On Moral Hazard and Joint R&D*

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Abstract

This paper analyzes how the determinants of two entrepreneurs' choice whether to conduct product innovation R&D projects alone, or in a cross license agreement, or in a research joint venture depend on the intrinsic nature of the R&D projects. Results show that in fundamental research – which is considered to be affected by moral hazard behavior of the researchers – there is a systematic bias toward conducting R&D projects alone and against making use of synergies in an RJV. Furthermore, from a social standpoint, in non-fundamental research – which is considered not to be affected by moral hazard behavior of the researchers – too few RJVs and too few cross license agreements are chosen; whereas in fundamental research too few RJVs, and too many cross license agreements are chosen.

Keywords: agency problems, R&D, joint projects, cross license agreements, RJVs, synergies, product innovation, fundamental research, non-fundamental research

JEL codes: D23, D82, L24, O31, O32

1 Introduction

A distinguishing feature of the organization of R&D is that *fundamental research* is often undertaken in a stand-alone fashion, either by research laboratories within private firms or by research bodies within academia for example, while *late-stage developments* are instead often conducted jointly by organizations which might even compete afterwards on the market where the innovation is to be used. R&D intensive industries, such as the software, electronics, pharmaceutical, and automobile industries, among others, provide plenty of examples for both stand-alone and joint research. In the biotechnology industry in particular there is a multitude of cases of *stand-alone research* for the discovery and patenting of new chemical entities which might then form

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the basis for further developments into therapeutical indications for new or improved drugs in the pharmaceutical market[1]. In the automobile industry, there many examples of new car models jointly designed by manufacturers which then keep on competing on the market where the car models are to be introduced. Other examples of joint late-stage development are abundant[2].

In this paper, we give a theoretical explanation of why we may observe these differences in the organization of *fundamental research* and *late-stage development*. In addition, we also shed light on the welfare consequences of the privately chosen R&D organizations. These are important economic and public policy questions. Arguing that the value created within R&D projects is often considerable and of high social interest, and that there are social benefits from conducting them jointly, there have been public programs set up by several governments and supranational authorities to support R&D projects, some of which target joint ones in particular. For example, within the 5th edition of the "*European Framework Programs*" set up by the EU to support R&D projects, from 1998 until 2000 out of the 363 million euro spent on "*Promotion of Innovation and Encouragement of SME[3] Participation in R&D*" about 200 million euro have been devoted specifically to "*Joint innovation/SME activities*". Thus, the natural question that arises is whether this support has been well-targeted and whether the answer to such a question depends on the type of the R&D project, i.e. whether it concerns fundamental or non-fundamental research.

In order to answer these questions, we build a model that combines several strands of literature. We first recognize that, in fundamental research, processes are typically less well defined and that researchers, thus, enjoy considerably more freedom or discretion than in late-stage developments. This parallels Aghion et al. (2005), who state "that the fundamental trade-off between academia and the private sector is one of creative control versus focus". We acknowledge this by modelling the R&D activity within an explicit principal-agent-structure where the efforts of the agents, responsible for conducting the R&D project, determine the probability with which an R&D project succeeds. Late-stage developments might be thought of as projects for which the procedures are relatively well defined, so that in our model they are associated with agents' efforts being contractible. Fundamental research is considered to involve a higher degree of discretion for the researchers, thus implying that their efforts cannot be observed, which in our model translates into the efforts being not contractible.

Second, as in Kamien et al. (1992), in our model there are two dimensions in which firms can

[1] An example, among many, is the one of the biotech company Fermion which is developing and producing NCEs for Orion Pharma. These NCEs-projects are developed by Fermion under exclusive agreements with Orion Pharma. For a review on innovation strategies in the pharmaceutical industry, see Pammolli (1996).

[2] In the automobile industry, examples include the *joint development* of a minivan by Citroën/Peugeot and Fiat/Lancia, which is being sold under the four different brand names separately, Citroën Evasion, Peugeot 807, Fiat Ulysse, and Lancia Phedra; or similarly the joint development of a minivan by Ford and Volkswagen, then sold separately under the names Ford Galaxy and Volkswagen Sharan; or the joint development of an SUV, a sports utility vehicle, by Porsche and Volkswagen, sold under the names Porsche Cayenne and Volkswagen Touareg. Other examples could be found in the software, electronics, pharmaceutical. Within the electronics industry, for example, Samsung Electronics Co. Ltd. and Sony Corporation share at the same time an *RJV* founded in April 2004 under the name S-LCD Corporation which concerns the *joint development and manufacturing* of liquid crystal display televisions - to be marketed in competition with each other afterwards under their respective brand names SONY and SAMSUNG. Within the pharmaceutical industry, for example, Sanofi-Aventis and Pfizer developed jointly Exubera®, an inhaleable form of insulin for the treatment of type 1 and type 2 diabetes.

[3] Small and medium sized enterprises.

potentially benefit from doing joint R&D[4]. First, firms can coordinate their R&D investment and second, they can choose to exploit possible synergies. In stand-alone projects, they neither coordinate their R&D investment nor do they exploit synergies. In research joint ventures (RJVs), we assume that there is coordination of R&D investments and exploitation of synergies as researchers work tightly together to eliminate possible duplication. In a cross license agreement (CLA), we assume that firms coordinate their R&D investments and that they share their success. However, they cannot exploit synergies as the researchers do not work tightly together.

By introducing the principal-agent-structure explicitly into the literature on the formation of joint R&D we are able to show that there exists a systematic bias toward stand-alone research in the presence of moral hazard, which mitigates the effects of the lack of coordination in R&D investments, characterized by Kamien et al. (1992) and d'Aspremont and Jacquemin (1988). The lack of control over the researchers increases the marginal cost of R&D as compared to the situation where there is no lack of control. This leads to a lower implemented level of investment and, thus, a reduction of the importance of the lack of coordination of R&D investments in the stand-alone organization, which ultimately means that firms have lower incentives to do joint R&D. We show that this result holds whether or not joint R&D involves more team problems[5] than stand-alone R&D: Even when restricting comparisons between CLA and stand-alone only, where each researcher's success can be observed separately in both cases, i.e. where there is no team problem in either organization, we get the stand-alone bias.

