\overline{V}),0,\overline{V})$$

(4) $\Pi(e(\underline{m},\underline{V}),\underline{m},\underline{V}) \geq \Pi(e(0,\underline{V}),0,\underline{V})$

(5) $\overline{m} \geq 0$

(6) $\underline{m} \geq 0$,

where $e(m,V)$ is the noncooperative Nash equilibrium effort given the monetary transfer m, that is, $e(S,V) = \frac{w+m}{\theta-\frac{V}{2}}$.

Both compatibility constraints (1) and (2) are fulfilled if $\overline{m} = \underline{m} = \widetilde{m}$ holds. Participation constraints (3) and (4) are satisfied if so are expressions (5) and (6). Then, the social planner solves:

$\underset{m}{Max}\left\{W(m,\overline{V},\underline{V}) = 2pf(m,\overline{V}) + 2(1-p)f(m,\underline{V})\right\}$

subject to $m \geq 0$

where $f(m,V) = \frac{w+m}{\theta-\frac{V}{2}}\left[\frac{w+m}{\theta-\frac{V}{2}}\frac{\theta}{2} - (1+\lambda)m\right]$ with $V \in \{\overline{V},\underline{V}\}$.

Step 2.1 If $\theta > 2\overline{V}$, the social objective function $W(m,\overline{V},\underline{V})$ is strictly concave in m for every $m \geq 0$ and strictly decreasing in m for every $m \geq \overline{V}w/(2\theta - 2\overline{V})$.

Step 2.2 If $\theta > 2\overline{V}$, the social objective function $W(m,\overline{V},\underline{V})$ and its first derivative with respect to m are strictly decreasing in λ for every $m > 0$.

Step 2.3 If $\theta > 2\overline{V}$, the second derivative of $W(m,\overline{V},\underline{V})$ with respect to m is strictly decreasing in λ and its first derivative with respect to m is linear in λ.

Step 2.4 $\frac{\partial W}{\partial m}(0,\overline{V},\underline{V}) = 0$ if and only if $\lambda = \lambda^m > 0$.

From previous steps, we can conclude that the optimal monetary transfer is zero above λ^m and strictly positive below it. For every $\lambda \in [0,\lambda^m)$, $\frac{\partial W}{\partial m}(\widetilde{m},\overline{V},\underline{V}) = 0$ defines $\widetilde{m}$ implicitly as a function of λ. Applying the implicit function theorem, the envelope theorem and previous steps, it is not difficult to prove that the optimal transfer and the maximum social benefit are strictly decreasing and convex functions of λ. Finally, we should prove that the optimal transfer is never above $\overline{V}w/(2\theta - 2\overline{V})$ but there always exists a lower bound λ_m such that below it $\widetilde{m} > \underline{V}w/(2\theta - 2\underline{V})$. From step 2.1, it is obvious that the optimal transfer is never above $\overline{V}w/(2\theta - 2\overline{V})$. To prove that there exist a lower bound λ_m such that below it $\widetilde{m} > \underline{V}w/(2\theta - 2\underline{V})$, it is sufficient to verify that $\frac{\partial W}{\partial m}(\frac{\underline{V}w}{2\theta - 2\underline{V}}, \overline{V}, \underline{V}) > 0$ for $\lambda = 0$. This completes the proof. ■

Proof of Propositiom 2.3. We know from Propositions 2.1 and 2.2 that the optimal patent subsidy $\widetilde{S}$ and the optimal monetary transfer $\widetilde{m}$ are zero for distortionary costs above λ^S and λ^m, respectively. Below λ^S and λ^m, the corresponding maximum social benefits $W(\widetilde{S}, \overline{V}, \underline{V})$ and $W(\widetilde{m}, \overline{V}, \underline{V})$ are strictly decreasing and convex functions in λ.

First, it can be checked that $\lambda^S > \lambda^m$ for every $p \in (0,1)$ and $\overline{V} > \underline{V}$, that is whenever there is an additional adverse selection problem. Second, we can prove that for no distortionary costs, patent subsidies induce higher social benefits. In particular, it can be proven that for $\lambda = 0$ it holds that: $W(\widetilde{S}, \overline{V}, \underline{V}) \geq W(p\frac{\overline{V}}{2} + (1-p)\frac{\underline{V}}{2}, \overline{V}, \underline{V}) > W(\widetilde{m}, \overline{V}, \underline{V})$ for every $p \in (0,1)$ and $\overline{V} > \underline{V}$. Finally, it can be shown through simulation that for every λ below λ^m,the first derivative of each maximum social benefits with respect to λ never coincides, in particular, $\left|\frac{\partial W(\widetilde{S}, \overline{V}, \underline{V})}{\partial \lambda}\right| > \left|\frac{\partial W(\widetilde{m}, \overline{V}, \underline{V})}{\partial \lambda}\right|$, for every $\lambda \in [0, \lambda^m]$. Then, since both maximum social benefits are strictly decreasing and convex functions in λ, we can conclude that the function $W(\widetilde{S}, \overline{V}, \underline{V})$ is always above $W(\widetilde{m}, \overline{V}, \underline{V})$ and they never intercept. This completes the proof. ■

Proof of Proposition 2.4. If the Government is interested in combining both partial results monitoring and patent subsidies, it will have to solve the following maximization program:

$$\underset{(\overline{S},\overline{m}),(\underline{S},\underline{m})}{Max} \left\{ \begin{array}{c} 2p\left[\Pi(e(\overline{m},\overline{S},\overline{V}),\overline{m},\overline{S},\overline{V}) - (1+\lambda)e^2(\overline{m},\overline{S},\overline{V})\overline{S} - (1+\lambda)e(\overline{m},\overline{S},\overline{V})\overline{m}\right] \\ +2(1-p)\left[\Pi(e(\underline{m},\underline{S},\underline{V}),\underline{m},\underline{S},\underline{V}) - (1+\lambda)e^2(\underline{m},\underline{S},\underline{V})\underline{S} - (1+\lambda)e(\underline{m},\underline{S},\underline{V})\underline{m}\right] \end{array} \right\}$$

subject to

$$(1)\ \Pi(e(\overline{m},\overline{S},\overline{V}),\overline{m},\overline{S},\overline{V}) \geq \Pi(e(\underline{m},\underline{S},\overline{V}),\underline{m},\underline{S},\overline{V})$$

$$(2)\ \Pi(e(\underline{m},\underline{S},\underline{V}),\underline{m},\underline{S},\underline{V}) \geq \Pi(e(\overline{m},\overline{S},\underline{V}),\overline{m},\overline{S},\underline{V})$$

$$(3)\ \Pi(e(\overline{m},\overline{S},\overline{V}),\overline{m},\overline{S},\overline{V}) \geq \Pi(e(0,0,\overline{V}),0,0,\overline{V})$$

$$(4)\ \Pi(e(\underline{m},\underline{S},\underline{V}),\underline{m},\underline{S},\underline{V}) \geq \Pi(e(0,0,\underline{V}),0,0,\underline{V})$$

(5) $\overline{m} \geq 0$

(6) $\underline{m} \geq 0$

(7) $\overline{S} \geq 0$

(8) $\underline{S} \geq 0$,

where $e(m, S, V)$ is the noncooperative Nash equilibrium effort given the monetary transfer m and patent subsidy S, that is, $e(m, S, V) = \frac{w+m}{\theta - \frac{V}{2} - S}$.

Constraints (1) and (2) represent the incentive compatibility constraints. Since profits are strictly increasing in research efforts, expressions (1) and (2) just imply that firms' efforts are higher under their own contract than under the other type's, that is $e(\overline{m}, \overline{S}, \overline{V}) > e(\underline{m}, \underline{S}, \overline{V})$ and $e(\underline{m}, \underline{S}, \underline{V}) < e(\overline{m}, \overline{S}, \underline{V})$, respectively. These conditions can be rewritten as:

$$
\begin{aligned}
(1')\ (\overline{m} - \underline{m})(\theta - \frac{\overline{V}}{2}) &\geq w(\underline{S} - \overline{S}) - \underline{m}\overline{S} + \overline{m}\underline{S} \\
(2')\ (\overline{m} - \underline{m})(\theta - \frac{\underline{V}}{2}) &\geq w(\underline{S} - \overline{S}) - \underline{m}\overline{S} + \overline{m}\underline{S}.
\end{aligned}
$$

For both expressions $(1')$ and $(2')$ to be satisfied it is easy to see that $\underline{m} \geq \overline{m}$ is a necessary condition. Again, if $\underline{m} \geq \overline{m}$ is satisfied, $\overline{S} \geq \underline{S}$ is a necessary condition for condition $(1')$ to hold. The main characteristics of the optimal separating menu of subsidies and monetary transfers of this program are summarized in the following step (the proof is provided below).

Step 4.1 The optimal separating menu of monetary transfers associated with partial results monitoring and patent subsidies $\left\{\left(\overline{m}, \overline{S}\right); \left(\underline{m}, \underline{S}\right)\right\}$ satisfies the following properties:

a) The incentive compatibility constraint for low value innovators binds though the incentive compatibility constraint for high value firms is not binding.

b) The optimal monetary transfers and subsidies satisfy that $\underline{m} > \overline{m} = 0$ and $\overline{S} > \underline{S}$.

Now we have to prove that any separating equilibrium $\left\{\left(0,\overline{S}\right);\left(\underline{m},\underline{S}\right)\right\}$ yields identical research efforts for each type of project to the pooling equilibrium $\left\{\widetilde{S};\widetilde{S}\right\}$, that is $e(0,\overline{S},\overline{V})=e(0,\widetilde{S},\overline{V})$ and $e(\underline{m},\underline{S},\underline{V})=e(0,\widetilde{S},\underline{V})$.

We will prove it by contradiction. Assume research efforts are not identical. Then, we must have any of the four following cases, each one with at least one strict inequality.

1. $e(0,\overline{S},\overline{V})\geq e(0,\widetilde{S},\overline{V})$ and $e(\underline{m},\underline{S},\underline{V})\leq e(0,\widetilde{S},\underline{V})$.
2. $e(0,\overline{S},\overline{V})\leq e(0,\widetilde{S},\overline{V})$ and $e(\underline{m},\underline{S},\underline{V})\geq e(0,\widetilde{S},\underline{V})$.
3. $e(0,\overline{S},\overline{V})\leq e(0,\widetilde{S},\overline{V})$ and $e(\underline{m},\underline{S},\underline{V})\leq e(0,\widetilde{S},\underline{V})$.
4. $e(0,\overline{S},\overline{V})\geq e(0,\widetilde{S},\overline{V})$ and $e(\underline{m},\underline{S},\underline{V})\geq e(0,\widetilde{S},\underline{V})$.

Let us analyze each case separately.

Case 1. First of all, notice that $e(0,\overline{S},\overline{V})\geq e(0,\widetilde{S},\overline{V})$ is satisfied if and only if $\overline{S}\geq\widetilde{S}$. Secondly, $e(\underline{m},\underline{S},\underline{V})\leq e(0,\widetilde{S},\underline{V})$ holds if and only if:

$$\frac{w+\underline{m}}{\theta-\frac{\underline{V}}{2}-\underline{S}}\leq\frac{w}{\theta-\frac{\underline{V}}{2}-\widetilde{S}}.$$

We know the incentive compatibility constraint for a low value firm binds so it must be satisfied that:

$$\frac{w+\underline{m}}{\theta-\frac{\underline{V}}{2}-\underline{S}}=\frac{w}{\theta-\frac{\underline{V}}{2}-\overline{S}}.$$

But since $\overline{S}\geq\widetilde{S}$ we run into a contradiction if there is any strict inequality.

Case 2. Again, on the one hand, notice that $e(0,\overline{S},\overline{V})\leq e(0,\widetilde{S},\overline{V})$ holds if and only if $\overline{S}\leq\widetilde{S}$. On the other hand, $e(\underline{m},\underline{S},\underline{V})\geq e(0,\widetilde{S},\underline{V})$ is satisfied if and only if:

$$\frac{w+\underline{m}}{\theta-\frac{\underline{V}}{2}-\underline{S}}\geq\frac{w}{\theta-\frac{\underline{V}}{2}-\widetilde{S}}.$$

But since the incentive compatibility constraint for a low value firm binds and $\overline{S}\leq\widetilde{S}$ we get into a contradiction if there is any strict inequality.

Case 3. This case is trivial. We have that it must hold that $\overline{S} \leq \widetilde{S}$ and $\underline{S} \leq \widetilde{S}$. Given that an increase in $\underline{m}$, $\underline{S}$ or $\overline{S}$ has the same associated distortion cost that an increase in $\widetilde{S}$ and $\widetilde{S}$ is a social optimum, we can conclude that $\underline{m}$, $\underline{S}$ and $\overline{S}$ cannot be optimal (if there is any strict inequality).

Case 4. This is similar to the previous case.

This completes the proof. ■

Proof of Step 4.1. Recall the maximization program of the Government is given by:

$$\underset{(\overline{S},\overline{m}),(\underline{S},\underline{m})}{Max} \; 2p\left[\Pi(e(\overline{m},\overline{S},\overline{V}),\overline{m},\overline{S},\overline{V}) - (1+\lambda)e^2(\overline{m},\overline{S},\overline{V})\overline{S} - (1+\lambda)e(\overline{m},\overline{S},\overline{V})\overline{m}\right]$$
$$+2(1-p)\left[\Pi(e(\underline{m},\underline{S},\underline{V}),\underline{m},\underline{S},\underline{V}) - (1+\lambda)e^2(\underline{m},\underline{S},\underline{V})\underline{S} - (1+\lambda)e(\underline{m},\underline{S},\underline{V})\underline{m}\right]$$

subject to

(1) $\Pi(e(\overline{m},\overline{S},\overline{V}),\overline{m},\overline{S},\overline{V}) \geq \Pi(e(\underline{m},\underline{S},\overline{V}),\underline{m},\underline{S},\overline{V})$

(2) $\Pi(e(\underline{m},\underline{S},\underline{V}),\underline{m},\underline{S},\underline{V}) \geq \Pi(e(\overline{m},\overline{S},\underline{V}),\overline{m},\overline{S},\underline{V})$

(3) $\Pi(e(\overline{m},\overline{S},\overline{V}),\overline{m},\overline{S},\overline{V}) \geq \Pi(e(0,0,\overline{V}),0,0,\overline{V})$

(4) $\Pi(e(\underline{m},\underline{S},\underline{V}),\underline{m},\underline{S},\underline{V}) \geq \Pi(e(0,0,\underline{V}),0,0,\underline{V})$

(5) $\overline{m} \geq 0$

(6) $\underline{m} \geq 0$

(7) $\overline{S} \geq 0$

(8) $\underline{S} \geq 0$.

First of all, notice that the participation constraints (3) and (4) are implied by the non-negative constraints (5), (6), (7) and (8). Through some manipulations, regulator's program can be rewritten as:

$$\underset{(\overline{S},\overline{m}),(\underline{S},\underline{m})}{Max} \; pf(\overline{m},\overline{S},\overline{V}) + (1-p)f(\underline{m},\underline{S},\underline{V})$$

subject to

(λ_1) $\overline{S} - \frac{(\underline{m}-\overline{m})(\theta-\frac{\overline{V}}{2})+(\overline{m}+w)\underline{S}}{\underline{m}+w} \geq 0$

(λ_2) $\frac{(\underline{m}-\overline{m})(\theta-\frac{\underline{V}}{2})+(\overline{m}+w)\underline{S}}{\underline{m}+w} - \overline{S} \geq 0$

(λ_3) $\overline{m} \geq 0$

(λ_4) $\underline{m} \geq 0$

(λ_5) $\overline{S} \geq 0$

(λ_6) $\underline{S} \geq 0$,

where $f(m,S,V) = e(m,S,V)\left[(\theta - 2(1+\lambda)S)\, e(m,S,V) - 2(1+\lambda)m\right]$ and λ_i is the Lagrange multiplier corresponding to constraint i.

The first order conditions of the Lagrange function with respect to $\overline{S}$, $\underline{S}$, $\overline{m}$, and $\underline{m}$ yield the following:

$$
\begin{aligned}
p\frac{\partial f(\overline{m},\overline{S},\overline{V})}{\partial \overline{S}} + \lambda_1 - \lambda_2 + \lambda_5 &= 0. \text{ (A)}\\
(1-p)\frac{\partial f(\underline{m},\underline{S},\underline{V})}{\partial \underline{S}} + (\lambda_2 - \lambda_1)\frac{\overline{m}+w}{\underline{m}+w} + \lambda_6 &= 0. \text{ (B)}\\
p\frac{\partial f(\overline{m},\overline{S},\overline{V})}{\partial \overline{m}} + \lambda_1 \frac{\theta - \frac{\overline{V}}{2} - \underline{S}}{\underline{m}+w} - \lambda_2 \frac{\theta - \frac{\underline{V}}{2} - \underline{S}}{\underline{m}+w} + \lambda_3 &= 0. \text{ (C)}\\
(1-p)\frac{\partial f(\underline{m},\underline{S},\underline{V})}{\partial \underline{m}} - \lambda_1 \frac{(\overline{m}+w)(\theta - \frac{\overline{V}}{2} - \underline{S})}{(\underline{m}+w)^2} + \lambda_2 \frac{(\overline{m}+w)(\theta - \frac{\underline{V}}{2} - \underline{S})}{(\underline{m}+w)^2} + \lambda_4 &= 0. \text{ (D)}
\end{aligned}
$$

A separating menu of patent subsidies and monetary transfers exits if $\underline{m} > \overline{m} \geq 0$ and $\overline{S} > \underline{S} \geq 0$, that is $\lambda_4 = \lambda_5 = 0$, and if any of the following possibilities holds:

1. $\lambda_1 = \lambda_2 = 0$.

2. $\lambda_1 > 0,\ \lambda_2 = 0$.

3. $\lambda_1 = 0,\ \lambda_2 > 0$.[18]

In order to prove that only the incentive compatibility constraint for low value innovators binds we have to verify that only the third case holds. We will do the proof by contradiction.

Case 1. Assume $\lambda_1 = \lambda_2 = 0$. In this case, expressions (A) and (D) are just the first order conditions of the social objective function with respect to $\underline{m}$ and $\overline{S}$. Let us denote

[18] Notice that the case in which both Lagrange multipliers are positive corresponds to the pooling equilibrium.

$\underline{m}^*$ and $\overline{S}^*$ the solutions of those first order conditions. Since $\lambda_2 = 0$, the incentive compatibility constraint for low value innovators is not binding. However, one can show that

$$\frac{(\underline{m}^* - \overline{m})(\theta - \frac{\overline{V}}{2}) + (\overline{m} + w)\underline{S}}{\underline{m}^* + w} - \overline{S}^* \geq 0,$$

is never satisfied for every non-negative $\overline{m}$ and $\underline{S}$ (and in particular, it is not satisfied for the optimal solutions $\overline{m}^*$ and $\underline{S}^*$). This yields a contradiction and we can conclude that it is not possible that $\lambda_1 = \lambda_2 = 0$.

Case 2. Assume $\lambda_1 > 0$, $\lambda_2 = 0$. Since $\lambda_1 = 0$, the incentive compatibility constraint for high value innovators binds, that is, in the optimum it must be satisfied that:

$$\overline{S}^* = \frac{(\underline{m}^* - \overline{m}^*)(\theta - \frac{\overline{V}}{2}) + (\overline{m}^* + w)\underline{S}^*}{\underline{m}^* + w}.$$

From condition (A) we can rewrite λ_1 as a function of $\overline{m}^*$, $\underline{m}^*$ and $\overline{S}^*$:

$$\lambda_1 = -p\frac{\partial f(\overline{m}, \overline{S}^*, \overline{V})}{\partial \overline{S}}.$$

Given the value of λ_1, it can be verified that:

$$p\frac{\partial f(\overline{m}, \overline{S}^*, \overline{V})}{\partial \overline{m}} + \lambda_1 \frac{\theta - \frac{\overline{V}}{2} - \underline{S}}{\underline{m} + w} = 0.$$

Then, for condition (C) to hold it must be satisfied that $\lambda_3 = 0$, that is $\overline{m}^*$ is strictly positive. Substituting the value of λ_1 in condition (D), and given that $\lambda_2 = \lambda_4 = 0$, we can easily obtained the optimal value of $\underline{m}$, as a function of $\underline{S}$, $\underline{m}^* = \underline{m}(\underline{S})$. Now we have to obtain the optimal value of $\overline{S}$. Suppose $\underline{S}$ is positive, that is $\lambda_6 = 0$. Then from condition (B) we can obtain the optimal value of $\underline{S}$ as a function of $\underline{m}$, $\underline{S}^* = \underline{S}(\underline{m})$. Solving the system of equations given by $\underline{m}^* = \underline{m}(\underline{S})$ and $\underline{S}^* = \underline{S}(\underline{m})$ we obtain a negative value for $\underline{m}^*$ which contradicts the assumption of $\underline{m}$ being nonnegative. Thus, we can conclude that it must be true that $\underline{S}^* = 0$ and λ_6 is positive. Finally, substituting $\underline{m}^* = \underline{m}(\underline{S}^* = 0)$, $\underline{S}^* = 0$ and $\overline{m}^* > 0$ in the value of λ_1 we obtain a negative value, which contradicts the assumption of λ_1 being positive. Hence, we can conclude that $\lambda_1 > 0$ and $\lambda_2 = 0$ is not possible.

Case 3. We have already proved by contradiction that if there exits a separating menu of patent subsidies and monetary transfers it must satisfy that $\lambda_1 = 0$ and $\lambda_2 > 0$. In this case, the incentive compatibility constraint for the low value innovators binds and the following is satisfy:

$$\begin{aligned} \overline{S}^* &= \frac{(\underline{m} - \overline{m})(\theta - \frac{V}{2}) + (\overline{m} + w)\underline{S}}{\underline{m} + w}. \\ \lambda_2 &= p\frac{\partial f(\overline{m}, \overline{S}^*, \overline{V})}{\partial \overline{S}}. \end{aligned}$$

We proceed to prove that $\overline{m}^* = 0$. Let us do it by contradiction. Assume $\overline{m}^*$ is positive and $\lambda_3 = 0$. Then, from condition (C) we can easily obtain the optimal value of $\overline{m}$ as a function of $\underline{S}$ and $\underline{m}$ and from condition (D), the optimal value of $\underline{m}$ as a function of $\underline{S}$ and $\overline{m}$. Solving this system of equations, we obtain a negative solution for $\overline{m}^*$. This contradicts the fact of $\overline{m}^*$ being positive and we can deduce that $\overline{m}^* = 0$ and λ_3 is positive. There exists a multiple optimal solution for $\underline{m}$ and $\underline{S}$. In particular, given the value of λ_2, if $\underline{S}^*$ is strictly positive the optimal solution satisfies:

$$\begin{aligned} (1-p)\frac{\partial f(\underline{m}^*, \underline{S}^*, \underline{V})}{\partial \underline{S}} + \lambda_2 \frac{w}{\underline{m}^* + w} &= 0. \\ (1-p)\frac{\partial f(\underline{m}^*, \underline{S}^*, \underline{V})}{\partial \underline{m}} + \lambda_2 \frac{w(\theta - \frac{V}{2} - \underline{S}^*)}{(\underline{m}^* + w)^2} &= 0. \end{aligned}$$

If $\underline{S}^*$ is zero, the optimal solution is given by the second equation of the above system.

This completes the proof. ■

Proof of Lemma 2.3. In order to implement the efforts (e, e) as a noncooperative Nash equilibrium, it must be satisfied that no single firm has incentives to deviate and exert a different effort, that is it must be hold that

$$\Pi_i(e,e) \geq \Pi_i(e_i(e,V),e) - qP, \tag{2.2}$$

where $e_i(e,V) = \frac{Ve+2w}{2\theta}$ represents firm i's reaction function, given that firm j is exerting an effort e. Condition (2.2) can be rewritten as

$$e^2(\frac{V}{2} - \frac{\theta}{2}) + ew \geq \frac{Ve+2w}{2\theta}e\frac{V}{2} + \frac{Ve+2w}{2\theta}w - \frac{\theta}{2}(\frac{Ve+2w}{2\theta})^2 - qP.$$

This yields that the minimum probability of auditing a project of type V to implement (e,e) as a Nash equilibrium is as follows:

$$q((e,e),V) = \frac{(e(\theta - \frac{V}{2}) - w)^2}{2\theta P}.$$

Finally, it can be easily noticed that $q((e,e),V)$ is a strictly increasing function in e and strictly decreasing in P and V, as we wanted to prove. ■

Proof of Proposition 2.5. If the regulator can perfectly distinguish the type of the project, it will solve the following maximization program:

$$\underset{e}{Max}\left\{W((e,e),V) = 2\left[\Pi((e,e),V) - (1+\lambda)k\frac{(e(\theta-\frac{V}{2})-w)^2}{2\theta P}\right]\right\}$$

subject to

(1) $\frac{\sqrt{2\theta P}+w}{\theta-\frac{V}{2}} \geq e \geq \frac{w}{\theta-\frac{V}{2}}$

(2) $\frac{\theta}{\theta-V}\frac{2w}{2\theta-V} \geq e.$

Constraint (1) implies that the audit probability $q((e,e),V)$ is well-defined, that is, it belongs to the interval $[0,1]$. Expression (2) indicates that research firms should be better off under the social Nash equilibrium (e,e) than under the noncooperative Nash equilibrium without public intervention $(e^{nc}(V), e^{nc}(V))$.

From condition (1) it is straight forward to see that, for $P = 0$, the research effort for a type V project is just the noncooperative Nash equilibrium without intervention and the probability of auditing is equal to zero. If P is strictly positive but not high enough, condition (1) binds and the optimal research effort is $e = (\sqrt{2\theta P} + w)/(\theta - \frac{V}{2})$.

At last, if P is strictly positive and sufficiently high, the optimal research effort is the interior solution of the first order condition of the social objective function, $e = e^{FOC}(V)$ where $e^{FOC}(V) \leq e^*(V)$ with equality if $k = 0$. In all cases the optimal research effort is strictly increasing in V so that $\overline{e} > \underline{e}$.

We will prove that even though the Government is not able to distinguish the type of the project, no type of RJV participants have incentives to lie and pretend to be other type.

Firstly, we will show that it is not optimal for low type firms to untruthfully declare they are high value. On the one hand, if low value firms lie about their type, they will have to exert the efforts $(\overline{e}, \overline{e})$ and be audited with a probability $q((\overline{e}, \overline{e}), \overline{V})$. However, the minimum audit probability to implement $(\overline{e}, \overline{e})$ as a Nash equilibrium for a low type project is given by

$$q((\overline{e}, \overline{e}), \underline{V}) = \frac{(\overline{e}(\theta - \frac{\underline{V}}{2}) - w)^2}{2\theta P} > q((\overline{e}, \overline{e}), \overline{V}) = \frac{(\overline{e}(\theta - \frac{\overline{V}}{2}) - w)^2}{2\theta P}.$$

Then, low value firms will have incentives to deviate and the resulting Nash equilibrium effort is the one without intervention, $(e^{nc}(\underline{V}), e^{nc}(\underline{V}))$. On the other hand, if low value firms truthfully reveal their type they exert the effort $(\underline{e}, \underline{e})$ and receive a payoff $\Pi((\underline{e}, \underline{e}), \underline{V})$. By definition these profits are higher than firms' profits without public intervention so low value researchers have no incentives to lie about their type.

Secondly, we will obtain the condition for which high innovators have incentives to reveal their true type and verify that this condition is satisfied by the optimal solution in the pure moral hazard case. In this case, the minimum probability to implement $(\underline{e}, \underline{e})$ as a noncooperative Nash equilibrium for the high value firms is:

$$q((\underline{e}, \underline{e}), \overline{V}) = \frac{(\underline{e}(\theta - \frac{\overline{V}}{2}) - w)^2}{2\theta P} < q((\underline{e}, \underline{e}), \underline{V}) = \frac{(\underline{e}(\theta - \frac{\underline{V}}{2}) - w)^2}{2\theta P}.$$

Then, the research effort $(\underline{e}, \underline{e})$ is implementable as a Nash equilibrium for a high type project and for them to have incentives to tell the truth the following condition must be hold:

$$\overline{e}^2(\frac{\overline{V}}{2}-\frac{\theta}{2})+\overline{e}w \geq \underline{e}^2(\frac{\overline{V}}{2}-\frac{\theta}{2})+\underline{e}w.$$

Given that the low value firms never want to lie, the Government will implement a research effort for a high type firm $\overline{e} > \underline{e}$ so that the previous condition reduces to

$$\overline{e}+\underline{e} \leq 2e^*(\overline{V}),$$

which is satisfied by the optimal solution in the pure moral hazard case. ■

Proof of Proposition 2.6. The proof is immediate. From Proposition 2.5 we know effort monitoring policy is unaffected by an additional adverse selection problem though Proposition 2.1 implies a loss of welfare in patent subsidies. If both policies were equivalent in the pure moral hazard case, it is obvious that effort monitoring socially dominates patent subsidies in the moral hazard and adverse selection case. ■

Proof of Proposition 2.7. We have just to verify that, if the Government can distinguish the type of the project, P is sufficiently high and effort monitoring and patent subsidies implement the same research effort, social benefit is higher for monitoring, that is patent subsidies imply a higher social cost. For P high enough and λ sufficiently small, we have that for a type V project, the effort implemented by monitoring $e = e^{FOC}(V)$ is equal to the research effort implemented by subsidies $e(S,V)$ if $k = -4\theta^2 P \frac{\lambda}{(2\theta-V)(1+\lambda)(2\theta\lambda-\lambda V-V)}$. Given these value for the inverse of the auditing process efficiency, we have that for λ sufficiently small:

$$W((e,e),V) = 2\left[e^2\frac{V}{2}+ew-\theta\frac{e^2}{2}-(1+\lambda)kq((e,e),V)\right] > W(S,V).$$

This completes the proof. ■

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Chapter 3

R&D investment as a signal in corporate takeovers

3.1 Introduction

There is little doubt about the positive effects of R&D investments on the growth and competitive position of firms (see, for example, Baysinger and Hoskisson, 1989, or Franko, 1989). R&D activity is crucial not only because it may generate innovations but also because it develops firms' ability to absorb and exploit existing technologies. Therefore, it is worth analyzing the factors and characteristics of the market that may increase firms' R&D intensity. In this paper, we focus on the effects of takeover threats on target firms' incentives to invest in R&D.

There is still an open debate in the literature about the consequences of takeover threats on R&D investments. The "managerial myopia" argument establishes that managers facing takeover threats might have incentives to sacrifice long-term investments, such as R&D investments, by short-term investments. They argue that R&D investments are difficult to be evaluated in the market, so that the fear of being bought at an undervalued price, leads managers to focus more heavily in short-term investments.

Under this theory, firms that focus in a long-term objective are more susceptible to receive a tender offer (Narayanan, 1985; Stein, 1988).

There is not clear empirical evidence sustaining the "managerial myopia" argument. Pugh, Page and Jahera (1992) find evidence that supports such theory, but Meulbroek et al (1990), Mahoney et al (1997), Garvey and Hanka (1999), and a study by the Office of the Chief Economist of the Securities and Exchange Commission (1985) find no evidence. Moreover, this latter study finds that the market places a positive value on announcements of long-term investments such as R&D.

Although empirical studies suggest that firms facing takeover threats may invest in R&D, no satisfactory theoretical explanation has been provided yet. Canoy, Riyanto and Van Cayseele (2000) assume that by decreasing R&D investments and concentrating on short-term investments, managers can increase firms' value and deter a possible takeover. This deterrence decision depends on the bargaining power of the acquiring firm. In particular, they assume that if a takeover occurs, the incumbent manager is dismissed and his compensation depends on the bargaining position of the acquiring firm. If the acquiring firm has too much bargaining power, the manager of the acquired firm will have incentives to deter the takeover and focus on short-term investments. So, according to these authors, increases in R&D are strongly dependent on low bargaining power of the acquiring firm.

The purpose of this paper is to provide an alternative and complementary analysis of R&D intensity under takeover threats. So far, the effects of takeover threats on target firms' R&D investments have been individually analyzed. However, firms compete in the market. Changes in the market structure, such as the acquisition of a rival, also affect other firms' profits. We show that target firms might have incentives to invest in R&D (even in the extreme case that the acquiring firm has all the bargaining power) in order to influence not only their own offers of acquisition but also the others' and induce a particular market structure.

We argue that firms may strategically use R&D investments to signal their ability to fit well. Mergers and acquisitions are more likely to work when a company chooses a partner that fits well, rather than one that is merely available. Important costs may appear in terms of organizational problems if firms do not carefully choose their potential partners. Sometimes firms tend to underestimate these costs and unprofitable acquisitions take place. For example, this happened when Wells Fargo bought First Interstate in 1996 since thousands of the banks' customers left because of missing records, queues and administrative snarl-ups. Another example is the acquisition of US Healthcare by Aetna. Aetna, an insurer, bought US Healthcare, a health-maintenance organization, partly for its computer systems, which could shift out the best doctors. But the two firms had terrible problems in combining their back offices (The Economist, 1999a). A study published by the Bank for International Settlements (BIS) in 1999 showed that bank profitability had fallen in 12 countries despite a wave of consolidation. The BIS highlights the importance of choosing a right partner and blames acquiring firms for systematically underestimating organizational problems (The Economist, 1999b).

We consider three firms with different marginal costs competing in a homogenous output oligopoly. We assume that the most efficient firm makes bids to acquire one of the other two. Target firms accept an offer of acquisition if they are offered at least what they would obtain in case of rejection, that is, their outside option. Once the takeover has been achieved, the acquiring firm must decide whether to close one of the plants, or to transfer its technology to the acquired firm and operate both plants in competition with each other. By competing against themselves, plants capture some sales from their rivals and increase the firm's profits. This possibility was first introduced by Kamien and Zang (1990). They claim that the automobile industry provides a clear example of divisionalized firms in which divisions compete with each other. Tombak (2002) also considers this possibility. He provides three specific examples of sequential acquisitions in which the brands of the acquired firms were retained in the product market: the cases of American Tobacco Co., Swedish Match and two funeral home and cemetery companies in North America, Service Corporation International and The Loewen Group.

Clearly, the decision on whether or not to shut down the acquired plant will strongly depend on the ability of the target firm to absorb new technologies. This ability can be understood as a measure of how the two firms fit.

There is a substantial number of papers that argue that R&D investments not only generate new technologies but also enhance firms' ability to assimilate and exploit existing technologies (see, for example, Cohen and Levinthal (1989), Cassiman and Veugelers (1999) or Kamien and Zang (2000)). Teece (1977), analyzing the characteristics of the transferee that affect the cost of transferring technological know-how, distinguishes the R&D activity: "When unusual technical problems are unexpected encountered, an in-house R&D capability is likely to be of value". Following the same argument, Oshima (1973) argues that the R&D intensity of Japanese firms facilitated the low cost importation of foreign technology and Mansfield *et al* (1977) find that diffusion occurs more rapidly in more R&D intensive industries.

Firms' strategic use of R&D investments may explain why some firms with financial problems keep on increasing their R&D expenditures over revenues, willing to be acquired at a good price. This is, for example, the case of Genta Inc., which although suffering important financial problems, kept on increasing its R&D expenditures during 2001 until it signed a $480 million deal with Aventis S.A. in 2002.[1] Another recent example is Novartis' tender offer for Lek, a pharmaceutical firm that has been increasing its R&D investments as percentage of sales in the last years.[2]

We start studying optimal takeovers in a symmetric information framework in which target firms' abilities to absorb new technologies are assumed to be common knowledge. We find that the identity of the acquired firm strongly depends on target firms' efficiency and compatibility and the market size. If the market size is big enough, it may be optimal

[1] Published in *Chemical & Engineering News*, vol.80, no 18, p.10. May 6, 2002.

[2] Published in *Slovenia Business Week*, no 6/2003. February 10, 2003.

for the most efficient firm to buy the less efficient company, since it accepts lower offers of acquisition. Secondly, we consider the type of one of the target firms to be privately known. We analyze the incentives for this firm to invest in R&D in order to signal its ability to absorb new technologies before the takeover process begins. This decision depends on the other firm's type, the cost of R&D investments and the market size. In particular, this firm only invests in R&D if the cost of R&D is low enough and no other target firm is compatible with the acquiring firm. We also come to prove that firms may have incentives to invest in R&D even if they are not finally bought, since they may change their outside option through R&D investments.

The rest of the paper is organized as follows. Section 3.2 presents the model. A symmetric information case is analyzed in section 3.3. In section 3.4, we study target firm's incentives to invest in R&D in order to signal its type in an asymmetric information framework. Finally, section 3.5 summarizes the main results and presents the conclusions.

3.2 The model

Consider three asymmetric firms that produce in a homogenous output market. Firms differ in their marginal cost. Firm 1 is the most efficient one while firm 3 is the less efficient. We assume a special structure for firms' marginal costs:[3]

$$c_2 = c_1 + \Delta < c_3 = c_1 + 2\Delta,$$

where Δ is a positive parameter that measures firms' asymmetries.

The inverse demand function is represented by $P = a - bQ$, where Q denotes the total market quantity and a and b are positive parameters. In order to guarantee that the model is well defined, we assume that $(a - c_1) > 6\Delta$.

[3] Similar structure is assumed in Barros (1998) and Lopes (2000).

Firm 1 might be interested in buying one of its competitors (monopoly is not allowed). We assume that this firm has all the bargaining power and makes offers to share potential joint profits to the other two firms. If a takeover is achieved, the acquiring firm might be interested in operating both its own plant and the acquired's in competition with each other. We assume that if the acquiring firm decides to operate both plants in the market, it transfers its technology to the acquired one.[4] However, transferring technological know-how may have a considerable associated cost.[5] This cost can be understood as a measure of how the two firms fit. It is assumed to be a fixed cost, proportional to the difference in marginal costs and the ability of the acquired firm to absorb new technologies, that is $s_i(c_i - c_1)$, where s_i is inversely related with firm i's ability to absorb new technologies, for every firm $i \neq 1$.