To our best knowledge, there is one study of joint research that takes an explicit principal-agent approach, Pastor and Sandonís (2002). Different from us, the authors do not consider, however, incentives to enter joint research projects: comparing CLAs with RJVs in the presence of agency problems, joint research is the only means entrepreneurs have to conduct a given project. Therefore, staying alone is not an option and, contrary to our model, the analysis of the underlying incentives to form a research alliance is ruled out by assumption. Thus, the impact of moral hazard on these incentives is not studied. The underlying assumption in their work is that each research unit's success is essential, both for the CLA and for the RJV cases. By contrast, we allow for several degrees of substitution between research units (agents) involved in the joint project in order to reach a success. Doing so, we are also able to characterize not only the decisions of how to join, but also the decision of whether to do so at all. These decisions will be a function of the value of the innovation, the competitiveness of the market in which the innovation is to be used, and the degree of substitutability of agents' efforts.

The main contribution of our paper is to characterize the impact moral hazard has on the decision of firms to conduct joint R&D projects as well as the impact this has on social welfare.

[4] Many studies have contributed to the explanation of the determinants for choosing to do R&D within a stand-alone, or joint configurations. The most prominent determinants for joint research which have been captured in the literature, are R&D cost sharing and spillover internalization, as e.g. in the seminal paper of Kamien et al. (1992), or complementarities and asymmetries among partners, as e.g. in Röller et al. (1998). Caloghirou et al. (2003) review the literature in industrial economics and strategic management that deals with RJV partner motives and RJV outcomes. For an empirical evaluation of the determinants of RJV formation, see Marín et al. (2003). However, the role that moral hazard within a principal-agent framework may play in explaining the choice of joint versus stand-alone R&D has been largely neglected in that literature.

[5] For a review of moral hazard in teams, refer to Holmstrom (1982), Itoh (1991) and for collusion in groups with moral hazard see Laffont and Rey (2000).

Our analysis shows that moral hazard (or researchers' freedom and discretion) introduces a bias toward conducting R&D projects alone and against making use of the advantages provided by CLAs and RJVs. This has been obtained by endogenizing the cost associated with conducting a research project through the implemented contracts between employers and researchers. Given that the cost of implementing a certain probability of success with moral hazard is higher than without moral hazard, the standard R&D cost sharing argument would ask for more joint research. Having endogenized the cost of conducting a research project through implemented contracts leads to the opposite result.

We are then able to show that from a social standpoint too little RJVs both in fundamental research and in late-stage development are chosen privately. However, in the case of fundamental research, government support for RJVs should be given only for very high synergy levels (e.g. higher complementarities), whereas moderate synergy levels are sufficient to make joint development socially preferred. We furthermore show that late-stage CLAs should be encouraged in industries with relatively low degrees of competition whereas they should be generally discouraged in fundamental research.

The rest of the paper is organized as follows. In section 2 we describe the setup of the model. Section 3 is devoted to the analysis of the contracts implemented in the three R&D configurations both, for the case with and the case without moral hazard. In section 4, we describe the privately chosen equilibrium R&D configurations. In section 5 we discuss their impact on the social welfare and we derive policy implications concerning the desirability of support for specific R&D configurations. Section 6 concludes.

2 The Model

In this section, we describe the characteristics of the R&D projects and the three possible configurations in which they can be executed: stand-alone, (S), cross licensing agreements, (CLA), or research joint ventures, (RJV). We furthermore describe the utility of the agents' conducting them, as well as the probability of success attached to the projects.

Timing We consider the following timing:

1. Entrepreneurs simultaneously decide how to conduct the project, i.e. (S), (CLA), or (RJV).
2. Entrepreneurs offer contract(s) to the agent(s) who conduct the project.
3. Agent(s) accept(s) or reject(s) the contract(s).
4. Agent(s) decide(s) on an effort level to be exerted.
5. The outcome is realized and the transfers are executed.

[Insert Figure 1 about here]

Projects Let two entrepreneurs, $i = 1, 2$, pursue R&D projects, which potentially lead to an innovation, a new product, intermediate input or service. The projects can be pursued in a stand-alone configuration, denoted by (S), in a cross licensing agreement, denoted by (CLA), or in a research joint venture, denoted by (RJV).

A stand-alone project, (S), is assumed to pay off $\Delta \in \mathbb{R}_+$ to a successful entrepreneur if he is the only one succeeding, or $\alpha\Delta$, with $\alpha \in \left[0, \frac{1}{2}\right]$, to each of them if both entrepreneurs succeed. The payoff Δ can be thought of, for example, as the monopoly profit someone can get from the invention of a product, intermediate input, or a service. The parameter α captures, therefore the *degree of competition played in the market targeted by the innovation.*

An $\alpha = \frac{1}{2}$ is the extreme case in which the degree of competition between the two successful entrepreneurs tends to zero as if the market was segmented such that entrepreneurs serve each an equally sized segment as a local monopolist, or as if entrepreneurs would collude on the market so as not to invade each other segment. An $\alpha < \frac{1}{2}$ on the other hand means that there is competition between these two uses of the invention[6]. In the extreme case of $\alpha = 0$, all rents from the invention are competed away. We assume that entrepreneurs get equal profits when both exploit the innovation. That means that the model accounts for an ex ante symmetric environment, i.e. equal capabilities of the entrepreneurs to exploit the invention and, therefore, an equal possibility to compete against each other for the whole market when both are successful. A non-succeeding entrepreneur receives a payoff of zero.

In the alternative configurations, (CLA) and (RJV), we will assume that entrepreneurs maximize joint profits[7], maintaining the assumption of competition in the market in which the invention is used. This means that we assume that their agreement concerns only the development of the product, intermediate input, or service, but not the subsequent phase of its marketing. Therefore, a success of a (CLA) or an (RJV) still leads to a payoff per entrepreneur of $\alpha\Delta$, with $\alpha \in \left[0, \frac{1}{2}\right]$. A success in (CLA) means that at least one entrepreneur invented the product, intermediate input or service, and both of them can use it on the market separately. Equally, when the (RJV) succeeds with the innovation, both entrepreneurs can use it on the market separately. In (CLA), if none of the two entrepreneurs succeeds, both of them receive a payoff of zero. In (RJV), a failure leads to zero payoffs for each entrepreneur.