Let us denote by $\overline{\Pi}^{1+i}$ the total profits that can be obtained if firm 1 buys firm i and leaves both plants operating. $\overline{\Pi}_j^{1+i}$ represents the profits earned by firm j when firm 1 buys firm i and operates both plants. If firm 1 buys firm i and operates both plants, joint profits for these firms and outsider's profits are given by:

$$\begin{aligned} \overline{\Pi}^{1+i} &= \underset{q_i}{Max}\{(a - bq_i - bq_j - bq_1 - c_1)q_i\} + \underset{q_1}{Max}\{(a - bq_i - bq_j - bq_1 - c_1)q_1\} \\ &\quad - s_i(c_i - c_1), \qquad (3.1) \\ \overline{\Pi}_j^{1+i} &= \underset{q_j}{Max}\{(a - bq_i - bq_j - bq_1 - c_j)q_j\} \text{ with } i \neq j \neq 1. \qquad (3.2) \end{aligned}$$

Denote by $\underline{\Pi}^{1+i}$ joint profits obtained by firm 1 and firm i, when firm i is acquired and its plant is shut down. $\underline{\Pi}_j^{1+i}$ indicates firm j's profits when firm 1 buys firm i and closes its plant. In this case, joint profits for firm 1 and firm i and outsider's profits can

[4] We assume that only takeovers that improve the market efficiency are allowed by the antitrust authority, that is, firm 1 is not allowed to operate an inefficient plant.

[5] Teece (1977), in a study of 26 technological transfers, estimates that transfer costs average 19% of total project costs (ranging from 2% to 59% of total project costs).

be formally written as:[6]

$$\underline{\Pi}^{1+i} = \underset{q_1}{Max}\left\{(a - bq_1 - bq_j - c_1)q_1\right\}, \tag{3.3}$$

$$\underline{\Pi}_j^{1+i} = \underset{q_j}{Max}\left\{(a - bq_1 - bq_j - c_j)q_j\right\} \text{ with } i \neq j \neq 1. \tag{3.4}$$

When deciding whether or not to close the acquired plant, firm 1 faces a trade off. It is optimal to operate both plants, if the cost of transferring technological know-how is low enough, that is, if firms 1 and i are compatible enough. On the other hand, if transfer costs are excessive, that is, firms 1 and i are not compatible, it is optimal for firm 1 to operate just its own plant.

Firm 1's decision on whether or not to shut down one of the plants affects outsider's profits. If firm 1 operates both plants, the outsider will have to compete against two efficient firms. On the contrary, if firm 1 decides to operate just its own plant, the outsider faces one less competitor. Denoting by Π_j firm j's Cournot profits when no takeover is performed and taking this case as a benchmark, the outsider is worse off if firm 1 leaves both plants operating, $\overline{\Pi}_j^{1+i} < \Pi_j$, while it is better off when one of the plants is shut down, $\underline{\Pi}_j^{1+i} > \Pi_j$.

For the sake of simplicity, we assume that firm i's ability to absorb new technologies can only take two different values, $s_i \in \{0, S_i\}$, where S_i is so large that if firm 1 buys firm i, it is optimal for firm 1 to operate just its own plant. Therefore, firms can only be two types, either completely compatible, $s_i = 0$, or totally incompatible, $s_i = S_i$. Firm 2's ability to absorb new technologies is common knowledge while firm 3's ability is privately known. All firms 1 and 2 know about firm 3's ability is the proportion $p_c \in (0, 1)$ of compatible types, $s_3 = 0$.

We assume firm 3 may be interested in signaling its type investing in R&D. Let k be the cost of R&D investments. Through R&D investments, firm 3 can improve its

[6]For simplicity, no shut down cost is considered. Results extend to the case in which shut down costs are relatively small comparing with technology transfer cost.

ability to absorb new technologies.[7] However, R&D technology is not out of failure. We assume, after investing in R&D, firm 3 becomes a fitting company with probability $q \in [0, 1]$.[8]

The timing of the game is as follows: In the first stage, firm 3 decides whether to invest in R&D or not. In the second period, firms 1 and 2 update their beliefs about firm 3's type and firm 1 makes simultaneous "take or leave it" offers to acquire firm 2 or firm 3. In the third stage, firms 2 and 3 simultaneously either accept or reject firm 1's offer of acquisition. In the next period, if a takeover has been performed, firm 3 reveals its true type and firm 1 decides whether to close one plant or transfer its technology to the acquired firm and leave both plants operating. In the last stage, plants compete á la Cournot and firms obtain their profits. The game is solved by backward induction.

In order to better understand the main insights of the model let us start analyzing the symmetric information case, that is, the case in which both firm 2 and firm 3's compatibilities are of common knowledge.

[7] For simplicity reasons, we do not consider any change in firms' efficiency after investing in R&D. Recall that the goal of the paper is to study the effects of takeover threats on target firms' R&D investments. We will prove that even if firms cannot improve their efficiency through R&D, they may have incentives to increase their R&D activity to signal their type. If firms improve their efficiency through R&D investments, they will have more incentives to invest in R&D, but this is not a direct effect of takeover threats.

[8] Note that if $q = 0$, firm 3 cannot improve its ability through R&D investments and we have a pure signaling model, like the one of Spence (1973). On the contrary, if $q = 1$, firm 3 becomes surely compatible investing in R&D and we have a signaling model à la Aoki and Reitman (1992). This probability q affects the way firms 1 and 2 update their beliefs about firm 3's type if firm 3 invests in R&D.

3.3 The symmetric information case

In this section we consider that both firm 2 and firm 3's abilities to absorb new technologies are commonly known. Given firms 2 and 3's abilities, firm 1 proposes simultaneous "take or leave it" offers to share potential joint profits to each of the other firms. Firms 2 and 3 simultaneously either accept or reject firm 1's offer. If none of the firms accept, no takeover takes place and all firms remain independent. If only one firm accepts, firm 1 buys that firm and the other firm remains alone. If both firms accept, the antitrust authority forces firm 1 to choose just one of the firms, so firm 1 acquires the one that provides higher profits. If it comes to be irrelevant for firm 1 to buy either firm 2 or firm 3, we assume that firm 1 buys firm 2.

Firms 2 and 3 accept the takeover if they are offered at least the profits they would obtain if they reject. We assume that if it is indifferent to firms 2 and 3 to accept or reject, they just accept. Firm i's best response function depends on firm j's decision. If firm j rejects, it is optimal for firm i to accept whenever it is offered at least the same profit that it would obtain if no takeover is performed. On the other hand, if firm j accepts, it is optimal for firm i to accept whenever it is offered at least the same profits that it would obtain in the situation in which firm 1 buys firm j, or whenever the profits that firm 1 obtains when buying firm j are higher than the profits obtained when acquiring firm i. Recall that if both firms accept, firm 1 is forced to choose just one of the firms. Even if firm i accepts, if firm 1 obtains higher gains buying firm j, it will for sure buy this latter firm. Since firm i knows it will not be bought anyway, it is indifferent to firm i to accept or reject firm 1's offer, and by assumption it accepts.

Let $(1 - x_1^{1+i}) \in [0, 1]$ be the share of joint profits that firm 1 offers to firm i. Firms 2 and 3's decisions of acceptance or rejection yield four possible Nash equilibria, as it is stated in the following lemma.

Lemma 3.1. *Under symmetric information, firms 2 and 3's decisions on accepting or rejecting firm 1's offers of acquisition yield four possible mutually exclusive Nash* *equilibria. The conditions that must be satisfied for each of these Nash equilibria to arise are summarized in Table 3.1.*

Firm 2 / Firm 3	ACCEPTS	REJECTS
ACCEPTS	If $x_1^{1+3}\Pi^{1+3} > x_1^{1+2}\Pi^{1+2}$ and $(1- x_1^{1+3})\Pi^{1+3} \geq \Pi_3^{1+2}$ or if $x_1^{1+2}\Pi^{1+2} \geq x_1^{1+3}\Pi^{1+3}$ and $(1- x_1^{1+2})\Pi^{1+2} \geq \Pi_2^{1+3}$.	If $x_1^{1+2}\Pi^{1+2} \geq x_1^{1+3}\Pi^{1+3}$, $(1- x_1^{1+2})\Pi^{1+2} < \Pi_2^{1+3}$ and $(1- x_1^{1+3})\Pi^{1+3} \geq \Pi_3$.
REJECTS	If $x_1^{1+3}\Pi^{1+3} > x_1^{1+2}\Pi^{1+2}$, $(1- x_1^{1+3})\Pi^{1+3} < \Pi_3^{1+2}$ and $(1- x_1^{1+2})\Pi^{1+2} \geq \Pi_2$.	If $(1- x_1^{1+i})\Pi^{1+i} < \Pi_i$ for every firm i = 2, 3.

Table 3.1: Conditions for every possible mutually exclusive Nash equilibrium for firms 2 and 3 under symmetric information

Firm 1 bids anticipating any of the four possible Nash equilibria for firms 2 and 3. If firm 1 wants any of the other firms to accept, it will propose the minimum share to induce an acceptance. Since firm 1 has all the bargaining power, firms 2 and 3 will receive an offer of acquisition which is equivalent to their outside option. Firms' outside options do not depend on their own type but on the answer and type of the other firm. If firm j is compatible, the worst situation for firm i corresponds to firm j's acceptance. On the other hand, if firm j is not a fitting company, the worst situation for firm i occurs when firm j rejects, for every firm $i \neq j \neq 1$.

Firm 1's optimal decision of buying either firm 2 or firm 3 depends not only on the type and efficiency of each firm but also on the market size. Firm 2 is more efficient than firm 3 and thus a tougher rival to be kicked out of the market. However, firm 2 requires an offer of higher profits to be acquired. If the market is large enough it may be optimal for firm 1 to leave such a tough rival in the market and acquire a cheaper firm. All possibilities are analyzed in the following lemma.

Lemma 3.2. *Under symmetric information, firms 1's optimal decision of acquisition depends on the market size and target firms' efficiency and compatibility. All possibilities are summarized in Table 3.2.*

Firm 2 / Firm 3	COMPATIBLE ($s_2 = 0$)	INCOMPATIBLE ($s_2 = S_2$)
COMPATIBLE ($s_3 = 0$)	Firm 1 buys firm 2 if the market is small enough and firm 3 otherwise.	Firm 1 buys firm 2 if the market is small enough and firm 3 otherwise.
INCOMPATIBLE ($s_3 = S_3$)	Firm 1 always buys firm 2.	Firm 1 buys firm 2 if the market is small enough, firm 3 if the market is not small enough and no firm if the market is sufficiently large.

Table 3.2: Firm 1's optimal decision of acquisition under symmetric information

If both firms 2 and 3 own fitting plants, it is optimal for firm 1 to make offers to be accepted by both firms. In this way, firms' outside option profits are reduced and so is the final amount paid by firm 1 to acquire any of the other companies. If the market size is not large enough firm 1 prefers to buy firm 2. However, if the market is large enough, firm 1 prefers to buy firm 3 at a lower cost and compete against firm 2. If firm 2 is a fitting company but firm 3 is not compatible, firm 1 always buys firm 2. In such a case, firm 1 would prefer firm 3 to reject the offer, in order to reduce the amount to be paid to firm 2.[9] Even if firm 2 is not compatible and firm 3 fits, it might be optimal for firm 1 to buy firm 2 instead of firm 3 if the market is not large enough. If neither firm 2 nor firm 3 are compatible, firm 1 buys firm 2 if the market is small, firm 3 if the market is not small enough and none of these firms if the market is sufficiently large.

[9] However, this is not possible unless the market is large enough. Recall that for firm 3 to reject firm 1's offer, it must be sure that if it accepts, firm 1 will buy it. Otherwise, it will indifferent to firm 3 to accept or reject, and it will accept (see Proof of Lemma 2 in Appendix for further explanation).

Firm 3's compatibility influences not only the share offered by firm 1 but also firm 2's incentives to accept, that is, firm 3's outside option. Joint profits when firm 1 buys firm 3 are higher if firm 3 owns a fitting plant. However, the amount of profits that firm 3 requires to be bought does not depend on its own type but on its outside option. Both types have the same outside option, so firm 1 has to offer a higher share of joint profits to incompatible firms. On the other hand, firm 3's type affects the profits that firm 2 would obtain if firm 1 finally buys firm 3. Firm 2's profits would be much lower if firms 1 and 3 fit well, so it will accept more easily an offer from firm 1.

In an asymmetric information framework, firm 2's type is common knowledge but firm 3's compatibility is privately know. By investing in R&D, firm 3 can improve its true type and affect other firms' beliefs. Firm 3 may invest in R&D even if it is not willing to be acquired, in order to affect firm 2's decision and change its own outside option. In the next section we will analyze under which conditions it is optimal for firm 3 to invest in R&D and how other firms should update their beliefs over firm 3's type.

3.4 The asymmetric information case: equilibria of the signaling game

In this section, we consider that firm 2's ability to absorb new technologies is of common knowledge while firm 3's type is privately known. In the first stage of this game, firm 3 decides whether to invest in R&D to improve or just signal its type to the other firms. We assume that, once firm 3 has or has not invested in R&D, firms 1 and 2 will update their beliefs accordingly. Firm 3's profits depend not only on its true type but also on the other two firms' beliefs. Let us denote by $\Pi_3(s_3 = 0, p)$ the profits obtained by compatible firm 3 when other firms think it is compatible with probability p, and by $\Pi_3(s_3 = S_3, p)$ the profits obtained by firm 3 when it is not compatible but firms 1 and 2 think it is compatible with probability p.

Firm 3 may be interested in lying about its true type and affecting both its outside option and the offer received from firm 1.[10] Firm 3's true type affects its incentives to accept or reject the share offered by firm 1. An incompatible type demands better offers than a compatible type, so that it will surely reject offers that any compatible firm would reject or would be indifferent between accepting or rejecting. In contrast, a compatible type may accept offers that an incompatible type would surely reject. Firm 3's profits depending on its true type and other firms' beliefs are analyzed in the following lemma.

Lemma 3.3. *If firms 1 and 2 think that firm 3 is compatible with probability* $p \in [0, 1]$*, then it is better for this firm to be compatible,* $\Pi_3(s_3 = S_3, p) \leq \Pi_3(s_3 = 0, p)$*. In particular, if other firms think that firm 3 is compatible with probability* 1*, firm 3's profits are independent of its true type,* $\Pi_3(s_3 = S_3, p = 1) = \Pi_3(s_3 = 0, p = 1)$*.*

Results from Lemma 3.3 are quite intuitive. On the one hand, if firms 1 and 2 belief that firm 3 is compatible with probability p, it is better for firm 3 to be a fitting company. The intuition is that both compatible and incompatible firms will have the same outside option, since outside options do not depend on firms' true type but on the other firms' beliefs. Both types will receive the same offer to share potential joint profits. If compatible firm 3 receives an offer that an incompatible type would accept, then it will also accept such an offer and will obtain more than in its outside option. Moreover, if compatible firm 3 receives an offer that an incompatible type would reject, then it may also accept such an offer and be again better off. On the other hand, once firms 1 and 2 think that firm 3 is compatible, it is indifferent for 3 to be or not a fitting company. In this case, no matter its true type, firm 3 will have the same offer and outside option that a compatible type would have under symmetric information. Although an incompatible firm will reject such offers, it will obtain the same profits that

[10] The offers that firm 3 receives from firm 1 are based on firm 1's beliefs about firm 3's type. We assume that no punishments may be imposed as a consequence of firm 3's lies, since firm 3's true type cannot be verified by a third party.

a compatible type would obtain in its outside option (exactly what a fitting firm would obtain in equilibrium either if it accepts or rejects).

We have already compared firm 3's profits for both types when firms 1 and 2 belief that it is compatible with a certain probability. However, firm 3 may also have incentives to lie about its true type in order to affect its outside option.

Lemma 3.4. *If firm 3 is not compatible, it prefers the other firms to think that it is compatible,* $\Pi_3(s_3 = S_3, p = 0) \leq \Pi_3(s_3 = S_3, p = 1)$. *However, if firm 3 is compatible, it may be interested in making the other firms think that it is not compatible,* $\Pi_3(s_3 = 0, p = 1)\Pi_3(s_3 = 0, p = 0)$.

Firstly, if firm 3 is not compatible, it prefers firms 1 and 2 to think that it is a compatible type since, this may help to change its outside option. To be more precise, suppose, for example, that firm 2 is incompatible. In this case, the worst situation for firm 3 would be the case in which firm 2 rejects, since $\Pi_3 < \underline{\Pi}_3^{1+2}$. If firm 2 thinks that firm 3 is compatible, it will more easily accept an offer from firm 1, and firm 3 will be better off. Secondly, if firm 3 is compatible, it might be interested in pretending to be an incompatible company. On the one hand, if firm 3 lies it will receive higher offers to share joint profits. But, on the other hand, by lying about its true type, firm 3 may change its outside option in an adverse sense. If, for example, firm 2 is not compatible and thinks that firm 3 is also incompatible, firm 2 will more easily reject an offer from firm 1, which is the worst situation for firm 3.

Once we have analyzed firm 3's profits as a function of its true type and the other firms' beliefs, let us study its incentives to invest in R&D. By investing in R&D, an incompatible type may improve its ability to absorb new technologies and become a compatible firm. We will show that for any positive cost of R&D, no equilibrium in which one type invests and the another does not can be found, no matter the probability q for an incompatible company to become a fitting firm through R&D investments.

Proposition 3.1. *For any probability* $q \in [0, 1]$ *of the R&D technology and positive cost*

k, there exists no separating equilibrium of the signaling game.

By investing in R&D, an incompatible company may improve its ability to absorb new technologies and perfectly fit with firm 1. A situation in which a fitting company invests in R&D but an unsuited firm does not, cannot be an equilibrium of the signaling game. If firm 3 invests in R&D, firms 1 and 2 will think that it is a compatible firm. Even if an incompatible firm cannot improve its ability through R&D investments, we know from Lemma 3.3 that it gains the same amount than a fitting company, given that firms 1 and 2 will think that it is compatible. So it is not possible that a fitting company has incentives to invest in R&D and an incompatible type does not. A situation in which an incompatible type invests but a fitting firm does not, cannot be an equilibrium either. In this case, if firm 3 invests other firms will think that it is compatible with probability q. We know from Lemma 3.3 that it is preferable for firm 3 to be compatible if other firms think that it is indeed compatible with a certain probability. However, by assumption, a compatible type has no incentives to invest in R&D. On the other hand, an incompatible firm cannot be interested in investing in R&D since, even if it manages to improve its type, R&D investment is not worth.

If the cost of R&D investments is low enough, both types of firm 3 may be interested in investing. A compatible type cannot improve its ability, so it will invest just to signal its type to firms 1 and 2. An incompatible type will invest to make the other firms think that it is a compatible company, thereby improving its ability.

Proposition 3.2. *There exists a pooling equilibrium in which both types of firm 3 invest in R&D if and only if the following condition is satisfied:*

$$0 < k < Min\left\{\Delta\Pi_3(s_3 = 0|I); \Delta\Pi_3(s_3 = S_3|I)\right\}, \tag{3.5}$$

where $\overline{p}$ denotes firms 1 and 2's posterior beliefs that firm 3 is compatible when it does not invest in R&D, and $\Delta\Pi_3(s_3|I)$ the difference in firm 3's profits when investing in R&D, with $s_3 \in \{0, S_3\}$.

We have already shown that the signaling game described along the paper may only have pooling equilibria. Proposition 3.2 shows that if the costs of R&D investments are low enough, we can find pooling equilibria in which both types of firm 3 invest in R&D. Even in this case, firms 1 and 2 may be able to update their beliefs about firm 3's type, since they know that there exists a probability $q \in [0, 1]$ for firm 3 to improve its ability to absorb new technologies and become a compatible firm. In the extreme case that $q = 0$, R&D investments are not informative at all and firms 1 and 2 could not update their prior beliefs. However, if $q = 1$, R&D investments fully reveal firm 3's type and the pooling equilibrium in which both types invest leads to a symmetric information situation.

Let us now study under which circumstances the necessary and sufficient condition for pooling equilibria in which both types of firm 3 invest is satisfied. Firm 3 invests in R&D if the profits obtained after investing are higher than the profits it would obtain if it does not invest. Thus, we need to characterize firm 3's profits in an asymmetric information framework. The first step consists in analyzing firm 1's minimum offer for acquiring firms 2 and 3 under every possible Nash equilibria. Then, we can obtain firm 3's profits in each possible case. Secondly, we will discuss the characteristics of firm 1's optimal offer that lead to an equilibrium in which both types of firm 3 invest in R&D. The first step is summarized in the following lemma.

Lemma 3.5. *Given firm 2's true type and firms 1 and 2's non-deterministic beliefs that firm 3 is compatible* $p \in (0, 1)$ *, firm 1's minimum offers of acquisition in each possible Nash equilibria yield the following profits for firm 3, with* $\Pi_3^{1+2} \in \left\{ \overline{\Pi}_3^{1+2}, \underline{\Pi}_3^{1+2} \right\}$ *and* $\overline{\Pi}^{1+3} > \underline{\Pi}^{1+3}$*:*

Firm 3 \ Firm 2	ACCEPTS	REJECTS
COMPATIBLE ($s_3 = 0$): ACCEPTS **INCOMPATIBLE ($s_3 = S_3$): ACCEPTS**	$\Pi_3(s_3 = 0, p) = \Pi_3(s_3 = S_3, p) = \Pi_3^{1+2}$ or $\Pi_3(s_3 = 0, p) = \frac{\Pi_3^{1+2}}{\underline{\Pi}^{1+3}} \overline{\Pi}^{1+3}$ and $\Pi_3(s_3 = S_3, p) = \Pi_3^{1+2}$	$\Pi_3(s_3 = 0, p) = \frac{\Pi_3}{\underline{\Pi}^{1+3}} \overline{\Pi}^{1+3}$ and $\Pi_3(s_3 = S_3, p) = \Pi_3$
COMPATIBLE ($s_3 = 0$): REJECTS **INCOMPATIBLE ($s_3 = S_3$): REJECTS**	$\Pi_3(s_3 = 0, p) =$ $\Pi_3(s_3 = S_3, p) = \Pi_3^{1+2}$	$\Pi_3(s_3 = 0, p) =$ $\Pi_3(s_3 = S_3, p) = \Pi_3$
COMPATIBLE ($s_3 = 0$): ACCEPTS **INCOMPATIBLE ($s_3 = S_3$): REJECTS**	$\Pi_3(s_3 = 0, p) =$ $\Pi_3(s_3 = S_3, p) = \Pi_3^{1+2}$	$\Pi_3(s_3 = 0, p) =$ $\Pi_3(s_3 = S_3, p) = \Pi_3$

Table 3.3: Firm 3's profits in each possible Nash equilibrium for firms 2 and 3 under asymmetric information

Firm 1 holds all the bargaining power, so it offers the minimum share to ensure acceptance in any of the possible Nash equilibria. However, irrespective of firm 1's offers, there are situations which are impossible to be sustained as a Nash equilibrium. This is the case of a situation in which firm 2 rejects the offer, but firm 3 accepts if it is not compatible and rejects if it is compatible. Such a situation is not possible, since any offer accepted by an incompatible firm will be also accepted by a fitting company. Similar arguments may be applied to a situation in which firm 2 accepts the offer, but firm 3 rejects if it is compatible and accepts if it is not compatible.

In most cases included in Lemma 3.5, firm 1 is interested in buying firm 2 or a compatible firm 3, so that the offers for firm 3 are the ones that a compatible company would receive. Firm 3 rejects such offers if it is not compatible, unless it is sure that it will not be bought anyway, in which case it is indifferent to firm 3 to accept or reject, and it will accept by assumption. There are three exceptions. The first one corresponds to the case in which all the firms reject the offers. In such a case, firm 1 buys none of the firms. The other two exceptions refer to the situation in which both types of firm

3 accept the offers. In this case, firm 1 buys firm 3 irrespective of its ability to fit well. In these cases, firm 3 receives an offer that an incompatible firm would accept. Notice that if firm 3 is compatible, it will also accept such an offer, since it will gain more than in its outside option.

The existence of pooling equilibria in which both types of firm 3 invest in R&D depends on firm 1's optimal offers of acquisition. For condition (3.5) of Proposition 3.2 to be satisfied we need different values of firm 3's profits for different beliefs. If firm 2 is a fitting company, it is never optimal for firm 1 to buy firm 3 when it is not compatible. Firm 3's profits are always equivalent to what it would obtain if firm 2 is bought and condition (3.5) never holds. This is formally stated in the following proposition.

Proposition 3.3. *If firm 2 is a fitting company, $s_2 = 0$, firm 3 never invests in R&D.*

Proposition 3.3 reflects an intuitive result. Since firm 2 owns a compatible plant, whenever firm 1 buys firm 2, it transfers its technology and operates both its own plant and the acquired's in mutual competition. Thus, the worst situation for firm 3 is firm 2's acceptance. Irrespective of the market size, it is optimal for firm 1 to buy either firm 2 or firm 3, if it is sure to be compatible.[11] In all cases, firm 1 makes an acceptable offer to firm 2. By investing in R&D, firm 3 reinforces even more this result. Firm 3's R&D investments increase its probability to be compatible and leads firm 2 to more easily accept firm 1's offer of acquisition.

If firm 2 is not a fitting company, firm 3 might have incentives to invest in R&D. In this case, the worst situation for firm 3 is firm 2's rejection of firm 1's offer. If it is optimal for firm 1 to offer a share to be rejected by firm 2, firm 3 may have incentives to invest in R&D and force firm 2 to accept more easily. That is why pooling equilibria in which both types of firm 3 invest in R&D may exist.

[11] Notice that in the case in which both firm 2 and firm 3 accept, firm 1 must choose just one of these firms. In this case, if firm 1 has offered something to be rejected by incompatible firm 3 but accepted by compatible firm 3, firm 1 will realize that firm 3 is for sure compatible.

Proposition 3.4. *If firm 2 is not compatible, $s_2 = S_2$, there may exist pooling equilibria in which both types of firm 3 invest in R&D.*

Firm 3's decision on whether or not to invest in R&D depends not only on firm 2's type and the cost of R&D investments but also on the market size. To be more precise, given a market size $(a - c_1) \in (6\Delta, 29\Delta]$, there are values for p and q, resulting in pooling equilibria in which both types invest. In all cases, there are values for firm 1's beliefs in which it is optimal for firm 1 to offer firm 2 an offer to be rejected. Let us look at the following example to better understand the necessary conditions to be met for such pooling equilibria.

Example 3.1. *Suppose firm 2 is not compatible, $s_2 = S_2$, and $(a - c_1) = 7$. Firstly, we have to obtain firm 1's optimal offers. To that end, we must compare firm 1's maximum profits in all possible Nash equilibria described in Lemma 3.5. In case that all firms accept, we must distinguish two different situations: either firm 1 buys firm 2, or firm 1 buys firm 3 irrespective of its type. In order to obtain firm 1's maximum profits, the following computations are needed:* $\Pi_1 = \frac{6.25}{b}\Delta^2$, $\overline{\Pi}^{1+3} - \Pi_3 = \frac{7.75}{b}\Delta^2$, $\frac{\underline{\Pi}^{1+3} - \Pi_3}{\underline{\Pi}^{1+3}}\overline{\Pi}^{1+3} = \frac{7.7188}{b}\Delta^2$, $\underline{\Pi}^{1+3} - \Pi_3 = \frac{6.8611}{b}\Delta^2$, $\underline{\Pi}^{1+2} - \Pi_2 = \frac{6.75}{b}\Delta^2$, $\overline{\Pi}^{1+3} - \underline{\Pi}_3^{1+2} = \frac{7}{b}\Delta^2$, $\underline{\Pi}^{1+2} = \frac{9}{b}\Delta^2$, $\overline{\Pi}_2^{1+3} = \frac{1}{b}\Delta^2$, $\underline{\Pi}_2^{1+3} = \frac{2.7778}{b}\Delta^2$, $\frac{\underline{\Pi}^{1+3} - \underline{\Pi}_3^{1+2}}{\underline{\Pi}^{1+3}}\overline{\Pi}^{1+3} = \frac{6.875}{b}\Delta^2$, *and* $\underline{\Pi}^{1+3} - \underline{\Pi}_3^{1+2} = \frac{6.1111}{b}\Delta^2$.

Using these computations, we can calculate firm 1's maximum profits in all possible Nash equilibria, as summarized in Table 3.4.[12]

[12] It can be verified that the necessary conditions for each Nash equilibrium to arise are satisfied.

Firm 3 \ Firm 2	ACCEPTS	REJECTS
COMPATIBLE ($s_3 = 0$): ACCEPTS INCOMPATIBLE ($s_3 = S_3$): ACCEPTS	[9 - p - 2.7778 (1 - p)] $b^{-1}\Delta^2$ or [6.875 p + 6.111 (1 - p)] $b^{-1}\Delta^2$	[7.718 p + 6.861 (1- p)] $b^{-1}\Delta^2$
COMPATIBLE ($s_3 = 0$): REJECTS INCOMPATIBLE ($s_3 = S_3$): REJECTS	6.75 $b^{-1}\Delta^2$	6.25 $b^{-1}\Delta^2$
COMPATIBLE ($s_3 = 0$): ACCEPTS INCOMPATIBLE ($s_3 = S_3$): REJECTS	[7 p + 6.75 (1 - p)] $b^{-1}\Delta^2$	[7.75 p + 6.25 (1 - p)] $b^{-1}\Delta^2$

Table 3.4: Firm 1's maximum profits in each possible Nash equilibrium under asymmetric information, for $s_2 = S_2$ and $(a - c_1) = 7$

Comparing firm 1's maximum profits in Table 3.4, we come to the conclusion that there is a threshold $\widetilde{p} = 0.694$ above which firm 1 induces the Nash equilibrium in which all firms accept (and firm 1 buys firm 2), and below which firm 1 induces the Nash equilibrium in which firm 2 rejects but both types of firm 3 accept. In this latter Nash equilibrium, firm 3's profits for each type are given by $\Pi_3(s_3 = 0, p) = \frac{\Pi_3}{\underline{\Pi}^{1+3}}\overline{\Pi}^{1+3} = \frac{0.28125}{b}\Delta^2$ and $\Pi_3(s_3 = S_3, p) = \Pi_3 = \frac{0.25}{b}\Delta^2$. If all firms accept and firm 1 buys firm 2, firm 3's profits are given by $\Pi_3(s_3 = 0, p) = \Pi_3(s_3 = S_3, p) = \underline{\Pi}_3^{1+2} = \frac{1}{b}\Delta^2$.

Let us now analyze the existence of pooling equilibria in which any type of firm 3 invests in R&D. From Bayes' law, we have that $p^* = p_c + (1 - p_c)q$ is firms 1 and 2's posterior beliefs that firm 3 is compatible when it invests in R&D. Out-of equilibrium beliefs are given by $\overline{p}$. If $p^* \geq 0.694$ and $\overline{p} \leq 0.694$, for k small enough, $0 < k < \frac{0.71875}{b}\Delta^2$,there exist pooling equilibria in which both types of firm 3 invest in R&D. In these pooling equilibria, optimal strategies for both types of firm 3 consist of investing in R&D and accepting firm 1's offer. If firm 1 observes that firm 3 invests, its optimal strategy is to offer firm 2 a share $(1 - x_1^{1+2}) = \frac{p^*\overline{\Pi}_2^{1+3} + (1-p^*)\underline{\Pi}_2^{1+3}}{\underline{\Pi}^{1+2}}$ and firm 3 a share high enough such that any type knows that even if it accepts, firm 1 will buy firm 2. On the *contrary, if firm 1 observes no investment from firm 3, its optimal strategy is to offer firm 3 a share* $(1 - x_1^{1+3}) = \frac{\Pi_3}{\underline{\Pi}^{1+3}}$ *and firm 2 a share low enough so as to be rejected. Finally, the optimal strategy for firm 2 is to accept firm 1's offer of acquisition.*

Notice that the pooling equilibria provided in the example quoted above satisfies the intuitive criterion of Cho and Kreps (1987). The intuitive criterion eliminates those perfect Bayesian equilibria which do not result very "intuitive" or seem "unreasonable", imposing conditions on out-of equilibrium beliefs (recall that, in equilibrium, beliefs are given by Bayes' law). In particular, Cho and Kreps consider for a given type the most optimistic situation after a deviation. If even in this case this type does not have incentives to deviate, but the other type is willing to deviate, it is not reasonable to assign a positive probability to the first type. However, in our example, the most optimistic situation for both types is the one in which firms 1 and 2 think that firm 3 is compatible with a probability above $\widetilde{p}$. In such a situation, both types will have incentives to deviate, since they would obtain the same result that they get after investing, without paying the R&D cost.

From Example 3.1, we can also conclude that firm 3 may invest in R&D with the aim of inducing firm 2's acceptance, and not just because it intends to become more attractive to firm 1. This is formally stated in the following corollary.

Corollary 3.1. *Firm 3 may have incentives to invest in R&D to become compatible even if it is not finally acquired.*

Firm 3 may invest in R&D to improve its ability to fit well even if it is not willing to be acquired. R&D investments can be used as a way to threaten firm 2 and force it to accept lower offers of acquisition. Thus, since firm 3 increases its outside option, it increases its profits, no matter if it is finally acquired or not.

3.5 Conclusions

The increasing number of takeover offers in U.S. during the eighties led to the adoption of a large number of state antitakeover laws and antitakeover amendments (see, for example, Roe, 1993). Critics of takeovers often complain that takeover threats may have a negative impact on R&D investment, damaging the economic health and competitive strength of firms, and thereby the national economy. In this paper, we try to provide an alternative and a complementary analysis of takeovers that does not sustain these criticisms. We find that takeover threats may nevertheless increase firms' R&D intensity, since firms might use R&D investment to signal their compatibility with the acquiring firm.

We consider three firms with different technology producing in a Cournot oligopoly. The most efficient firm might be interested in buying any of the other two. This decision strongly depends on the efficiency and compatibility of firms and the market size. Target firms' may invest in R&D to affect other firms' decisions. Through R&D investments these firms signal potential outsiders the kind of competition they may face and force them to accept lower takeover offers.

Firms are not alone in the market and profits are affected by any change in the level of competition, such as the acquisition of a rival. As target firms' profits depend not only on their own offers of acquisition but also on the others', firms may be interested in investing in R&D to influence not only their own offers but also the others' offers.

Finally, we have to point out that even though we have considered in the model that R&D investments do not generate new technologies but only enhance firms' abilities to absorb and exploit existing technologies, such investments are still worth for the economy and should be strongly encouraged. Indeed, these investments are precisely those which facilitate the low cost importation of foreign technology and the economic growth in Japan (Oshima, 1973).

3.6 Appendix

Proof of Lemma 3.2. If both firms 2 and 3 are compatible, whenever firm 1 buys any of these firms, it operates both plants. In this case, solving the maximization programs given by expressions (3.1) and (3.2), profits are given by $\overline{\Pi}^{1+i} = \frac{1}{8b}(a - 2c_1 + c_j)^2$ and $\overline{\Pi}_j^{1+i} = \frac{1}{16b}(a + 2c_1 - 3c_j)^2$, with $i \neq j \neq 1$. For each possible Nash equilibrium given by Lemma 3.1, firm 1 offers the minimum share to induce an acceptance and any share large enough to guarantee rejection. Using the conditions given by Lemma 3.1, with equality in case of acceptance, we have to compute firm 1's profits in any possible Nash equilibrium for firms 2 and 3 and compare them. Taking the Nash equilibrium that yields firm 1 the maximum profits, we get that firm 1's optimal offers of acquisition are such that if $(a - c_1) \in (6\Delta, 16.5\Delta]$, both firms 2 and 3 accept and firm 1 buys firm 2. However, if $(a - c_1) > 16.5\Delta$, both firms 2 and 3 accept and firm 1 buys firm 3.

If firm 2 is a fitting company, whenever firm 1 buys this firm, it operates both plants. Firms 1 and 2's joint profits and firm 3's profits are computed solving the maximization programs given by expressions (3.1) and (3.2), that is, $\overline{\Pi}^{1+2} = \frac{1}{8b}(a - 2c_1 + c_3)^2$ and $\overline{\Pi}_3^{1+2} = \frac{1}{16b}(a + 2c_1 - 3c_3)^2$. However, if firm 3 is not compatible, whenever a takeover is performed, firm 1 closes firm 3's plant. Remaining firms solve the maximization problems given by expressions (3.3) and (3.4), that is, $\underline{\Pi}^{1+3} = \frac{1}{9b}(a - 2c_1 + c_2)^2$ and $\underline{\Pi}_2^{1+3} = \frac{1}{9b}(a-2c_2+c_1)^2$.Computing firm 1's maximum profits for every Nash equilibrium and comparing them, we obtain that firm 1's optimal offers of acquisition are such that if $(a - c_1) \in (6\Delta, 7.35\Delta]$, both firms 2 and 3 accept and firm 1 buys firm 2. However, if $(a - c_1) > 7.35\Delta$, firm 2 accepts but firm 3 rejects so firm 1 buys firm 2.

If firm 2 is not compatible and firm 3 compatible, firms' profits in each case are given by $\underline{\Pi}^{1+2} = \frac{1}{9b}(a - 2c_1 + c_3)^2$, $\underline{\Pi}_3^{1+2} = \frac{1}{9b}(a - 2c_3 + c_1)^2$, $\overline{\Pi}^{1+3} = \frac{1}{8b}(a - 2c_1 + c_2)^2$, and $\overline{\Pi}_2^{1+3} = \frac{1}{16b}(a+2c_1-3c_2)^2$. Computing firm 1's maximum profits for every possible Nash equilibrium and comparing them, we get that firm 1's optimal offers of acquisition are such that if $(a - c_1) \in (6\Delta, 7.95\Delta]$, both firms 2 and 3 accept and firm 1 buys firm 2.

However, if $(a - c_1) > 7.95\Delta$, firm 3 accepts but firm 2 rejects so firm 1 buys firm 3.