Projects are assumed to be carried out by agents (research units, divisions, etc.) employed by the entrepreneurs. The agents affect the probability of success of the project they conduct through their chosen effort. We assume that in (S), each entrepreneur employs one agent (research unit, division, etc.) to conduct the project. In a (CLA), entrepreneurs employ two agents, each of whom runs a project on his own in parallel to the other one. In an (RJV), entrepreneurs decide to let their two agents work tightly together to conduct the project. We

[6] One possible example to explain which might be the magnitude of α could be to take the case of a linear demand for a homogenous good and, on the one hand, two firms competing à la Cournot and a monopoly on the other one. The monopolistic profit would correspond to our Δ and the Cournot duopolistic profits to our $\alpha\Delta$. For this case, $\alpha = \frac{4}{9} \approx 0.44$.

[7] The assumption that, in a (CLA), entrepreneurs maximize their joint expected profits implicitely rules out any possibility for free riding: Entrepreneurs observe each others choices and decide on the contracts to be implemented for conducting the research and they share the costs and benefits deriving from conducting R&D. If entrepreneurs could not design the contracts to be implemented in (CLA) jointly, then they would not be able to overcome the negative payoff externality they impose on each other when conducting R&D in (S) otherwise.

are implicitly assuming that each agent has embedded the scientific knowledge/capability to conduct the project alone. We assume that in an (RJV) and in (CLA), entrepreneurs share equally both, the costs of letting the agents carry out the project as well as the benefits deriving from a success, as mentioned above.

Agents Agents $i = 1, 2$ affect the probability of success of the project they conduct through their effort. We consider both, the cases where the agents exert an observable and contractible effort $e_i \in \mathbb{R}_+$ and where they exert a non observable, therefore not contractible[8], effort. Exerting this effort e_i implies a disutility for the agent that is equal to $c_i(e_i) = \frac{1}{2}e_i^2$. For conducting the project, agents receive a transfer $t_i \geq 0$ from the entrepreneurs employing them. Both, entrepreneurs and agents are risk neutral. Agents are protected by limited liability. We assume the agents' utility U_i to be additively separable between transfers and effort,

$$U_i = t_i - \frac{1}{2}e_i^2.$$

The constraint $U_i = t_i - \frac{1}{2}e_i^2 \geq 0$, that is the agents' individual rationality constraint, has to be considered by the entrepreneurs when making their optimal choices. Due to the limited liability assumption, this constraint is only binding for observable efforts.

In case of unobservable efforts, a contract, specifying a transfer to the agents cannot be made contingent on their exerted efforts, but only on the observable and verifiable success or failure of the project. In this case, the optimal contract requires the transfer to the agents made by the entrepreneurs employing them to be of the following type:

$$t_i(R) = \begin{cases} b_i & \textit{if success} \\ 0 & \textit{if failure.} \end{cases}$$

Probability of success As already mentioned, agents affect the probability of success of the project by selecting which level of effort to exert. We define this probability of success[9] to be equal to $\min\left\{\left(\sum_i e_i^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}, 1\right\}$, where $\varepsilon \in [\underline{\varepsilon}, 1[$, $\underline{\varepsilon} \in \mathbb{R}_{--}$, captures different possible degrees of agents' efforts' substitutability in the (RJV) case. We restrict ε to this interval in order to fulfill the second order conditions of the maximization problem entrepreneurs face in this case. The value of $\varepsilon = 1$ is not considered, as the function $\left(\sum_i e_i^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}$ is not defined in this point.

As in (RJV) we have $\Pr(\textit{success}\,|RJV) \equiv p(RJV) = \min\left\{\left(e_1^{1-\varepsilon} + e_2^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}, 1\right\}$, a value of $\varepsilon = 0$ would mean that agents' efforts are perfect substitutes, i.e. the two agents efforts contribute additively to the overall success probability. Alternatively, a value of $\varepsilon \in]0, 1[$ is allowed for in order to account for slight complementarity between agents' efforts. The mere fact of interacting increases the efficiency of each agent's contribution to the joint project. We allow for ε to be negative in order to capture situations, in which agents' efforts start duplicating each other: despite possible interactions among agents, their contributions to the joint project cannot be avoided to overlap to some extent.

[8]See Rogerson (1985).

[9]See also Fabrizi and Lippert (2004) for a similar measure of the probability of success.

In (S), the success probability collapses to $\Pr_i(success\,|S) \equiv p_i(S) = \min\{e_i, 1\}$ for $i = 1, 2$.

In a (CLA), each of the two agents devoted to the project (in parallel) has a probability of coming up with the innovation which is $\Pr_i(success\,|CLA) = p_i(CLA) = \min\{e_i, 1\}$. We assume that the success of each project is independent from the success of the other one. This means that the probability of each entrepreneur to have a product to market as a result of a (CLA) corresponds to $\Pr(success\,|CLA) \equiv p(CLA) = p_1(CLA) + p_2(CLA) - p_1(CLA)\,p_2(CLA)$.

In any of these configurations, the restriction of the probability of success not to exceed the value of one does not imply that also the efforts have to be maintained between zero and one. Efforts leading to $\left(\sum_i e_i^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}} > 1$ would not be implemented by the entrepreneurs as they are not optimal. Implementing a higher level of effort than the optimal one deriving from the solution of the *constrained optimization problem* entrepreneurs face, given by the fact that the probability of success cannot exceed the value of one, would not translate into an increased expected revenue, but lead instead to higher costs.

Expected payoffs Summarizing the assumptions made, we can write the different *per entrepreneur payoffs* $R_i(\cdot)$ associated with the three different R&D configurations described:

$$R_i(S) = \begin{cases} \Delta & \text{with} \quad p_i(S)\,(1 - p_{-i}(S)) \\ \alpha\Delta & \text{with} \quad p_i(S)p_{-i}(S) \\ 0 & \text{with} \quad 1 - p_i(S), \end{cases}$$

where $-i$ is the other entrepreneur,

$$R_i(CLA) = \begin{cases} \alpha\Delta & \text{with} \quad p(CLA) \\ 0 & \text{with} \quad 1 - p(CLA), \end{cases}$$

and

$$R_i(RJV) = \begin{cases} \alpha\Delta & \text{with} \quad p(RJV) \\ 0 & \text{with} \quad 1 - p(RJV). \end{cases}$$

Before solving the model, let us relate our R&D organizations to those used by Kamien et al. (1992)[10]. In our stand-alone organization, there is no coordination of R&D investments and no use of synergies. This corresponds to Kamien et al.'s (N) case. In our RJV organization, there is coordination of R&D investments and use of synergies, paralleling Kamien et al.'s (CJ) case. Our CLA organization of R&D where R&D project owners coordinate their R&D investments but do not choose to let their agents work tightly together, thus do not make use of synergies, matches Kamien et al.'s (C) case. In addition, we are assuming that in an RJV only the outcome (success or failure) is observable, which implies a moral hazard in teams problem only for the RJV case.

3 Analysis

In this section we solve the maximization problems entrepreneurs face in the three configurations for both, the case without moral hazard and with moral hazard, as well as the optimal effort

[10]Note that they consider R&D that leads to a process innovation, whereas we consider R&D that may lead to a product innovation.

levels and the resulting expected profits for each entrepreneur. The no moral hazard case can be thought of as a standard R&D model, where the is no separation between who is responsible of taking the decision whether to conduct R&D projects jointly, and who is responsible of conducting the R&D activities. The no moral case is equivalent to the case where entrepreneurs are at the same time researchers. Instead, the moral hazard case allows for considering a principal-agent structure, due to the non-observability of the agents' efforts put into the R&D activities, and to account for possible differences in the underlying incentives entrepreneurs may have when deciding how to conduct R&D projects.

3.1 No Moral Hazard

In this case, agents' efforts being observable, therefore contractible, the entrepreneurs maximization problem can be solved taking the agents' individual rationality constraints as binding. Therefore, $t_i = \frac{1}{2}e_i^2$, $\forall i$.

3.1.1 Stand-alone

Each entrepreneur $i = 1, 2$ maximizes

$$\max_{e_i} \left[p_i(S)(1 - p_{-i}(S))\Delta + p_i(S)p_{-i}(S)\alpha\Delta - \frac{1}{2}e_i^2 \right].$$

The solution to these maximization problems gives the following optimal effort for both entrepreneurs:

$$e_1^o(S) = e_2^o(S) = e^o(S) = \begin{cases} \frac{\Delta}{1+(1-\alpha)\Delta} & \text{if } \Delta < \frac{1}{\alpha} \\ 1 & \text{otherwise,} \end{cases}$$

where o, stands for the "observable" agents' efforts case.

This gives per entrepreneur profits of

$$\Pi_i^o(S) = \begin{cases} \frac{1}{2}\left(\frac{\Delta}{1-\Delta\alpha+\Delta}\right)^2 & \text{if } \Delta < \frac{1}{\alpha} \\ \alpha\Delta - \frac{1}{2} & \text{otherwise.} \end{cases}$$

3.1.2 Cross Licensing Agreements

Remember that in this case we have assumed that entrepreneurs agree on letting the projects be run in parallel, while sharing the cost of conducting the projects, as well as on keeping on competing against each other on the market afterwards in case of success.

The entrepreneurs maximize the joint profits

$$\max_{e_1,e_2} \left[p(CLA)\,2\alpha\Delta - \frac{1}{2}e_1^2 - \frac{1}{2}e_2^2 \right],$$

which gives optimal effort levels equal to

$$e_1^o(CLA) = e_2^o(CLA) = e^o(CLA) = \frac{2\alpha\Delta}{2\alpha\Delta + 1}.$$

The corresponding per entrepreneur profit is

$$\Pi_i^o(CLA) = \frac{1}{2}\frac{(2\alpha\Delta)^2}{2\alpha\Delta + 1}.$$

3.1.3 Research Joint Venture

In this case the two agents conduct the project tightly together and the joint venture maximizes

$$\max_{e_1,e_2}\left[p\left(RJV\right)2\alpha\Delta-\frac{1}{2}e_1^2-\frac{1}{2}e_2^2\right].$$

The optimal probability of success resulting from this maximization program is

$$p^o\left(RJV\right)=\begin{cases}2^{\frac{2}{1-\varepsilon}}\alpha\Delta & \text{if }\Delta<\frac{1}{2^{\frac{2}{1-\varepsilon}}\alpha}\\ 1 & \text{otherwise,}\end{cases}$$

and the optimal effort levels are

$$e_1^o\left(RJV\right)=e_2^o\left(RJV\right)=e^o\left(RJV\right)=\begin{cases}2^{\frac{1}{1-\varepsilon}}\alpha\Delta & \text{if }\Delta<\frac{1}{2^{\frac{2}{1-\varepsilon}}\alpha}\\ 2^{-\frac{1}{1-\varepsilon}} & \text{otherwise.}\end{cases}$$

The per entrepreneur profit in an (RJV) amounts to

$$\Pi_i^o\left(RJV\right)=\begin{cases}\frac{1}{2}2^{\frac{2}{1-\varepsilon}}\left(\alpha\Delta\right)^2 & \text{if }\Delta<\frac{1}{2^{\frac{2}{1-\varepsilon}}\alpha}\\ \alpha\Delta-2^{\frac{\varepsilon-3}{1-\varepsilon}} & \text{otherwise.}\end{cases}$$

3.1.4 Basic Trade-offs

On the one hand, the (S) organization is characterized by uncoordinated R&D efforts. Thus firms, by choosing their investments non-cooperatively, do not internalize the negative effect of their actions on the revenue of the competing firm, which leads to a higher implemented effort in (S) than in (CLA)

$$e_i^o\left(S\right)=\min\left\{\frac{\Delta}{1+\left(1-\alpha\right)\Delta},1\right\}\geq\frac{2\alpha\Delta}{2\alpha\Delta+1}=e_i^o\left(CLA\right),$$

with equality only for $\Delta=0$ and $\alpha=\frac{1}{2}$. This negative effect of missing coordination in (S) is the more important the higher the value of the project, Δ, as a higher Δ implies higher implemented effort levels and thus increases the probability with which the entrepreneurs succeed both in their projects.

On the other hand, for any given symmetric implemented probability of success, p, (S) offers a weakly higher expected revenue for each entrepreneur as compared to (CLA)

$$p\left(1-p\right)\Delta+p^2\alpha\Delta\geq\left(2p-p^2\right)\alpha\Delta\Leftrightarrow\left(1-2\alpha\right)\left(1-p\right)\geq0,$$

with equality only for $\alpha=\frac{1}{2}$, i.e. for the case of no competition[11], or $p=1$, which is never optimally implemented in (CLA). This effect does not depend on the value of the project, Δ.

For these reasons, we should observe entrepreneurs choosing a (CLA) over (S) for high values of Δ combined with low degrees of competition, α.