If both firms 2 and 3 are not compatible, whenever firm 1 buys any of these firms, it operates just its own plant. Profits are given by $\underline{\Pi}^{1+i} = \frac{1}{9b}(a - 2c_1 + c_j)^2$ and $\underline{\Pi}_j^{1+i} = \frac{1}{9b}(a - 2c_j + c_1)^2$, with $i \neq j \neq 1$. Again, computing firm 1's maximum profits for every possible Nash equilibrium and comparing them, we obtain that firm 1's optimal offers of acquisition are such that if $(a - c_1) \in (6\Delta, 6.6\Delta]$, firm 2 accepts but firms 3 rejects so firm 1 buys firm 2. If $(a - c_1) \in (6.6\Delta, 29\Delta]$, firm 3 accepts but firm 2 rejects so firm 1 buys firm 3. Finally, if $(a - c_1) > 29\Delta$, both firms 2 and 3 reject so no takeover is performed. This completes the proof. ■

Proof of Lemma 3.3. Firstly, we have to prove that $\Pi_3(s_3 = S_3, p) \leq \Pi_3(s_3 = 0, p)$.In this case, firms have the same outside option but different offers to share joint profits. A compatible firm always accepts offers that an incompatible company accepts, and it obtains higher profits than in its outside option. Moreover, a good type may accept offers that a bad type would reject, and again obtain higher profits than in its outside option.

Secondly, we have to prove that $\Pi_3(s_3 = S_3, p = 1) = \Pi_3(s_3 = 0, p = 1)$. By assumption, firms receive profits equivalent to their outside option. But, firm 3's outside option does not depend on its true type but on what the others think it is. An incompatible firm will always reject a good type's offer but it will receive the same profits since firm 2 thinks it is a fitting company. ■

Proof of Lemma 3.4. Firstly, we have to prove that $\Pi_3(s_3 = S_3, p = 0) \leq \Pi_3(s_3 = S_3, p = 1)$. Suppose firm 2 is good type. If $(a - c_1) \in (6\Delta, 16.5\Delta]$, we know from Lemma 3.2 that firm 1 buys firm 2, so $\Pi_3(s_3 = S_3, p = 0) = \overline{\Pi}_3^{1+2}$. If firm 3 lies and firms 1 and 2 think it is good type, firm 2 receives an offer to be accepted. Even if firm 3 accepts its offer, firm 1 thinks it is good type and prefers to buy 2, so $\Pi_3(s_3 = S_3, p = 1) = \overline{\Pi}_3^{1+2} = \Pi_3(s_3 = S_3, p = 0)$. If $(a - c_1) > 16.5\Delta$, again from Lemma 3.2, $\Pi_3(s_3 = S_3, p = 0) = \overline{\Pi}_3^{1+2}$. If firm 3 lies and firms 1 and 2 think it is compatible, firm 2 receives an offer to be accepted. However, firm 1 thinks that firm 3 is a fitting company, so it is offered a compatible firm's share. This share is not large enough for a bad type to accept and firm 3 rejects. Then firm 1 is forced to buy firm 2 and $\Pi_3(s_3 = S_3, p = 1) = \overline{\Pi}_3^{1+2} = \Pi_3(s_3 = S_3, p = 0)$. Suppose firm 2 is not compatible. If $(a - c_1) \in (6\Delta, 6.6\Delta]$, we know from Lemma 3.2 that firm 1 buys firm 2 so $\Pi_3(s_3 = S_3, p = 0) = \underline{\Pi}_3^{1+2}$. If firm 3 lies and firms 1 and 2 think it is good type, firm 2 receives an offer to be accepted. Even though firm 3 accepts its offer, firm 1 thinks it is compatible and prefers to buy 2, so $\Pi_3(s_3 = S_3, p = 1) = \underline{\Pi}_3^{1+2} = \Pi_3(s_3 = S_3, p = 0)$. If $(a - c_1) \in (6.6\Delta, 7.95\Delta]$, from Lemma 3.2, firm 2 rejects and firm 1 buys firm 3, so $\Pi_3(s_3 = S_3, p = 0) = \Pi_3$. If firm 3 lies and firms 1 and 2 think it is compatible, firm 2 receives an offer to be accepted. Even if firm 3 accepts its offer, firm 1 thinks it is good type and prefers to buy 2 and close 2's plant, so $\Pi_3(s_3 = S_3, p = 1) = \underline{\Pi}_3^{1+2} > \Pi_3 = \Pi_3(s_3 = S_3, p = 0)$. If $(a - c_1) \in (7.95\Delta, 29\Delta]$, from Lemma 3.2, $\Pi_3(s_3 = S_3, p = 0) = \Pi_3$. If firm 3 lies and firms 1 and 2 think it is good type, firm 2 receives an offer to be rejected. Firm 1 offers to 3 something that it would accept if it is good type but, since firm 3 is bad type, it rejects. Then no firm is bought and $\Pi_3(s_3 = S_3, p = 1) = \Pi_3 = \Pi_3(s_3 = S_3, p = 0)$. Finally, if $(a - c_1) > 29\Delta$, from Lemma 3.2, $\Pi_3(s_3 = S_3, p = 0) = \Pi_3$. If firm 3 lies and firms 1 and 2 think it is a fitting company, firm 2 receives an offer to be rejected. Firm 1 offers to firm 3 a share that a good type would reject so bad type rejects as well and no takeover is performed, $\Pi_3(s_3 = S_3, p = 1) = \Pi_3 = \Pi_3(s_3 = S_3, p = 0)$.

Secondly, we have to prove that $\Pi_3(s_3 = 0, p = 1)\Pi_3(s_3 = 0, p = 0)$. Suppose firm 2 is bad type and $(a - c_1) \in (6.6\Delta, 7.95\Delta]$. We know from Lemma 3.2 that both firms 2 and 3 accept. Firm 1 buys firm 2 and closes 2's plant, so $\Pi_3(s_3 = 0, p = 1) = \underline{\Pi}_3^{1+2}$. If firm 3 lies and firms 1 and 2 think it is bad type, firm 2 is offered a share to be rejected. If firm 3 is offered a bad type offer to be accepted, $(1 - x_1^{1+3}) = 1 - \frac{\underline{\Pi}^{1+3} - \Pi_3}{\underline{\Pi}^{1+3}}$. Firm 3 accepts and firm 1 buys it, so $\Pi_3(s_3 = 0, p = 0) = \frac{\Pi_3}{\underline{\Pi}^{1+3}}\overline{\Pi}^{1+3}$. It is easy to show that $\Pi_3(s_3 = 0, p = 1) = \underline{\Pi}_3^{1+2} > \frac{\Pi_3}{\underline{\Pi}^{1+3}}\overline{\Pi}^{1+3} = \Pi_3(s_3 = 0, p = 0)$. Suppose now that firm 2 is still incompatible but $(a - c_1) \in (7.95\Delta, 29\Delta]$. From Lemma 3.2, we know firm 3 accepts but firm 2 rejects so firm 1 buys firm 3 and $\Pi_3(s_3 = 0, p = 1) = \Pi_3$. If firm 3 lies and firms 1 and 2 think it is not compatible, as in the previous case, firm 3 is bought and offered a bad type's share, $\Pi_3(s_3 = 0, p = 0) = \frac{\Pi_3}{\underline{\Pi}^{1+3}}\overline{\Pi}^{1+3} > \Pi_3 = \Pi_3(s_3 = 0, p = 1)$. ■

Proof of Proposition 3.1. Let us do the proof by contradiction. Firstly, we will prove that a situation in which a compatible firm invests but an incompatible company does not, cannot be an equilibrium. From Bayes' rule, $prob(good/I) = 1$ and $prob(good/NI) = 1$. Its is optimal for a good type to invest if and only if:

$$\Pi_3(s_3 = 0, p = 1) - k > \Pi_3(s_3 = 0, p = 0). \tag{A}$$

It is optimal for a bad type not to invest if and only if:

$$\Pi_3(s_3 = S_3, p = 0) > \Pi_3(s_3 = S_3, p = 1) - k. \tag{B}$$

Conditions (A) and (B) yield to a contradiction since we know from Lemma 3.3 that $\Pi_3(s_3 = S_3, p = 1) = \Pi_3(s_3 = 0, p = 1)$ and $\Pi_3(s_3 = S_3, p = 0) \leq \Pi_3(s_3 = 0, p = 0)$.

Secondly, we have to prove that a situation in which an incompatible firm invests but a fitting company does not, cannot be an equilibrium. In this case, from Bayes' rule, $prob(good/NI) = 1$ and $prob(good/I) = q$. It is optimal for a good type not to invest if and only if:

$$\Pi_3(s_3 = 0, p = 1) > \Pi_3(s_3 = 0, q) - k. \tag{C}$$

It is optimal for a bad type to invest if and only if:

$$q\Pi_3(s_3 = 0, q) + (1 - q)\Pi_3(s_3 = S_3, q) - k > \Pi_3(s_3 = S_3, p = 1). \tag{D}$$

We know from Lemma 3.3 that $\Pi_3(s_3 = S_3, p = 1) = \Pi_3(s_3 = 0, p = 1)$. From conditions (C) and (D) we have that:

$$q\Pi_3(s_3 = 0, q) + (1 - q)\Pi_3(s_3 = S_3, q) > \Pi_3(s_3 = 0, p = 1) + k > \Pi_3(s_3 = 0, q),$$

which is only satisfied if $\Pi_3(s_3 = S_3, q) > \Pi_3(s_3 = 0, q)$. This contradicts Lemma 3.3. ■

Proof of Proposition 3.2. We have to prove that the situation in which both types of firm 3 invest in R&D may be an equilibrium of the signaling game. If an incompatible firm invests, there exits a probability q that this firm becomes compatible. From Bayes' rule, $prob(good/I) = p_c + (1 - p_c)q$. If firms do not invest, Bayes' rule cannot be applied. Let $\overline{p}$ be firms 1 and 2's posterior belief that firm 3 is compatible when it does not invest in R&D, that is, $prob(good/NI) = \overline{p}$. It is optimal for a good type to invest if and only if:

$$\Pi_3(s_3 = 0, p + (1 - p)q) - k > \Pi_3(s_3 = 0, \overline{p}). \tag{E}$$

It is optimal for a bad type to invest if and only if:

$$q\Pi_3(s_3 = 0, p + (1 - p)q) + (1 - q)\Pi_3(s_3 = S_3, p + (1 - p)q) - k > \Pi_3(s_3 = S_3, \overline{p}). \tag{F}$$

Denoting by $\Delta\Pi_3(s_3 = 0|I) = [\Pi_3(s_3 = 0, p+(1-p)q) - \Pi_3(s_3 = 0, \overline{p})]$, and by $\Delta\Pi_3(s_3 = S_3|I) = [q\Pi_3(s_3 = 0, p + (1 - p)q) + (1 - q)\Pi_3(s_3 = S_3, p + (1 - p)q) - \Pi_3(s_3 = S_3, \overline{p})]$, the result follows directly from conditions (E) and (F). ■

Proof of Lemma 3.5. Firstly, we argue that a situation in which firm 2 rejects but firm 3 accepts if it is not compatible and rejects if it is compatible cannot be sustained as a Nash equilibrium. This situation is not possible since any offer accepted by an incompatible firm will be also accepted by a fitting company. Similar argument can be applied to the situation in which firm 2 accepts but firm 3 rejects if it is compatible and accepts if it is not compatible.

Let us analyze remaining possibilities:

(a) Both firms 2 and 3 reject firm 1's offer of acquisition if and only if $(1 - x_1^{1+3})\overline{\Pi}^{1+3} < \Pi_3$ and

$(1 - x_1^{1+2})\Pi^{1+2} < \Pi_2$. In this case, no firm is bought and $\Pi_3(s_3 = 0, p) = \Pi_3(s_3 = S_3, p) = \Pi_3$.

(b) Firm 2 rejects and firm 3 accepts if it is compatible and rejects if it is not compatible.

$x_1^{1+2}\Pi^{1+2} \geq x_1^{1+3}\overline{\Pi}^{1+3}$, $(1-x_1^{1+2})\Pi^{1+2} < p\overline{\Pi}_2^{1+3} + (1-p)\Pi_2$, and

$(1-x_1^{1+3})\overline{\Pi}^{1+3} \geq \Pi_3 > (1-x_1^{1+3})\underline{\Pi}^{1+3}$. In equilibrium the last expression holds with equality and x_1^{1+2} is set high enough so that the first condition is satisfied. In this case, firm 1 buys firm 3 if it is compatible and no firm if it is not compatible so $\Pi_3(s_3 = 0, p) = \Pi_3(s_3 = S_3, p) = \Pi_3$.

(c) Firm 2 rejects but both types of firm 3 accept if and only if $x_1^{1+2}\Pi^{1+2} \geq x_1^{1+3}[p\overline{\Pi}^{1+3} + (1-p)\underline{\Pi}^{1+3}]$, $(1-x_1^{1+2})\Pi^{1+2} < p\overline{\Pi}_2^{1+3} + (1-p)\underline{\Pi}_2^{1+3}$, and

$(1-x_1^{1+3})\underline{\Pi}^{1+3} \geq \Pi_3$. In equilibrium the last expression holds with equality and x_1^{1+2} is set high enough so that the first condition is satisfied. In this case, firm 1 buys firm 3 independently of its type, and $\Pi_3(s_3 = 0, p) = \frac{\Pi_3}{\underline{\Pi}^{1+3}}\overline{\Pi}^{1+3}$ and $\Pi_3(s_3 = S_3, p) = \Pi_3$.

(d) Firm 2 accepts but both types of firm 3 reject. We need $x_1^{1+3}[p\overline{\Pi}^{1+3} + (1-p)\underline{\Pi}^{1+3}] > x_1^{1+2}\Pi^{1+2}$, $(1-x_1^{1+3})\overline{\Pi}^{1+3} < \Pi_3^{1+2}$, and $(1-x_1^{1+2})\Pi^{1+2} \geq \Pi_2$. In equilibrium, the last expression holds with equality and x_1^{1+3} is set high enough so that the first condition is satisfied. However, there may be the case that, even if $x_1^{1+3} = 1$, the first condition cannot be satisfied. Then, a suboptimal strategy for firm 1 to induce this Nash equilibrium is to set $x_1^{1+3} = 1$ and $x_1^{1+2} = \frac{p\overline{\Pi}^{1+3} + (1-p)\underline{\Pi}^{1+3}}{\Pi^{1+2}} - \varepsilon$,with $\varepsilon \longrightarrow 0$. In both cases, firm 1 buys firm 2 so $\Pi_3(s_3 = 0, p) = \Pi_3(s_3 = S_3, p) = \Pi_3^{1+2}$.

(e) Firm 2 accepts and firm 3 accepts if it is compatible and rejects if it is not compatible. Since only one type accepts, firms 1 and 2 know that if firm 3 accepts it is compatible. Hence, we need $x_1^{1+3}\overline{\Pi}^{1+3} > x_1^{1+2}\Pi^{1+2}$, $(1-x_1^{1+3})\overline{\Pi}^{1+3} \geq \Pi_3^{1+2} > (1-x_1^{1+3})\underline{\Pi}^{1+3}$, and $(1-x_1^{1+2})\Pi^{1+2} \geq \Pi_2$. In equilibrium, expressions hold with equality. However, there may be the case that with this strategy the first condition cannot be satisfied. Then, a suboptimal strategy for firm 1 to induce this Nash equilibrium is to set $x_1^{1+3} = \frac{\overline{\Pi}^{1+3} - \Pi_3^{1+2}}{\overline{\Pi}^{1+3}}$ and $x_1^{1+2} = \frac{\overline{\Pi}^{1+3} - \Pi_3^{1+2}}{\Pi^{1+2}} - \varepsilon$, with $\varepsilon \longrightarrow 0$. In both cases, firm 1 buys firm 2 or firm 3 if it accepts an offer of a compatible type, that is, $\Pi_3(s_3 = 0, p) = \Pi_3(s_3 = S_3, p) = \Pi_3^{1+2}$.

(f) Both firms 2 and 3 accept firm 1's offer of acquisition. Firms 1 and 2 cannot guess anything about firm 3's type if it accepts. We can distinguish two subcases:

(f.1) If $x_1^{1+2}\Pi^{1+2} \geq x_1^{1+3}[p\overline{\Pi}^{1+3} + (1-p)\underline{\Pi}^{1+3}]$ and $(1 - x_1^{1+2})\Pi^{1+2} \geq p\overline{\Pi}_2^{1+3} + (1-p)\underline{\Pi}_2^{1+3}$. In equilibrium, last expression holds with equality and x_1^{1+3} is set low enough so that the first condition is satisfied. In this case, firm 1 buys firm 2 and $\Pi_3(s_3 = 0, p) = \Pi_3(s_3 = S_3, p) = \Pi_3^{1+2}$

(f.2) If $x_1^{1+3}[p\overline{\Pi}^{1+3} + (1-p)\underline{\Pi}^{1+3}] > x_1^{1+2}\Pi^{1+2}$ and $(1 - x_1^{1+3})\underline{\Pi}^{1+3} \geq \Pi_3^{1+2}$. In equilibrium, last expression holds with equality and x_1^{1+2} is set low enough so that the first condition is satisfied. In this case, firm 1 buys firm 3 independently of its type so $\Pi_3(s_3 = 0, p) = \frac{\Pi_3^{1+2}}{\underline{\Pi}^{1+3}}\overline{\Pi}^{1+3}$ and $\Pi_3(s_3 = S_3, p) = \Pi_3^{1+2}$.

This completes the proof. ■

Proof of Proposition 3.3. A necessary condition for a pooling equilibrium in which both types invest is that $\Pi_3(s_3 = 0, p_c + (1-p_c)q) > \Pi_3(s_3 = 0, \overline{p})$. In other words, we need $\Pi_3(s_3 = 0, p)$ to change for different values of p. Let us analyze firm 1's optimal offers. In each of the Nash equilibrium described in Lemma 3.5, firm 1's maximum profits are given by: (a) Π_1, (b) $p(\overline{\Pi}^{1+3} - \Pi_3) + (1-p)\Pi_1$, (c) $p\frac{\underline{\Pi}^{1+3} - \Pi_3}{\underline{\Pi}^{1+3}}\overline{\Pi}^{1+3} + (1-p)(\underline{\Pi}^{1+3} - \Pi_3)$, (d) $\overline{\Pi}^{1+2} - \Pi_2$ if $p\overline{\Pi}^{1+3} + (1-p)\underline{\Pi}^{1+3} > \overline{\Pi}^{1+2} - \Pi_2$, and $p\overline{\Pi}^{1+3} + (1-p)\underline{\Pi}^{1+3}$ otherwise, (e) $p(\overline{\Pi}^{1+3} - \overline{\Pi}_3^{1+2}) + (1-p)(\overline{\Pi}^{1+2} - \Pi_2)$ if $(a - c_1) > 6.83\Delta$, and $\overline{\Pi}^{1+3} - \overline{\Pi}_3^{1+2}$ otherwise, (f.1) $\overline{\Pi}^{1+2} - p\overline{\Pi}_2^{1+3} - (1-p)\underline{\Pi}_2^{1+3}$, (f.2) $p\frac{\underline{\Pi}^{1+3} - \overline{\Pi}_3^{1+2}}{\underline{\Pi}^{1+3}}\overline{\Pi}^{1+3} + (1-p)(\underline{\Pi}^{1+3} - \overline{\Pi}_3^{1+2})$.