Equivalent effects are present in the comparison of (S) with (RJV). In addition, in an RJV, there is the effect of the synergies as expressed in ε. As higher ε correspond to higher synergies,

[11] If there is no competition, there is nothing to be gained from succeeding when the other one is failing.

for any level of competition, the minimum value of the project, Δ, for which (RJV) is preferred over (S) is falling in ε. As before, it is also falling in α, i.e. the lower the competition, the lower the necessary Δ for entrepreneurs to prefer (RJV) over (S).

Finally, in comparing (CLA) with (RJV), note that in both cases, R&D efforts are coordinated. A difference between (RJV) and (CLA) is that in a (CLA), entrepreneurs have two independent draws, whereas in an (RJV) they do not. This is especially important when the implemented effort levels are not giving a probability of success which is close to one. A high $\alpha\Delta$ implies high implemented effort levels whereas a low $\alpha\Delta$ implies low implemented effort levels. Therefore, cross license agreements should be preferred over an (RJV) for low $\alpha\Delta$ and vice versa for high $\alpha\Delta$. Clearly, having higher synergies ε should make entrepreneurs prefer (RJV) over (CLA), thus decreasing the $\alpha\Delta$ necessary to prefer (RJV) over (CLA).

3.2 Moral Hazard

With unobservable efforts, agents choose the effort level that maximizes their utility given the bonus they receive. For this reason we will need to analyze the agents' maximization problem first, to obtain the agents' incentive compatibility constraint which entrepreneurs will need to satisfy when maximizing their own profit.

3.2.1 Stand-alone

Agents receive a bonus, b_i, in case the project they conduct succeeds, which happens with probability $p_i(S) = \min\{e_i, 1\}$, and they have to incur a disutility, $\frac{1}{2}e_i^2$, for exerting an effort. Therefore, each agent solves for

$$\max_{e_i} \left[p_i(S)\, b_i - \frac{1}{2} e_i^2 \right],$$

which gives the following incentive compatibility constraint to be accounted for in the entrepreneurs' profit maximization

$$e_i = \begin{cases} b_i & \text{if } b_i < 1 \\ 1 & \text{otherwise.} \end{cases}$$

Each entrepreneur $i = 1, 2$ solves

$$\max_{b_i} \left[p_i(S)\left(1 - p_{-i}(S)\right)\Delta + p_i(S)\, p_{-i}(S)\, \alpha\Delta - p_i(S)\, b_i \right]$$

$$s.t.\ e_i = \begin{cases} b_i & \text{if } b_i < 1 \\ 1 & \text{otherwise.} \end{cases}$$

The solution to these maximization problems gives optimal bonuses and efforts of

$$b_1^u(S) = b_2^u(S) = e_1^u(S) = e_2^u(S) = e^u(S) = \begin{cases} \frac{\Delta}{2+(1-\alpha)\Delta} & \text{if } \Delta < \frac{2}{\alpha} \\ 1 & \text{otherwise,} \end{cases}$$

where u, stands for the "unobservable" agents' efforts case.

This gives per entrepreneur profits of

$$\Pi_i^u(S) = \begin{cases} \left(\frac{\Delta}{2+(1-\alpha)\Delta}\right)^2 & \text{if } \Delta < \frac{2}{\alpha} \\ \alpha\Delta - 1 & \text{otherwise.} \end{cases}$$

3.2.2 Cross Licensing Agreements

The agents solve again for

$$\max_{e_i}\left[p_i\left(CLA\right)b_i-\frac{1}{2}e_i^2\right]$$

and their incentive compatibility constraint is again

$$e_i=\begin{cases} b_i & \text{if } b_i<1 \\ 1 & \text{otherwise.}\end{cases}$$

The entrepreneurs maximize the joint profits

$$\max_{b_1,b_2}\left[p\left(CLA\right)2\alpha\Delta-p_1\left(CLA\right)b_1-p_2\left(CLA\right)b_2\right]$$

$$s.t.\ e_i=\begin{cases} b_i & \text{if } b_i<1 \\ 1 & \text{otherwise,}\end{cases}$$

which gives optimal bonuses and efforts of

$$b_1^u\left(CLA\right)=b_2^u\left(CLA\right)=e_1^u\left(CLA\right)=e_2^u\left(CLA\right)=e^u\left(CLA\right)=\frac{\Delta\alpha}{\Delta\alpha+1}.$$

The corresponding per entrepreneur profit is

$$\Pi_i^u\left(CLA\right)=\frac{\left(\Delta\alpha\right)^2}{\Delta\alpha+1}.$$

3.2.3 Research Joint Venture

In a (RJV) agents interact. They get each a bonus if the project succeeded which happens with probability $p(RJV)=\min\left\{\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}},1\right\}$. This probability may depend on each agent effort so that the incentive compatibility constraint is determined in a Nash equilibrium[12].

In a joint venture, the agents maximize the following program

$$\max_{e_i}\left[p\left(RJV\right)b_i-\frac{1}{2}e_i^2\right].$$

the first order conditions of which are:

$$\begin{aligned} e_1^{-\varepsilon}\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{\varepsilon}{1-\varepsilon}}b_1-e_1 &= 0, \\ e_2^{-\varepsilon}\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{\varepsilon}{1-\varepsilon}}b_2-e_2 &= 0. \end{aligned}$$

Given these implicit incentive compatibility constraints, it is possible to show that only symmetric efforts are cost minimizing (see appendix A) for the (RJV). Therefore, the bonuses to be paid to the agents are also symmetric, $b_i=b\ \forall i$. Given this result, the incentive compatibility can be rewritten as

$$e_1\left(RJV\right)=e_2\left(RJV\right)=e\left(RJV\right)=\begin{cases} 2^{\frac{\varepsilon}{1-\varepsilon}}b & \text{if } b<2^{-\frac{1+\varepsilon}{1-\varepsilon}} \\ 2^{-\frac{1}{1-\varepsilon}} & \text{otherwise.}\end{cases} \quad (IC)$$

[12] This means that each agent maximizes his utility taking as given the other agent's effort. We therefore implicitly assume that there is no possibility of coordination or collusion among agents in their decision upon how much effort to exert in the joint project.

The joint venture solves, therefore, for:

$$\max_b \Pi(RJV) = \max_b \left[p(RJV)\left(2\alpha\Delta - 2b\right)\right]$$
$$s.t. \quad e(RJV) = \begin{cases} 2^{\frac{\varepsilon}{1-\varepsilon}} b & \text{if } b < 2^{-\frac{1+\varepsilon}{1-\varepsilon}} \\ 2^{-\frac{1}{1-\varepsilon}} & \text{otherwise.} \end{cases} \qquad \forall i$$

The optimal bonus each agent receives is:

$$b^u(RJV) = \begin{cases} \frac{\alpha\Delta}{2} & \text{if } \Delta < \frac{1}{2^{\frac{2\varepsilon}{1-\varepsilon}}\alpha} \\ 2^{-\frac{1+\varepsilon}{1-\varepsilon}} & \text{otherwise,} \end{cases}$$

and, as a consequence, the implemented efforts and probability of success are:

$$e^u(RJV) = \begin{cases} 2^{\frac{\varepsilon}{1-\varepsilon}} \frac{\alpha\Delta}{2} & \text{if } \Delta < \frac{1}{2^{\frac{2\varepsilon}{1-\varepsilon}}\alpha} \\ 2^{-\frac{1}{1-\varepsilon}} & \text{otherwise,} \end{cases}$$
$$p^u(RJV) = \begin{cases} 2^{\frac{1+\varepsilon}{1-\varepsilon}} \frac{\alpha\Delta}{2} & \text{if } \Delta < \frac{1}{2^{\frac{2\varepsilon}{1-\varepsilon}}\alpha} \\ 1 & \text{otherwise.} \end{cases}$$

Given the implemented efforts and bonuses each entrepreneur expects a profit equal to:

$$\Pi_i^u(RJV) = \begin{cases} 2^{\frac{1+\varepsilon}{1-\varepsilon}} \left(\frac{\alpha\Delta}{2}\right)^2 & \text{if } \Delta < \frac{1}{2^{\frac{2\varepsilon}{1-\varepsilon}}\alpha} \\ \alpha\Delta - 2^{-\frac{1+\varepsilon}{1-\varepsilon}} & \text{otherwise.} \end{cases}$$

3.2.4 Basic Trade-offs

The trade-offs mentioned in subsection 3.1.4 still hold in the case of moral hazard. However, as moral hazard increases the marginal cost of implementing a given probability of success, lower efforts will be optimally chosen by the entrepreneurs. This reduces the problem of non-coordination in (S), which leads to less pressure to choose (CLA) or (RJV) and ultimately to a stand-alone bias. Put differently, the Δ necessary to choose (CLA) or (RJV) over (S) is higher than without moral hazard.

In addition to the effects in place without moral hazard, in (RJV), there is also a moral hazard in teams problem, which makes this organization less favorable and chosen only for higher levels of ε than without moral hazard.

4 Equilibrium Organization

In this section, we will describe which is the privately chosen configuration under both, observable and unobservable efforts, as a function of the degree of competition, α, the value of the project, Δ, and different degrees of substitutability among agents' efforts, ε.

With and without moral hazard, and independently from the value of Δ and the degree of substitutability of agents' efforts, for $\alpha = 0$, i.e. for perfect competition on the market on which the innovation is to be used, (S) is always preferred to both, (CLA) and (RJV). The reason is that if the market for the invention is perfectly competitive, the only way for entrepreneurs to assure a non-zero expected profit is to conduct the innovation project alone, so as to maximize their chances to be alone on the market on which the innovation is to be used. In the (CLA) and (RJV) configurations a success in the innovation project would lead both entrepreneurs to face each other's competition with the result of losing all possible rents they could have derived by succeeding alone instead.

Given this, we will restrict our attention in this section to the analysis of the equilibrium configurations chosen for degrees of competition other than $\alpha = 0$.

The comparisons for the different entrepreneurs' expected payoffs for each configuration can now be performed using the results of the analysis made in the previous section.

To do so, we can define the entrepreneurs' explicit profit-indifference curves as follows:

$$\begin{aligned} \Delta_{\Pi}^{j}(\alpha,\varepsilon) &:= \left\{ \Delta \middle| \, \Pi_i^j(CLA) = \Pi_i^j(S) \right\} \\ \widehat{\Delta}_{\Pi}^{j}(\alpha,\varepsilon) &:= \left\{ \Delta \middle| \, \Pi_i^j(CLA) = \Pi_i^j(RJV) \right\} \text{ and} \\ \widetilde{\Delta}_{\Pi}^{j}(\alpha,\varepsilon) &:= \left\{ \Delta \middle| \, \Pi_i^j(S) = \Pi_i^j(RJV) \right\}. \end{aligned}$$

where $j = o, u$, stands for the "observable" or "unobservable" agents' efforts cases. These curves determine the cut-off values of the parameters of the model, for which entrepreneurs prefer one configuration over another one and vice versa (see appendix B for the properties of the profit indifference curves).

The detailed analysis of the two basic trade-offs described in sections 3.1.4 and 3.2.4 lead to the private choices in each environment, with and without moral hazard, which are summarized in Proposition 1 and 2.

Proposition 1 *For no moral hazard and*

1. *low α (high competition), entrepreneurs choose (RJV) for high Δ and/or high ε, where the minimum Δ for choosing (RJV) is decreasing in ε, choose (S) for low Δ and low ε, and never choose (CLA);*

2. *intermediate α (intermediate competition), entrepreneurs choose (RJV) for high Δ and/or high ε, where the minimum Δ for choosing (RJV) is decreasing in ε, choose (CLA) for intermediate Δ and low ε, and (S) for low Δ and low ε;*

3. *high α (no competition), entrepreneurs choose (RJV) for high Δ and/or high ε, where the minimum Δ for choosing (RJV) is decreasing in ε, choose (CLA) for low Δ and low ε, and never choose (S).*

Proposition 2 *For moral hazard, the choices are similar, where the minimum Δ and ε for choosing (RJV) over (CLA) or over (S) are higher than without moral hazard and the minimum Δ for choosing (CLA) over (S) is higher than without moral hazard.*

These results further imply the following:

Corollary 1 *As compared to no moral hazard, the presence of moral hazard makes entrepreneurs choose*

1. *less often a research joint venture;*

2. *more often a stand-alone configuration;*

3. *and more often cross license agreements if they face no, or very weak, competition.*

To illustrate how the choices between one and the other configurations by entrepreneurs vary when the parameters of our model, Δ, α, ε, vary as well, we also provide graphical comparisons in figures 2-3 where the same behavior described in our propositions 1 and 2 can be seen in the $(\Delta, \varepsilon) -$ space[13]. As a general feature, in the unobservable efforts case all the profit-indifference curves are systematically above their corresponding ones for observable efforts, which illustrates the stand-alone bias.