It is easy to prove that $\underline{\Pi}^{1+3} > \Pi_1$ and $\overline{\Pi}^{1+2} - \Pi_2 > \Pi_1$. Then, firm 1's profits are always higher in case (d) than in case (a). We know that $\Pi_3 > \overline{\Pi}_3^{1+2}$, so firm 1's profits are always higher in case (f.2) than in case (c). It is also simple to prove that

$\overline{\Pi}^{1+3} - \overline{\Pi}_3^{1+2} > \Pi_1$, and $\overline{\Pi}^{1+3} - \overline{\Pi}_3^{1+2} > \frac{\underline{\Pi}^{1+3} - \overline{\Pi}_3^{1+2}}{\underline{\Pi}^{1+3}} \overline{\Pi}^{1+3}$. Thus, firm 1's profits are always higher in case (e) than in cases (b) and (f.2).

Firm 1's optimal offers are such that the Nash equilibrium of cases (a), (b), (c) and (f.2) are never induced. In all remaining options, we know from Lemma 3.5, that $\Pi_3(s_3 = 0, p) = \overline{\Pi}_3^{1+2}$ for every $p \in (0, 1)$. From the proof of Lemma 3.4, we also know that $\Pi_3(s_3 = 0, p = 1) = \overline{\Pi}_3^{1+2}$, though $\Pi_3(s_3 = 0, p = 0) \geq \overline{\Pi}_3^{1+2}$. However, $p_c + (1 - p_c)q \geq p_c > 0$, so it is impossible that the necessary condition of Proposition 3.2 holds. ■

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Chapter 4

Mergers and the importance of fitting well

4.1 Introduction

Frightened by the increasing market liberalization, by the aggressive competition, by the uncertainties of technological change or by the soaring costs of research, companies are merging as never before. Although mergers are supposed to create value, important costs may appear in terms of organizational problems if firms do not carefully choose their potential partners. Problems in combining firms' information technology or different cultures can be crucial to make a merger unprofitable. In this sense, a study published by the Bank for International Settlements (BIS) in 1999 showed that bank profitability had fallen in 12 countries despite a wave of consolidation. The BIS highlights the importance of choosing a right partner and blames acquirers for systematically underestimating organizational problems (The Economist, 1999).

It might seem that the easier to find a fitting partner, the easier for firms to merge. Nevertheless, empirical evidence shows that this is not the case since industries facing higher difficulties in bringing together their technologies and back offices, such as banks, telecoms or the computer industry, are the ones with higher number of mergers. We provide a simple model to explain this phenomenon. We consider three asymmetric firms competing in the market. Only mergers between two firms are analyzed. We assume that mergers profitability depends on how firms fit. We prove that if all firms fit perfectly, no stable merger can be performed since the outsider makes pressure and manages to break the agreement. On the contrary, if not all firms fit, stable mergers may arise, even if the strongest definition of stability is applied.

Although mergers with asymmetric firms have been already studied in the literature (see, for example, Barros, 1998), the importance of partners fitting well for stable mergers to arise has been ignored so far.

4.2 The model

Consider a Cournot oligopoly with three firms of different technologies. Let c_i be firm i's marginal cost. Each firm owns just one plant. In particular, firm 1 owns the most efficient plant while firm 3 the less efficient, that is, $c_1 < c_2 < c_3$. The inverse demand function is represented by $P = a - bQ$, where Q denotes the total market quantity and a and b are positive parameters. In order to guarantee that the model is well defined, we assume that $a > 3c_3 - 2c_1$.

We assume that mergers to monopoly are not allowed by the antitrust authority so just mergers between two firms are considered. Merged firms may wish to operate both plants in competition with each other. This possibility was first introduced by Kamien and Zang (1990). They prove that a owner of several firms might optimally choose to operate more than one of them at a positive level since by competing against himself, he captures some sales from his rivals and increases his market share. The automobile industry provides a clear example of divisionalized firms in which divisions compete with each other.

We assume that if merged firms decide to leave both plants operating, the most efficient plant transfers its technology to the less efficient one. However, transferring technological know-how may have a considerable associated cost.[1] This transfer cost can be understood as a measure of how firms fit. It is assumed to be fixed and proportional to the difference in marginal costs and the ability of the less efficient firm to absorb new technologies. Thus, there exists a trade-off for merged firms to leave both plants operating. Formally, if firms i and j merge and they decide to operate both plants, merged firms' profits are given by:

$$\Pi^{i+j} = \underset{q_i}{Max}\{(a-bq_i-bq_j-bq_k-c_j)q_i\}+\underset{q_j}{Max}\{(a-bq_i-bq_j-bq_k-c_j)q_j\}-s_i(c_i-c_j), \quad (4.1)$$

where $i \neq j \neq k$, $c_i > c_j$ and s_i is inversely related with firm i's ability to absorb new technologies.

On the contrary, if firms i and j merge but they decide to shut down the less efficient plant, they obtain a duopoly profit, that is:

$$\Pi^{i+j} = \underset{q_j}{Max}\left\{(a - bq_j - bq_k - c_j)q_j\right\}. \quad (4.2)$$

Note that merged firms' decision on whether to shut down or not one of the plants affects the outsider's profits. Taking the triopoly case as a benchmark, the outsider is worse off if merged firms leave both plants operating while it is better off when one of the plants is shut down.

The timing of the game is as follows. First, firms decide whether to merge or not. Second, merged firms decide how many of their plants to operate. Finally, plants compete à la Cournot and firms get their payoffs. The game is solved by backward induction.

4.3 Stable mergers

Let x_i^{i+j} be the share of joint profits that firm i obtains when merging with firm j and Π_k^{i+j} the profits obtained by firm k when firms i and j merge. The first condition that

[1] Teece (1977), in a study of 26 technological transfers, estimates that transfer costs average 19% of total project costs (ranging from 2% to 59% of total project costs).

must be satisfied for a merger between firms i and j to be stable is that none of these firms have incentives to deviate and merge with firm k. We assume firm k exerts the maximum pressure to break the merger between i and j, that is, it offers to any of these firms a share of joint profits such as firm k is obtaining the same profits that in the case in which firms i and j merge. After some manipulations, this condition can be written as:[2]

$$\Pi^{i+j} - \Pi^{j+k} + \Pi_k^{i+j} \geq \Pi^{i+k} - \Pi_k^{i+j}. \tag{4.3}$$

The second condition that must be satisfied to guarantee stability is related with the reaction of external firms after a deviation. There is a large variety of equilibrium or stability concepts in the literature depending on what external players do after a deviation (see Hart and Kurz, 1983). The strongest definition of stability is due to Shenoy (1979) that considers that when a firm deviates the others are going to react in the most favorable way to that firm. In our model, we can consider three different cases when analyzing the stability of a merger between firms i and j. The first one corresponds to the case in which whenever firms i and k or firms j and k merge, they leave both plants operating. In this case, if firm i or j deviates, the best reaction of the others is to stand alone. If even in this situation, nor i nor j wants to deviate, then merger between i and j is surely stable:

$$x_i^{i+j}\Pi^{i+j} \geq \Pi_i \text{ and } (1 - x_i^{i+j})\Pi^{i+j} \geq \Pi_j, \tag{4.4}$$

where Π_i represents firm i's profits when all firms stand alone. Combining both conditions, we can obtain:

$$\Pi^{i+j} \geq \Pi_i + \Pi_j. \tag{4.5}$$

The second case corresponds to the case in which whenever firms i and k or firms j and k merge, they close the less efficient plant. In this case, if firm i or j deviates, the

[2]Full derivation of this formula can be found in Barros (1998).

best reaction of external firms is to merge so the stability condition is given by:[3]

$$\Pi^{i+j} \geq \Pi_i^{j+k} + \Pi_j^{i+k}. \tag{4.6}$$

The last case is a combination of the previous ones. If whenever firms i and k merge, they close one plant, but if firms j and k merge, they leave both plants operating, a stable merger between firms i and j must satisfy:

$$\Pi^{i+j} \geq \Pi_i^{j+k} + \Pi_j. \tag{4.7}$$

Summarizing, for a merger between firms i and j to be stable, the first condition that must be satisfied is given by expression (4.3). Once this condition has been fulfilled, we apply the strongest definition of stability given by condition (4.5), (4.6), or (4.7), depending on which case we are in. The following proposition states that no stable merger arises if there is no cost of transferring technological know-how.

Proposition 4.1. *If there is no cost of transferring technological know-how, no stable merger arises in the market, even if the weakest definition of stability is considered.*

Proof. There are three possible mergers:$\{\{1,2\},3\}$, $\{\{1,3\},2\}$ or $\{\{2,3\},1\}$. Since there is no transfer cost, merged firms solve the maximization program given by expression (4.1). It is easy to show that for any possible merger, the first condition given by expression (4.3) is never satisfied. Take, for example, the first case. Merger between firms 1 and 2 is stable if and only if the following condition is satisfied:

$$\Pi^{1+2} - \Pi^{2+3} + \Pi_3^{1+2} \geq \Pi^{1+3} - \Pi_3^{1+2}.$$

For this condition to hold, we need the following to be satisfied:

$$2a(c_3 - c_1) + 2a(c_3 - c_2) \leq (c_3 - c_1)(5c_3 - 3c_1) + (c_3 - c_2)(5c_3 + 5c_2 - 8c_1).$$

[3] Barros (1998) only considers the case in which whenever two firms merge, they close the less efficient firm. However, he assumes that after a deviation all firms remain as singletons, which as we can see, is not the strongest definition of stability to be applied.

We know $a > 3c_3 - 2c_1$, so from previous expression, we obtain the following:

$$2(3c_3 - 2c_1)(c_3 - c_1) + 2(3c_3 - 2c_1)(c_3 - c_2) <$$
$$(c_3 - c_1)(5c_3 - 3c_1) + (c_3 - c_2)(5c_3 + 5c_2 - 8c_1).$$

This condition can be rewritten as $(c_3 - c_2)^2 + (c_3 + c_1 - 2c_2)^2 < 0$, which is obviously not satisfied. ■

Proposition 4.1 may seem at first sight counterintuitive. The absence of transfer costs indicates that firms fit perfectly, so more mergers should be expected. However, because all firms are compatible, all firms want to be involved in a merger. Whenever a firm remains as an outsider, this firm makes all the pressure to break the agreement of the others so, for every possible definition of stability, no stable merger can arise in the market. On the contrary, if there are costs of transferring technological know-how, some firms fit better than others and a non-compatible outsider cannot make so much pressure to break an agreement. This result is formally stated in the following proposition.

Proposition 4.2. *If there are costs of transferring technological know-how, stable mergers may arise in the market, even if the strongest definition of stability is considered.*

Proof. In order to prove that even if we consider the strongest definition of stability, a stable merger may arise, we provide an example. Suppose $c_1 = 1$, $c_2 = 2$, $c_3 = 100$, $a = 299$, $b = 1$, $s_2 = 0$ and $s_3 = 100$. We will prove that in this case the merger between 1 and 2 is stable. If 1 and 2 merge it is optimal for them to leave both plants operating so $\Pi^{1+2} = 19701$ and $\Pi_3^{1+2} = 0.0625$. However, if firms 1 and 3 or firms 2 and 3 merge, it is optimal for them to close firm 3's plant so $\Pi^{1+3} = 9933.4$, $\Pi_2^{1+3} = 9735.1$, $\Pi^{2+3} = 9735.1$, and $\Pi_1^{2+3} = 9933.4$. The first condition to be fulfilled is given by:

$$\Pi^{1+2} - \Pi^{2+3} + \Pi_3^{1+2} \geq \Pi^{1+3} - \Pi_3^{1+2},$$

which is satisfied. The strongest definition of stability in this case implies that $\Pi^{1+2} \geq \Pi_2^{1+3} + \Pi_1^{2+3}$,which is also satisfied. ■

4.4 Conclusions

It is usually claimed that mergers are more likely to work when a company chooses a partner that fits well, rather than one that is merely available. However, it is not the case that the more firms fit, the more they merge. We provide a very simple model to explain why the easier is to find a compatible partner in the market, the harder is to perform a stable merger since outsiders make huge pressure to break the agreement. In particular, we find that if all firms are perfectly compatible, it is impossible to reach an agreement to merge, no matter the definition of stability used. On the contrary, if not all firms fit, a stable merger might arise, even if the strongest definition of stability is applied. This simple model may explain why industries with higher difficulties for firms to fit together due to the complexity of combining back offices, different cultures and high technologies, such as banks, telecoms or computer industry, are on the contrary the ones with larger number of mergers.

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Chapter 5

Mergers and the limited liability effect

5.1 Introduction

Over the last twenty years, companies around the world have merged at an unprecedented scale. In 1999, the worldwide value of mergers rose to more than \$3.4 trillion, and the number of merger deals announced was around thirty times what it was in 1981 (The Economist, 2000).

Given this considerable number of merger announcements, the role of antitrust authorities becomes crucial to guarantee that only mergers that increase social welfare are finally carried out. Moreover, mergers producing social gains should be encouraged even if they are not profitable for the merging parties. Policies promoting such mergers are quite common in Asian countries. A clear example is the Financial Institution Merger Law (FIML) implemented by the Chinese Government in 2000. The FIML encourages mergers among financial institutions by offering both tax and non-tax incentives. The Law also simplifies the procedures of mergers and acquisitions in order to reduce the costs arising from mergers. Other examples are the incentives offered by the Bangko

Sentral in Philippines or the MITI in Japan. Spain has also provided fiscal advantages to mergers (Neven, Nuttall and Seabright, 1993), and in United States, the Pentagon has encouraged mergers within the Defence and pharmaceutical industries through a generous program to reimburse contractors for the costs of those mergers (Piachaud and Moustakis, 2000).

Most of the firms involved in mergers have limited liability, that is, if firms become insolvent, creditors are paid whatever operating profits are available. The purpose of this paper is to analyze the effects that mergers of limited liability companies have on firms' profits and social welfare, providing important implications to regulation policy.

The linkage between product and financial markets was first analyzed by Brander and Lewis (1986). They consider two symmetric firms competing à la Cournot in a homogenous output market under uncertainty over demand or costs. Under some assumptions (including linear demand and constant marginal costs), they find that the limited liability provisions of debt financing imply that changes in financial structure alter the output market equilibrium. In particular, they show that, if marginal profits depend positively on the uncertainty term, the higher the debt level, the more aggressively firms compete.[1] This is what they call the limited liability effect of debt financing. Considering some conditions to guarantee uniqueness of equilibrium (see, for example, Kolstad and Mathiesen,1987), Brander and Lewis (1986) results can be easily generalized to a n-firms oligopoly.[2]

We consider n firms that compete in a Cournot market with uncertainty over demand, fixed costs and constant marginal costs. All firms enjoy a limited liability situation and own the same level of debt obligation. Output decisions are taken before the uncertainty over demand is realized.

[1] Other authors discussing the relationship between financial structure and output market performance are Glazer (1994), Poitevin (1989) and (1990) and Showalter (1995).

[2] For empirical literature analyzing the links between financial structure and product market decisions, see Campos (2000), Chevalier (1995), Philips (1995), Showalter (1999), or Wanzenried (2000).

Because financial structure influences the output market equilibrium, foresighted owners of the firms will have incentives to use financial structure to influence output in their favor. Given the behavior of the rival, a firm which ignored the strategic effect of financial decisions would have lower total value than a firm that took advantage of these limited liability effects. Mergers imply an increase in the new firm's debt level and hence a possible way of taking advantage of the limited liability effect to influence the equilibrium outputs.

We assume before operating in the market firms face a fixed cost. Although fixed cost savings may increase mergers profitability, they may be still injurious to the merging parties. Salant, Switzer and Reynolds (1983) demonstrate that, even with fixed cost savings, mergers may reduce the endogenous joint profits of the firms that are colluding in a complete information setting. Moreover, they show that privately unprofitable mergers may be socially gainful.

We use as benchmark a situation in which firms have no debt obligation at all (and hence there is no limited liability effect). Privately and socially profitable mergers are analyzed. This benchmark slightly differs from the one of Salant, Switzer and Reynolds (1983) since there is uncertainty over the future demand. Given the uncertainty over demand, more mergers are privately profitable than in the case of Salant, Switzer and Reynolds (1983). It is also shown that in absence of any debt, mergers that increase social welfare might cause private losses to the colluding firms. In these circumstances, public intervention is needed. One possibility consists on subsidizing mergers. Faulí-Oller (2002) analyzes mergers between asymmetric firms. He finds the minimum subsidy required to guarantee that mergers that increase social welfare take place. In this paper, we propose another possible way of encouraging socially optimal mergers: limited liability debt financing.

As debt raises, given the limited liability, firms focus on good states of demand and compete more aggressively. The higher the debt level, the more likely is that the strategic effect of debt increases insiders' profits and the merger become privately advantageous. That is why some mergers that are not privately lucrative in absence of any debt may produce private gains for debt levels high enough. Moreover, it is shown that the combination of limited liability debt financing and a specific antitrust policy leads higher social welfare than a subsidy policy. On the one hand, the limited liability effect increases firms' incentives to merge and the society benefits from fixed costs savings. On the other hand, mergers imply a decrease in market quantity, but this reduction is lower given that firms compete more aggressively. This latter effect is not obtained through subsidies.

Even though limited liability debt financing has never been applied to mergers, it has already been used for regulatory purposes. Indeed, something similar is what Spanish Government does to finance certain R&D projects (*Proyectos Concertados*): firms are granted with free-of-interest-credits but if they are finally unable to reach their technical purposes, firms are not obliged to pay the whole debt. Although this kind of policy may involve incentives (moral hazard) problems, it encourages the execution of risky projects that would not be carried out without public intervention.

Limited liability debt financing affects firms' attitude towards risk. Notice that limited liability firms only care about good states of the world, that is, firms are risk lovers. Indeed, the worst firms can do is going bankrupt, so as debt level increases, firms take chances they would not take in other situations. Although so far mergers between risk lovers firms have not been analyzed in the literature, there are some papers analyzing mergers between risk averter firms as a mean of better sharing and diversifying risk. Some empirical and theoretical contributions to this literature can be found in Amihud and Lev (1981), Banal-Estañol and Ottaviani (2003), Brown and Chiang (2002), and Levy and Sarnat (1970).

The rest of the paper is organized as follows. Section 5.2 presents the general model of limited liability. In section 5.3, the benchmark case in which firms do not have any debt obligation is considered. Both the private incentives and social welfare of mergers are studied. Section 5.4 is devoted to the analysis of the main results of the limited liability model. We apply the limited liability effect to regulation policy in section 5.5. Finally, section 5.6 concludes.

5.2 The model

Consider n identical firms that produce in a homogenous output market with uncertainty over demand, with $n \geq 2$.[3] Let us compare the Cournot equilibrium of this industry with the Cournot equilibrium in which $m+1$ firms decide to merge, while the other firms remain independent (m being an integer between 0 and $n-1$). All decisions are taken before the uncertainty over demand is realized.