[Figures 2 - 3 about here]

5 Social welfare analysis

As we want to draw conclusions about the welfare impact of the entrepreneurs' organizational choice ((S), (CLA), or (RJV)), we need to define a measure of social welfare $W(\cdot)$ which can be used for each of the different environments we consider.

Given the general setup of the model which accounts for different degrees of competition and does not adopt one specific functional form for the demand for the good/service resulting from an invention, we can only define a measure of welfare which is approximate; however, which still allows us to draw some general qualitative conclusions as they are not sensitive to the specific environment adopted for the analysis.

Starting from this consideration, we assume that an overall value of Δ is created for the society as a whole whenever an innovation succeeded. Given that, the degree of appropriation of this value by each of the different actors in the economy will depend on the type of competition which is played: if for example in the stand-alone configuration one firm succeeds alone, she will be able to appropriate the whole value of the invention; whenever two firms have instead access to the innovation, the value of what each of them can appropriate will be inversely related with the degree of competition they face with each other. The higher the degree of competition among these firms, the higher the share of the overall value of the invention to be appropriated by the consumers. We therefore characterize the social welfare in the following way: social welfare is assumed to consist of the sum of the entrepreneurs' expected net profits and the agents' expected utility of effort, together with the expected value of the invention which is appropriated by the consumers. The expected social welfare in the stand-alone configuration takes therefore the following form:

[13] The choice of representing the private behavior in this space has been made in order to facilitate the understanding of the main driving forces of the entrepreneurs' decisions among different configurations. We focus in particular on $\alpha = 0.01$ (high competition); $\alpha = 0.35$ (intermediate competition); $\alpha = 0.49$ (low competition); and, finally, $\alpha = 0.5$ (no competition). We let $\varepsilon \in [-1, 1[$ as this focusses the attention to the relevant values of ε for which either one or another configuration will be chosen.

$$\begin{aligned} W(S) \quad : \quad &= (p_1(S)(1-p_2(S)) + p_2(S)(1-p_1(S)))\Delta \\ &+ p_1(S)p_2(S)2\alpha\Delta + p_1(S)p_2(S)(\Delta - 2\alpha\Delta) - \frac{1}{2}e_1^2 - \frac{1}{2}e_2^2 \\ &= (p_1(S) + p_2(S) - p_1(S)p_2(S))\Delta - \frac{1}{2}e_1^2 - \frac{1}{2}e_2^2. \end{aligned}$$

Following the same logic, we can write the expected social welfare for the (CLA) and (RJV) in the following way:

$$\begin{aligned} W(CLA) \quad &: \quad = p(CLA)\Delta - \frac{1}{2}e_1^2 - \frac{1}{2}e_2^2, \text{ and} \\ W(RJV) \quad &: \quad = p(RJV)\Delta - \frac{1}{2}e_1^2 - \frac{1}{2}e_2^2. \end{aligned}$$

The *induced* expected social welfare will be the result of the specific configuration chosen for undertaking the project and the corresponding implemented probability of success for each of the two environments we are considering: observable and unobservable efforts.

Using the optimal efforts and probability levels derived in section 3, for both the observable and unobservable efforts cases, we can now characterize the impact of each of the potential configurations which could be privately chosen on our measure of social welfare.

$$\begin{aligned} W^o(S) &= \left(2e^o(S) - (e^o(S))^2\right)\Delta - (e^o(S))^2 \\ &= \begin{cases} \left(\frac{\Delta}{1+(1-\alpha)\Delta}\right)^2 (1 + \Delta - 2\alpha\Delta) & \text{if } \Delta < \frac{1}{\alpha} \\ \Delta - 1 & \text{otherwise,} \end{cases} \end{aligned}$$

$$\begin{aligned} W^o(CLA) &= p^o(CLA)\Delta - (e^o(CLA))^2 \\ &= \alpha\left(\frac{2\Delta}{2\alpha\Delta + 1}\right)^2 (1 + \alpha\Delta - \alpha), \end{aligned}$$

$$\begin{aligned} W^o(RJV) &= p^o(RJV)\Delta - (e^o(RJV))^2 \\ &= \begin{cases} 2^{\frac{2}{1-\varepsilon}}\alpha\Delta^2(1-\alpha) & \text{if } \Delta < \frac{1}{2^{\frac{2}{1-\varepsilon}}\alpha} \\ \Delta - 2^{-\frac{2}{1-\varepsilon}} & \text{otherwise,} \end{cases} \end{aligned}$$

$$\begin{aligned} W^u(S) &= \left(2e^u(S) - (e^u(S))^2\right)\Delta - (e^u(S))^2 \\ &= \begin{cases} \left(\frac{\Delta}{2+(1-\alpha)\Delta}\right)^2 (3 + (1-2\alpha)\Delta) & \text{if } \Delta < \frac{2}{\alpha} \\ \Delta - 1 & \text{otherwise,} \end{cases} \end{aligned}$$

$$\begin{aligned} W^u(CLA) &= p^u(CLA)\Delta - (e^u(CLA))^2 \\ &= \alpha\left(\frac{\Delta}{\Delta\alpha + 1}\right)^2 (2 + \alpha\Delta - \alpha), \end{aligned}$$

$$
\begin{aligned}
W^u(RJV) &= p^u(RJV)\Delta - (e^u(RJV))^2 \\
&= \begin{cases} 2^{\frac{2\varepsilon}{1-\varepsilon}}\alpha\Delta^2\left(1-\frac{\alpha}{4}\right) & \text{if } \Delta < \frac{1}{2^{\frac{2\varepsilon}{1-\varepsilon}}\alpha} \\ \Delta - 2^{-\frac{2}{1-\varepsilon}} & \text{otherwise.} \end{cases}
\end{aligned}
$$

In order to asses which configuration is the socially preferred in terms of induced welfare for any other value of the parameters of the model we define, in a similar way as we did for the private comparisons, the social welfare-indifference curves as follows:

$$
\begin{aligned}
\Delta_W^j(\alpha,\varepsilon) &:= \left\{\Delta \middle| W_i^j(CLA) = W_i^j(S)\right\} \\
\widehat{\Delta}_W^j(\alpha,\varepsilon) &:= \left\{\Delta \middle| W_i^j(CLA) = W_i^j(RJV)\right\} \text{ and} \\
\widetilde{\Delta}_W^j(\alpha,\varepsilon) &:= \left\{\Delta \middle| W_i^j(S) = W_i^j(RJV)\right\}.
\end{aligned}
$$

where $j = o, u$ stands as before for "observable" or "unobservable" agents' efforts case. The properties of the welfare indifference curves are described in detail in appendix C.