The demand function is given by $P = Max\{\theta - Q, 0\}$, where Q denotes the total market quantity and θ is a random variable that reflects the uncertainty that all firms have over the future demand.[4] The demand intercept θ is assumed to be uniformly distributed over the interval $[0, \overline{\theta}]$. Before operating in the market, all firms face a fixed cost F. Operating marginal costs are assumed to be constant and, for simplicity, are set to zero. Let D denote the initial debt obligation for every firm in the market. If $m+1$ firms merge, merged firm's debt level is the result of the sum of the debt obligations of its participants, $D_c = (m+1)D$.[5]

[3] Results do not change if, instead of uncertainty over demand, we consider uncertainty on firms' costs.

[4] As Salant, Switzer and Reynolds (1983) point out, the assumption of unitary slope is unrestrictive, since any linear demand curve can be expressed in this form if the output units are properly defined.

[5] We do not consider that merging firms increase financial leverage following mergers. Merging parties can increase financial leverage either because of an increase in debt capacity or because of unused debt capacity from pre-merger years (see for example, Ghosh and Jain, 2000, Kim and McConnell, 1977, or Lewellen, 1971). Assuming an increase in financial leverage following mergers reinforces even more our results.

All firms enjoy a limited liability situation. We denote by $\widehat{\theta_k}$ firm k's critical bankruptcy threshold, reflecting the state of demand for which firm k can just meet its debt obligations with nothing left over. In bad states of demand ($\theta < \widehat{\theta_k}$), firm k is unable to pay debt claims and goes bankrupt. We assume that $0 < \widehat{\theta_k} < \overline{\theta}$ for every firm k, that is, firms never go bankrupt if the demand happens to be the highest one. Firm k's expected current-period profit is denoted by π^k:

$$\pi^k(q_k, q_{-k}, D_k) = \frac{1}{\overline{\theta}} \int_{\widehat{\theta_k}}^{\overline{\theta}} [(\theta - Q)q_k - D_k)]d\theta, \tag{5.1}$$

where $\widehat{\theta_k}$ is defined as follows:

$$\widehat{\theta_k} = \frac{D_k}{q_k} + Q, \tag{5.2}$$

where $D_k = D$ if firm k is an independent firm and $D_k = (m+1)D$ if firm k is the coalition of $m+1$ firms, with m being an integer belonging to the interval $(0, n-1]$. Expression (5.1) represents firm k's expected current-period profits net of debt obligations in good states of demand ($\theta \geq \widehat{\theta_k}$). In bad states ($\theta < \widehat{\theta_k}$), firm k earns zero as all of its earnings are paid to debt-holders. Firm k's total expected profit Π^k is obtained through the sum of the current-period profit given by expression (5.1) and the level of debt obligation, D_k, that firm k borrowed in a previous period. Besides, firm k must pay a fixed cost F before operating in the market. So firm k's total expected profit Π^k is given by:

$$\Pi^k = \pi^k(q_k, q_{-k}, D_k) + D_k - F. \tag{5.3}$$

The timing of the game is as follows. In an initial stage, each firm borrows a debt level D. In the second stage of the game, $m+1$ firms decide to merge while the other firms remain independent. In next period, firms pay a fixed cost F and compete à la Cournot under uncertainty over demand. Finally, θ is realized and firms obtain their payoffs. Firms are obliged to meet their debt obligations out of operating profits, if possible. If operating profits are insufficient to pay creditors, the firm goes bankrupt.[6]

[6]Note that firms are only obliged to pay debt out of operating profits. If the debt taken exceeds

Parameters of the model are assumed to be such that we obtain uniqueness of equilibrium for every possible coalition structure. To better understand the main insights of the model let us start with the simple case in which firms do not have any debt obligation before deciding on production, that is $D = 0$. In this benchmark, even if a positive number of firms merge, all firms remain identical, though through mergers they save fixed costs.

5.3 Benchmark case. Private incentives and social welfare of mergers

In this section, we consider that firms do not have any debt obligation before decisions on equilibrium outputs are taken, that is, $D = 0$ for every firm. In this framework, let us analyze the private incentives and social welfare of a merger of $m+1$ firms. Denote by $\Pi^c(n, m, 0)$ the joint profits that these $m+1$ firms obtain if they collude and debt obligation is zero. Denote by $\Pi^{nc}(n, m, 0)$ the joint profits that the $m+1$ insiders would noncooperatively obtain if they do not merge and the level of debt obligation is zero. Let us denote by $g(n, m, 0)$ the increase in insiders' joint profits if $m+1$ firms decide to collude and debt obligation is zero:

$$g(n, m, 0) = \Pi^c(n, m, 0) - \Pi^{nc}(n, m, 0). \tag{5.4}$$

$\Pi^{nc}(n, m, 0)$ results just from the sum of the $m+1$ profits obtained in an oligopoly of n symmetric firms, minus $m+1$ fixed costs. Because the debt obligation is set to zero, once the insiders have merged, they behave exactly as the other $n - m - 1$ symmetric firms in the industry, and the operating profits merged firm obtains are the operating

the fix cost, the firm distributes the money to the shareholders before operating in the market. As Dastidar (2003) points out, this kind of leveraged recapitalisations are sometimes empirically observed, for example, as anti-takeover measures.

profits a firm would obtain in an industry with $n-m$ identical firms, with a fixed cost savings of mF. Thus, expression (5.4) can be rewritten as:

$$g(n,m,0) = \pi(n-m) - (m+1)\pi(n) + mF. \tag{5.5}$$

Each of the n symmetric firms of the industry maximizes its profits taken as given the other firms' outputs. In our case, firms decide quantities before the uncertainty over demand is realized so profits are taken in expected form. Prices cannot be negative so if the demand happens to be lower than expected, firms earn zero profits.[7] Every firm i solves the following maximization program:

$$\underset{q_i}{Max}\ \pi^i(q_i, q_{-i}, 0) = \underset{q_i}{Max} \int_Q^{\overline{\theta}} (\theta - Q) q_i \frac{1}{\overline{\theta}} d\theta. \tag{5.6}$$

The choice of output for firm i is obtained by setting the first derivative of $\pi^i(q_i, q_{-i}, 0)$ with respect to q_i equal to zero. Using subscripts to denote partial derivatives, the first order condition of the above maximization program can be written as:

$$\pi_i^i(q_i, q_{-i}, 0) = \frac{1}{\overline{\theta}} \int_Q^{\overline{\theta}} (\theta - Q - q_i) d\theta = 0. \tag{5.7}$$

The second order condition of firm i's maximization program is given by:

$$\pi_{ii}^i(q_i, q_{-i}, 0) = \frac{1}{\overline{\theta}}(q_i - \int_Q^{\overline{\theta}} 2d\theta) < 0. \tag{5.8}$$

In a symmetric Nash equilibrium, outputs offered by all firms in the industry are identical, so the market quantity can be expressed as $Q = nq$. The unique symmetric Cournot equilibrium output that satisfies both the first and second order conditions is given by $q = \overline{\theta}/(n+2)$. Substituting equilibrium quantities in firms' benefits, we obtain equilibrium operating profits for each of the n identical firms of the industry, which are given by the following:

$$\pi(n) = \frac{2\overline{\theta}^2}{(n+2)^3}. \tag{5.9}$$

[7] This is the main difference between our benchmark case and the model of Salant, Switzer and Reynolds (1983).

Thus, the change in insiders' profits due to a merger of $m+1$ firms when debt obligation is zero can be expressed as:

$$g(n,m,0)=\frac{2\overline{\theta}^2}{(n-m+2)^3}-(m+1)\frac{2\overline{\theta}^2}{(n+2)^3}+mF. \tag{5.10}$$

For a merger of $m+1$ firms to be profitable, the change in insiders' profits must be positive, $g(n,m,0)>0$. The most interesting properties of this function are summarized in the following lemma.

Lemma 5.1. *The increase in insiders' joint profits if $m+1$ firms decide to collude and debt obligation is zero, $g(n,m,0)$, is strictly convex in the number of colluding firms m. $g(n,m,0)$ is zero for $m=0$ and merger to monopoly is always profitable. If fixed cost F is not high enough, $g(n,m,0)$ is initially negative and decreases in m, while every merger is profitable if fixed cost is sufficiently large. Finally, if there is no fixed cost, for any n, it is sufficient for a merger to be unprofitable that less than the 65.44 percent of the firms collude.*

The function $g(n,m,0)$ is strictly convex in m. On the one hand, if fixed cost savings are not large enough, it is initially negative and decreasing in m. Thus, merger by a larger number of firms may cause a loss to the colluding firms. However, when all firms collude joint profits are maximized and firms' profits are always higher than in the pre-merger equilibrium. On the other hand, if costs savings are large enough, every merger cause private gains to the colluding parties. The uncertainty over demand makes some mergers that would be unprofitable in a certain environment profitable in our model. In particular, we find that for any n and no saving costs, it is sufficient for a merger to be unprofitable that less than the 65.44 percent of the firms collude (instead of the 80 percent of Salant, Switzer and Reynolds, 1983).

Let us now analyze the social welfare of mergers. We are considering so far that firms produce and send their production to the market before the uncertainty over demand is resolved. Hereafter, if the demand happens to be lower than expected and prices inevitably fall to zero, consumers will acquire the goods at zero price.[8] The consumer surplus is obtained through the following formula:

$$CS = \frac{1}{\overline{\theta}}(\int_0^Q \frac{\theta^2}{2} d\theta + \int_Q^{\overline{\theta}} \frac{Q^2}{2} d\theta). \tag{5.11}$$

Social welfare is defined as the sum of consumer surplus and the profits of all firms competing in the market. The gain in social welfare due to the merger of $m+1$ firms in a $n-$firms oligopoly with zero debt obligation is given by:

$$S(n,m,0) = CS(n,m,0) + (n-m)\ \pi(n-m) - CS(n,0) - n\ \pi(n) + mF, \tag{5.12}$$

which in our benchmark model can be rewritten as:

$$\begin{aligned} S(n,m,0) = {} & (n-m)\frac{2\overline{\theta}^2}{(n-m+2)^3} + \frac{\overline{\theta}^2}{2}[\frac{(n-m)^2}{(n-m+2)^2} - \frac{2}{3}\frac{(n-m)^3}{(n-m+2)^3}] \\ & - n\frac{2\overline{\theta}^2}{(n+2)^3} - \frac{\overline{\theta}^2}{2}[\frac{n^2}{(n+2)^2} - \frac{2}{3}\frac{n^3}{(n+2)^3}] + mF. \end{aligned} \tag{5.13}$$

For small m, we can find values for fixed costs F such that there exists social gains of mergers though they cause private losses to the merging firms, that is, $S(n,m,0) > 0 > g(n,m,0)$.[9] This is formally stated in the following proposition.

Proposition 5.1. *Mergers that increase social welfare might be unprofitable to the colluding parties.*

Many examples satisfy Proposition 5.1. For the sake of illustration, take for instance the case of ten firms, and suppose, for simplicity, that θ is uniformly distributed over

[8] For simplicity, we have considered the marginal cost to be zero. However, notice that, even if the marginal cost is strictly positive, firms may be interested in selling outputs at prices below the marginal cost, since production is sent to the market before the uncertainty over demand is realized.

[9] In absence of fixed cost savings, mergers are never socially advantageous. However, for small m the social loss is smaller than the loss to the merging parties. Fixed cost savings benefit both the merging parties and society in the same amount, so it is possible to select $F > 0$ so that $S(n,m,0) > 0 > g(n,m,0)$.

the interval $[0, 100]$. Suppose also that fixed costs are $F = 4$. In this example, mergers of two, three and four firms are socially advantageous though none of these firms cause private profits to the merging firms. Indeed, in this example, for a merger to be privately profitable it is necessary that at least six firms decide to collude. Figure 5.1 plots both the gain in insiders' profits and social welfare if $m+1$ firms merge in a ten-firms oligopoly.

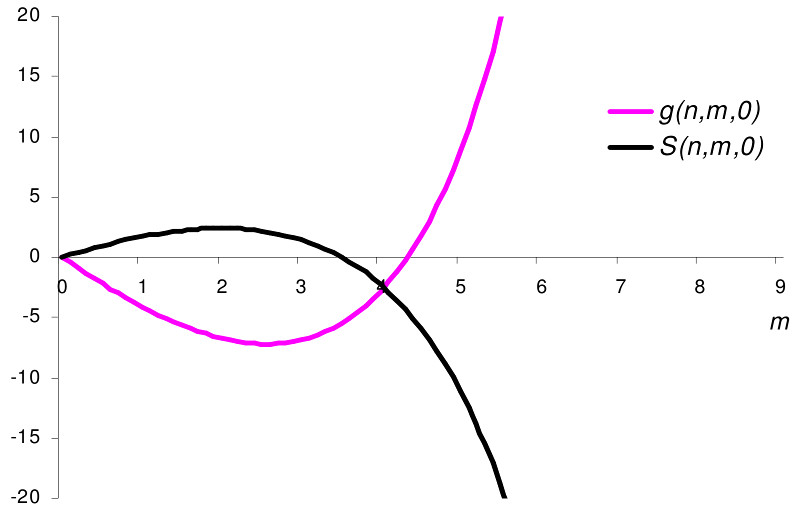

Figure 5.1: Social and private gains to insiders if $m + 1$ firms merge, for $n = 10$, $F = 4$ and $\overline{\theta} = 100$

So far we have considered that firms do not face any debt obligation before output decisions are taken. However, if firms are debt financed, a merger of $m+1$ firms increases the debt obligation of the resulting firm. Given that firms enjoy a limited liability situation, an increase in debt level makes merged firm to compete more aggressively than the other $n - m - 1$ symmetric firms in the industry. In next section, we discuss the consequences of the limited liability effect on the private incentives and social welfare of mergers.

5.4 The limited liability effect

This section examines how the limited liability aspects of debt financing affect the strategic output decisions of firms, and hence their incentives to merge. In order to make comparisons let us start with the case in which all firms remain independent. Taking existing debt level D as given, each of the n symmetric firms chooses output in order to maximize current-period expected profits:

$$\underset{q_i}{Max}\ \pi^i(q_i, q_{-i}, D) = \underset{q_i}{Max} \int_{\widehat{\theta}_i}^{\overline{\theta}} [(\theta - Q)q_i - D]\frac{1}{\overline{\theta}}d\theta, \tag{5.14}$$

where $\widehat{\theta}_i$ is defined by:

$$\widehat{\theta}_i = \frac{D}{q_i} + Q. \tag{5.15}$$

The first order condition of the above maximization program is obtained setting the first derivative of $\pi^i(q_i, q_{-i}, D)$ with respect to q_i equal to zero:[10]

$$\pi^i_i(q_i, q_{-i}, D) = \int_{\widehat{\theta}_i}^{\overline{\theta}} (\theta - Q - q_i)\frac{1}{\overline{\theta}}d\theta = 0. \tag{5.16}$$

The second order condition is given by:

$$\pi^i_{ii}(q_i, q_{-i}, D) = \frac{1}{\overline{\theta}}[-2\overline{\theta} + 2(\frac{D}{q_i} + Q) - (\frac{-D}{q_i^2} + 1)(\frac{D}{q_i} - q_i)] < 0. \tag{5.17}$$

All firms are identical so the Cournot equilibrium output is symmetric, $q_i = q_j = q$ for every firm $i \neq j$. Market quantity can be expressed as $Q = nq$. The symmetric Nash equilibrium quantity satisfies both the first and second order conditions given by expressions (5.16) and (5.17).[11]

In bad states of demand, firms' profits are not sufficient to meet debt obligations and firms go bankrupt. The limited liability aspects of debt financing implies that firms

[10] Besides the expression in (5.16), the derivative of $\pi^i(q_i, q_{-i}, D)$ includes another term, $-\frac{d\widehat{\theta}_i}{dq_i}\frac{1}{\overline{\theta}}[(\widehat{\theta}_i - Q)q_i - D]$, which is zero by definition.

[11] In general, the symmetric solution of expression (5.16) is not unique but we can always impose restrictions on the debt level D such that there is only one solution that satisfies the second order condition given by expression (5.17).

are only concerned about good states of demand, $\theta \in \left[\widehat{\theta}_i, \overline{\theta}\right]$. Increases in the level of debt obligation raises the critical bankruptcy threshold $\widehat{\theta}_i$ and forces firms to take output decisions they would not take in other circumstances. As debt raises firms compete more aggressively. The worst the firms can do is going bankrupt, and if they do not compete more aggressively they will go bankrupt anyway. In other words, limited liability implies that firms are risk lovers and the symmetric Cournot equilibrium output increases as debt level raises.

Lemma 5.2. *The unique symmetric Cournot equilibrium output for the case in which all firms remain independent q is strictly increasing in the initial level of debt obligation D.*

The most interesting results of the limited liability model arise when there is an unilateral increase in the level of debt obligation due to a merger of firms. The Cournot equilibrium output in which $m+1$ firms merge is not longer purely symmetric- for m belonging to the interval $(0, n-1)$. The coalition of these $m+1$ firms faces a level of debt higher than the other $n-m-1$ symmetric firms in the industry and merged firm will not exactly behave as the others. Denote by q_c and q_i the quantity offer by the coalition of firms and each of the other $n-m-1$ firms in the market, respectively. The coalition of $m+1$ firms solves the following maximization program:

$$\underset{q_c}{Max}\ \pi^c(q_c, q_i, D) = \underset{q_c}{Max} \int_{\widehat{\theta}_c}^{\overline{\theta}} [(\theta - Q)q_c - (m+1)D]\frac{1}{\overline{\theta}}d\theta, \tag{5.18}$$

where $\widehat{\theta}_c$ is defined by:

$$\widehat{\theta}_c = \frac{(m+1)D}{q_c} + Q. \tag{5.19}$$

Each of the $n-m-1$ symmetric firms that remain independent solves:

$$\underset{q_i}{Max}\ \pi^i(q_c, q_i, D) = \underset{q_i}{Max} \int_{\widehat{\theta}_i}^{\overline{\theta}} [(\theta - Q)q_i - D]\frac{1}{\overline{\theta}}d\theta, \tag{5.20}$$

where $\widehat{\theta}_i$ is defined by:

$$\widehat{\theta}_i = \frac{D}{q_i} + Q. \tag{5.21}$$

The $n-m-1$ outsiders act in the same way so the market quantity can be expressed as $Q = q_c + (n-m-1)q_i$. The Nash equilibrium outputs q_c and q_i are obtained from the simultaneous solution of the first order conditions of the above maximization programs. These first order conditions can be written as:

$$\frac{\overline{\theta}^2}{2} - \overline{\theta}(Q+q_c) - \frac{1}{2}(\frac{(m+1)D}{q_c} + Q)^2 + (Q+q_c)(\frac{(m+1)D}{q_c} + Q) = 0. \tag{5.22a}$$

$$\frac{\overline{\theta}^2}{2} - \overline{\theta}(Q+q_i) - \frac{1}{2}(\frac{D}{q_i} + Q)^2 + (Q+q_i)(\frac{D}{q_i} + Q) = 0. \tag{5.22b}$$

The simultaneous Nash solution of expressions (5.22a) and (5.22b) must also satisfy the following second order conditions:[12]

$$3q_c^4 + 2[(n-m-1)q_i - \overline{\theta}]q_c^3 + (m+1)^2D^2 \;<\; 0. \tag{5.23a}$$

$$[2(n-m)-1]q_i^4 + 2(q_c - \overline{\theta})q_i^3 + D^2 \;<\; 0. \tag{5.23b}$$

As shown in Lemma 5.2, firms are only concerned about good states of demand and as debt raises, firms take more aggressive output decisions. The merger of $m+1$ firms implies a unilateral increase in debt. Hence, mergers will not only affect the number of firms competing in the market but also merged firm's behavior. Indeed, the increase in the debt level serves as a commitment of the merged firm to compete more aggressively.

Lemma 5.3. *In the unique Cournot equilibrium, merged firm competes more aggressively than the other $n-m-1$ symmetric firms in the industry: $q_c > q_i$.*

In absence of any debt obligation, once insiders have merged, they behave exactly as the other $n-m-1$ firms in the industry. However, the strategic effect of debt in a limited liability context affects merged firm's behavior. Merged firm has to pay a higher level of debt. If it does not take more risk, merged firm is more likely to bankrupt.

[12] Again, the solution of expressions (5.22a) and (5.22b) is not generally unique but we can always impose restrictions on the debt level D such that there is only one solution that satisfies the second order conditions given by expressions (5.23a) and (5.23b).

Let us now analyze firms' private incentives to merge. Recall firm k's total expected profit Π^k is the result of firm i's current-period profit π^k, plus the level of debt firm k borrowed in a previous period D_k, minus the fixed cost firm k paid before operating in the market F. Denote by $\Pi^c(q_c, q_i, D)$ total expected profits if $m+1$ firms with initial level of debt D collude, where q_c and q_i are the Cournot equilibrium outputs resulting from the simultaneous solution of expressions (5.22a) and (5.22b). Denote by $\Pi(q, D)$ the joint profits that the $m+1$ insiders would noncooperatively obtain if they do not merge, where q is the symmetric Cournot output given by expression (5.16). Let $g(n, m, D)$ denote the increase in insiders' joint profits if $m+1$ firms decide to collude with initial debt obligation D.

$$g(n, m, D) = \Pi^c(q_c, q_i, D) - (m+1)\Pi(q, D) = \pi^c(q_c, q_i, D) - (m+1)\pi(q, D) + mF. \quad (5.24)$$

The higher the initial level of debt obligation, the higher the limited liability effect of debt financing. The higher the limited liability effect, the more aggressive merged firm competes and the larger the difference between the cooperative and noncooperative profits of insiders. As initial debt raises, mergers that are not privately profitable may become beneficial.

Proposition 5.2. *If the initial level of debt obligation D is high enough, the limited liability effect makes some mergers that are not privately profitable with zero debt obligation $g(n, m, 0) < 0$, privately profitable, $g(n, m, D) > 0$.*

In order to see that the limited liability effect increases mergers profitability, take again the case of ten firms, with θ uniformly distributed over the interval $[0, 100]$ and $F = 4$. We know in absence of any debt obligation, merger of three firms is not privately profitable: $g(n, m, 0) = -6.722$, for $n = 10$ and $m = 2$. However, it is easy to show that if the initial level of debt obligation is high enough, for example $D = 40$, merger of three firms becomes privately beneficial: $g(n, m, 40) = 2.1874$, for $n = 10$ and $m = 2$.

Social welfare is the result of the sum of consumer surplus, firms' total expected profits and creditors' profits. Creditors' profits are equal to their revenues minus the level of debt they lent to each firm in a previous period. In good states of demand creditors are paid the whole debt. However, if firms become insolvent creditors can only collect firms' current- period operating profits.[13] Figure 5.2 plots the revenues creditors obtained from firm k as function of the state of the demand.

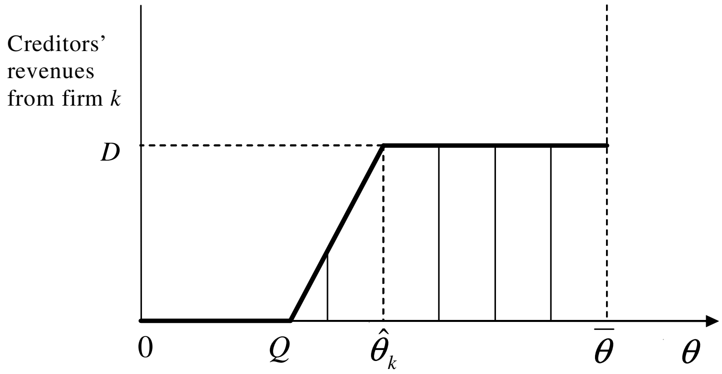

Figure 5.2: Creditors' revenues from firm k as function of the state of demand

If all firms remain independent in a $n-$firms oligopoly, creditors' profits are given by the following expression:

$$Cr(n, D) = -nD + n\int_{Q}^{\widehat{\theta}} (\theta - Q)q\frac{1}{\overline{\theta}}d\theta + n\int_{\widehat{\theta}}^{\overline{\theta}} D\frac{1}{\overline{\theta}}d\theta, \tag{5.25}$$

where q is the symmetric Cournot solution of expression (5.16), $Q = nq$ is the market quantity, and $\widehat{\theta} = \frac{D}{q} + nq$, the critical bankruptcy threshold of each of the symmetric firms in the market.

On the other hand, if $m + 1$ firms in an industry of n firms collude, creditors' profits

[13] For the sake of simplicity and following Brander and Lewis (1986), we assume that the asset value of firms is zero (as if assets are completely used up in the production of output). Therefore, creditors can only collect current operating profits if firms go bankrupt.

can be expressed as:

$$Cr(m,n,D) = -nD + \int_Q^{\widehat{\theta}_c} (\theta - Q) q_c \frac{1}{\overline{\theta}} d\theta + (m+1) \int_{\widehat{\theta}_c}^{\overline{\theta}} D \frac{1}{\overline{\theta}} d\theta \tag{5.26}$$
$$+(n-m-1) \int_Q^{\widehat{\theta}_i} (\theta - Q) q_i \frac{1}{\overline{\theta}} d\theta + (n-m-1) \int_{\widehat{\theta}_i}^{\overline{\theta}} D \frac{1}{\overline{\theta}} d\theta,$$

where q_c and q_i are the Cournot equilibrium outputs resulting from the simultaneous solution of expressions (5.22a) and (5.22b) and the market quantity is given by $Q = q_c + (n-m-1)q_i$.

The gain in social welfare due to the merger of $m+1$ firms in an $n-$firms oligopoly with initial debt obligation D is the result of the difference between the social welfare if $m+1$ firms collude and the social welfare if all firms remain independent in the market. Formally, the gain in social welfare can be obtained through the following expression:

$$S(n,m,D) = CS(n,m,D) + Cr(n,m,D) + \pi^c(q_c, q_i, D) \tag{5.27}$$
$$+(n-m-1)\pi^i(q_c, q_i, D) - CS(n,D) - Cr(n,D) - n\pi(q,D) + mF.$$

5.5 Policy implications

Important results of the limited liability model can be applied to regulation policy. In absence of any debt, mergers may increase social welfare. However, socially optimal mergers may be privately injurious to the colluding parties. We will show that, in these circumstances, a social planner may be interested in financing firms in a limited liability situation in order to increase their incentives to merge.

To demonstrate that this possibility can indeed arise, let us consider once again the simple case of ten firms. We know that, if θ is uniformly distributed over the interval $[0, 100]$ and $F = 4$, in absence of any debt, for mergers to be privately profitable it is necessary that at least six firms decide to merge. However, any merger between more than four firms causes social losses and should be forbidden by antitrust authorities.

On the other hand, mergers up to four firms increase social welfare and should be encouraged. One possibility is through the limited liability model.

If the initial level of debt obligation is high enough, any merger becomes privately beneficial. Table 1 compares the gain in insiders' profits and social welfare in the cases of $D = 0$ and $D = 40$ for the ten-firms example.

$n = 10$, $\bar{\theta} = 100$, $F = 4$	$D = 0$	$D = 40$		
	$m = 2$	$m = 1$	$m = 2$	$m = 3$
Gain in insiders' profits if m+1 firms merge	**-6.722**	**0.7619**	**2.1874**	**4.5629**
Social welfare if m+1 firms merge	**1621.4**	**1625.7**	**1627.5**	**1627.9**
Consumer surplus	1493.4	1573.0	1548.3	1514.9
Firms' profits	128.0	404.9	425.15	451.54
Creditors' profits	0	-352.2	-345.95	-338.54
Social welfare if firms remain independent	**1619.0**	**1623.1**	**1623.1**	**1623.1**
Consumer surplus	1543.2	1591.3	1591.3	1591.3
Firms' profits	75.8	389.61	389.61	389.61
Creditors' profits	0	-357.81	-357.81	-357.81
Gain in social welfare if m+1 firms merge	**2.4**	**2.6**	**4.4**	**4.8**

Table 5.1: Gain in insiders' profits and social welfare if $m + 1$ firms merge, for $n = 10$, $\bar{\theta}= 100$ and $F = 4$

In absence of debt and given that mergers between more than four firms are not allowed by the antitrust authority, all firms remain independent. In this case, social welfare is $SW(n, 0) = 1619$, for $n = 10$.

However, if the social planner finance limited liability firms with initial debt level $D = 40$, any merger becomes privately profitable. Social welfare is maximized if four firms merge. Allowing mergers up to four firms, the minimum social welfare is obtained for the case in which none of the firms merge, and even in this case, social welfare is higher than in the case in which firms are not financed and remain independent: $SW(n, m, 40) = 1623.1 > 1619$, for $n = 10$ and $m = 1$. It is obvious that in this simple example, it is advantageous for the social planner to finance firms with limited liability.

Proposition 5.3. *In order to induce a certain market structure, it might be optimal for the social planner to finance firms in a limited liability situation.*

Mergers that create social benefits may be detrimental for the colluding firms. In these cases, it may be optimal for the social planner to finance firms with limited liability. Given the limited liability aspects of debt financing, merging parties compete more aggressively and privately injurious mergers may become beneficial.

From the data provided in Table 5.1, we can also see the advantage of the limited liability debt financing over subsidies. In absence of any debt, social welfare is maximized if three firms merge. However, we know such merger is not privately profitable and it will not occur without public intervention. One possibility is subsidizing the merger, and the social welfare will be $S(n, m, 0) = 1621.4$. It is obvious that financing firms with initial debt level $D = 40$ and forbidding any merger larger than four firms yields higher social welfare.

Corollary 5.1. *The combination of limited liability debt financing and an appropriate antitrust policy leads higher social welfare than a subsidy policy.*

On the one hand, mergers reduce the market quantity and hence they have a negative effect on consumers' surplus. On the other hand, mergers imply fixed costs savings. Subsidizing mergers, the society will benefit from fixed costs savings, but consumers will be surely worse off. Limited liability debt financing also increase firms' incentives to merge, so that fixed cost savings are achieved. Besides, it also affects firms' aggressiveness and the reduction in market quantity is mitigated.

Social planner's intervention not only affect the total value of welfare but also its distribution among agents. As debt raises firms compete more aggressively, so the higher the debt and level of competition, the better consumers are. For creditors, it is the other way around. The higher the debt and level of competition, the more likely firms go bankrupt, and the lower creditor's profits are.

In the ten-firms example, if few firms merge ($m = 1$ and $m = 2$) and $D = 40$, consumers are better off than in the case in which no firm merges and there is not debt at all. The reason is that, though there is less level of competition, the limited liability effect forces firms to compete more aggressively and the market quantity is not finally reduced.

5.6 Conclusions

The search of firms' optimal size is the main reason for the processes of mergers and acquisitions in which many firms have been involved in recent years. Most firms that try to restructure their businesses enjoy a limited liability situation, that is, if the firm is unable to meet its debt obligations, its creditors are paid whatever operating profits are available. This paper analyzes firms' private incentives to merge in a homogenous product market with uncertainty over demand, fixed costs, and limited liability debt financing. It also studies the gain in social welfare due to mergers and some applications to regulatory policy.

It has been argued that increases in the debt level raise the output market equilibrium. This is what Brander and Lewis (1986) call the limited liability effect of debt financing: as firms take on more debt, they will have an incentive to pursue output strategies that raise returns in good states and lower returns in bad states. The basic point is that firms will ignore reductions in returns in bankrupt states.

A unilateral increase in firm's debt causes that the firm competes more aggressively and obtains higher returns. Given that the level of debt obligation is assumed to be exogenous, the only way firms have to take advantage of the strategic effect of financial decisions is through a merger.

The first part of the paper analyzes the private and social benefits of mergers in absence of any debt obligation. If fixed cost savings are not high enough, the gain in insiders' profits initially decreases in the number of colluding parties and then it increases. Therefore, if fixed cost savings and the number of merging firms are not sufficiently large, mergers are not privately profitable. Those mergers may be socially advantageous, though they will not occur without public intervention.

If firms own an initial level of debt obligation, mergers cause an unilaterally increase of debt and merged firm competes more aggressively. If the strategic effect of debt is large enough to guarantee large returns to the merger, mergers that were unprofitable in absence of debt might become privately beneficial.

This result has important policy implications since socially beneficial mergers may be unprofitable to the merging parties. In these cases, it may be optimal for the social planner to finance limited liability firms and increase their incentives to merge. Combining this way of intervention with a precise antitrust policy, social welfare is shown to be larger than if just subsidies are used. The reason is that the limited liability effect increases firms' aggressiveness so the reduction in market quantity due to mergers is alleviated.

In the analysis of this paper, no bankrupt costs have been considered. However, bankrupts may have a considerable cost associated, including legal fees, court costs, consultant fees, documents, and the social problems derivated from firing large numbers of workers. As an example of the importance that such costs may have, we can look at the case of Enron, whose bankruptcy costs are expected to hit $1 billion by the end of 2006.

If firm's have debt obligations and bankrupcy costs are large enough, it might be optimal to encourage firms' mergers in order to decrease the probability of bankrupcy. In this case, the combination of public limited liability debt financing and an antitrust policy might be again a suitable way of intervention, since the probability of bankrupcy is reduced without reducing too much the quantity offered in the market.

5.7 Appendix

Proof of Lemma 5.1. Most properties stated in Lemma 5.1 can be easily checked computing the first and second derivatives of $g(n,m,0)$ and verifying that, for $n \geq 2$, $\frac{\partial g(n,m,0)}{\partial m} \mid_{m=0} = F - 2\overline{\theta}^2 \frac{n-1}{(n+2)^4} < 0$ iff $F < 2\overline{\theta}^2 \frac{n-1}{(n+2)^4}$, $\frac{\partial^2 g(n,m,0)}{\partial m^2} = \frac{24\overline{\theta}^2}{(n-m+2)^5} > 0$, and $g(n, n-1, 0) = n(n^2+6n-15)+8+(n-1)F > 0$. To prove that for $F = 0$ and any n, it is sufficient for a merger to be unprofitable that less than the 65.44 percent collude, denote by $m^*(n)+1$ the number of firms such that $g(n, m^*, 0) = 0$ and by $(m^*(n)+1)/n$ the fraction of those firms in the industry. Then, it is easy to check that this fraction reaches its minimum value of 0.6544 for $n = 7$. ■

Proof of Lemma 5.2. We can exploit the symmetry of this case, $q_i = q_j = q$ for every firm $i \neq j$, and totally differentiate just one of the first-order conditions:

$$\pi^i_{ii} dq + (n-1)\pi^i_{ij} dq + \pi^i_{iD} dD = 0.$$

Then, the derivative of q with respect to D can be written as:

$$\frac{dq}{dD} = -\frac{\pi^i_{iD}}{\pi^i_{ii} + (n-1)\pi^i_{ij}} > 0,$$

since $\pi^i_{ii} < 0$ by definition, $\pi^i_{iD} = -\frac{d\widehat{\theta}_i}{dD}(\widehat{\theta}_i - Q - q)\frac{1}{\overline{\theta}} = -\frac{1}{q\overline{\theta}}(\widehat{\theta}_i - Q - q) > 0$ and $\pi^i_{ij} = \frac{1}{\overline{\theta}}[-\int_{\widehat{\theta}_i}^{\overline{\theta}} d\theta - \frac{d\widehat{\theta}_i}{dq_j}(\widehat{\theta}_i - Q - q)] = -\frac{1}{\overline{\theta}}(\overline{\theta} - Q - q) < 0$, by first-order condition. ■

Proof of Lemma 5.3. In order to prove that merged firm competes more aggressively, let us start supposing that $D_c = D_i$. In this case, we would have that $q_c = q_i$. Suppose now that D_c unilaterally increases. To obtain the change in Cournot outputs following the unilateral increase in D_c, we have to totally differentiate the first order conditions for the merged firm and the other $n - m - 1$ independent firms, which are given by:

$$\pi^c_c = \frac{1}{\overline{\theta}} \int_{\widehat{\theta}_c}^{\overline{\theta}} (\theta - Q - q_c) d\theta = 0,$$

$$\pi^i_i = \frac{1}{\overline{\theta}} \int_{\widehat{\theta}_i}^{\overline{\theta}} (\theta - Q - q_i) d\theta = 0.$$

Exploiting the symmetry for the $n-m-1$ firms, totally differentiation of the above first order conditions generates the following system:

$$\begin{aligned}\pi^c_{cc}dq_c + (n-m-1)\pi^c_{ci}dq_i + \pi^c_{cD_c}dD_c &= 0,\\ \pi^i_{ic}dq_c + \pi^i_{ii}dq_i + \pi^i_{iD_c}dD_c &= 0.\end{aligned}$$

Firstly, note that π^i_i does not depend on D_c. The solution of the system yields the following comparative static effects:

$$\begin{aligned}\frac{dq_c}{dD_c} &= -\frac{\pi^i_{ii}\pi^c_{cD_c}}{\pi^c_{cc}\pi^i_{ii} - (n-m-1)\pi^c_{ci}\pi^i_{ic}},\\ \frac{dq_i}{dD_c} &= \frac{\pi^i_{ic}\pi^c_{cD_c}}{\pi^c_{cc}\pi^i_{ii} - (n-m-1)\pi^c_{ci}\pi^i_{ic}}.\end{aligned}$$

Notice that $\pi^c_{cc}\pi^i_{ii} - (n-m-1)\pi^c_{ci}\pi^i_{ic} > 0$ since the Cournot output is assumed to be unique (see Kolstad and Mathiesen, 1987), and $\pi^i_{ii} < 0$, by definition. Moreover, $\pi^i_{ic} = -\frac{1}{\overline{\theta}}(\overline{\theta} - Q - q_i) < 0$, and $\pi^c_{cD_c} = -\frac{1}{q_c\overline{\theta}}(\widehat{\theta}_c - Q - q_c) > 0$, by first order conditions. Then, we can conclude that $dq_c/dD_c > 0$ and $dq_i/dD_c < 0$.

We know mergers imply a unilateral increase in debt, $D_c = (m+1)D_i$, so $q_c > q_i$, as we wanted to prove. ■

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