The detailed analysis of these indifference curves lead to the following results:

Proposition 3 *For no moral hazard and*

1. *low α (high competition), society prefers (RJV) for high Δ and/or high ε, where the minimum Δ for preferring (RJV) is decreasing in ε, prefers (S) for low Δ and low ε, and never prefers (CLA);*

2. *intermediate α (intermediate competition), society prefers (RJV) for high Δ and/or high ε, where the minimum Δ for preferring (RJV) is decreasing in ε, prefers (CLA) for intermediate Δ and low ε, and (S) for low Δ and low ε;*

3. *high α (no competition), society prefers (RJV) for high Δ and/or high ε, where the minimum Δ for preferring (RJV) is decreasing in ε, prefers (CLA) for low Δ and low ε, and never prefers (S).*

Proposition 4 *For moral hazard, the social preferences are similar to the case without moral hazard, where the minimum Δ and ε for preferring (RJV) over (CLA) or over (S) are higher than without moral hazard and the minimum Δ for preferring (CLA) over (S) is higher than without moral hazard. However, for high α (no competition), society prefers (S) as long as Δ and ε are not too high; and for intermediate and high competition (CLA) is never socially preferred.*

Corollary 2 *As compared to no moral hazard, the presence of moral hazard makes society prefer*

1. *less often a research joint venture;*

2. *more often a stand-alone configuration;*

3. *and never cross license agreements, unless there exists a very weak or no competition for the use of the innovation.*

Proposition 5 *For no moral hazard, society systematically prefers* (RJV) *over* (CLA) *or* (S) *and* (CLA) *over* (S) *for lower values of* Δ *than the minimum values* Δ *for which* (RJV) *would be privately chosen over* (CLA) *or* (S) *and* (CLA) *over* (S)*, respectively.*

Proposition 6 *For moral hazard, society systematically prefers* (RJV) *over* (CLA) *or* (S) *for lower values of* Δ *and* (CLA) *over* (S) *for higher values of* Δ *than the minimum values* Δ *for which* (RJV) *would be privately chosen over* (CLA) *or* (S) *and* (CLA) *over* (S)*, respectively.*

The result for which the stand-alone configuration is more often socially preferred in a world affected by moral hazard as opposed to the case of observable efforts, mirrors the one already obtained for the privately chosen configuration when introducing moral hazard behavior. The intuition of why these preferences coincide, should be explained by looking at the different effects at play when moral hazard is introduced.

Social welfare consists of the sum of expected net profits, agents' utility, and the part of the expected value of the innovation which is not appropriated by the entrepreneurs.

We know from the entrepreneurs' maximization analyses made in section 3 that the optimal implemented efforts under moral hazard are lower than the corresponding optimal implemented efforts under no moral hazard, i.e. across configurations. Lower implemented efforts under moral hazard reduces the effect of the lack of coordination induced by the choice of conducting the project alone as opposed of doing so in a cross license agreement, for example, could generate. This increases both the expected profit component of the social welfare, and the part of the expected value appropriated by the rest of the society, at least for values of the innovation which are big enough and levels of duplication severe enough, or for competition which is not too weak, or absent. The reason why these components increase is due to the fact that the probability to obtain a successful innovation in the overall economy is increased by choosing to conduct the project in a stand-alone configuration as opposed to a cross license agreement. Only the agents' utility is affected negatively by this decision: the level of efforts implemented in stand-alone is higher than the one implemented under cross license agreements, which results in a lower utility for agents under a cross license agreements than in a stand-alone configuration.

As anticipated, if there is weak or no competition instead, the higher the duplication combined to higher levels of the value of the innovation, the more likely the option of cross license is chosen over stand alone and research joint venture. Under moral hazard, if the value of the innovation is very high, it becomes much more costly to implement a given probability of success within the stand-alone configuration as opposed to doing so within a cross license agreement. This makes cross license be privately preferred to stand-alone for high values of the innovation. For the values of the innovation above which this happens, if in addition the duplication of efforts is high enough, cross license agreements are also preferred to research joint ventures.

In order to visualize how the different possible configurations impact on social welfare, we can also draw graphical comparisons. Figures 4-5 describe these comparisons for the same (Δ, ε) bi-dimensional space[14].

[Figures 4 - 5 about here]

Using the results just obtained, we can derive the following policy implications.

Corollary 3 *From a social standpoint, for non-fundamental research,*

1. *and intermediate levels of competition and not too high agents' efforts complementarities, as well as for moderate values of the innovation, cross license agreements should be encouraged over stand-alone;*

2. *the higher the competition the higher the level of agents' efforts complementarities below which society should start supporting research joint ventures, over both stand-alone and cross license agreements.*

Corollary 4 *From a social standpoint, for fundamental research,*

1. *cross license agreements should be discouraged except if society faces combinations of both very high agents' effort duplications and very high values of innovation;*

2. *point (2) of Corollary 3 applies, but for higher levels of agents' efforts complementarities.*

6 Conclusion

In this paper we have analyzed the impact of moral hazard on two entrepreneurs' choice whether to conduct R&D projects alone, to sign cross license agreements, or to form a research joint venture. We have done so, considering varying degrees of competition in the market in which the invention is to be used, as well as allowing synergies or duplication deriving from agents' efforts interactions, and for different values of the innovation to be used by the successful entrepreneurs.

Within this framework, we have shown how moral hazard introduces a bias toward the private decision to conduct R&D projects in a stand-alone configuration at the expenses of either exploiting synergies in an RJV, or reducing the costs through coordination in a cross license agreement.

When comparing the impact of privately chosen configurations on the social welfare, we have concluded that when there is no moral hazard both too few RJVs and too few cross license agreements are chosen; whereas when there is moral hazard too few RJVs, and too many cross license agreements are chosen. In this sense, moral hazard changes the nature of the conflict between socially and privately preferred configurations.

Our results shed some light on the type of policies which could be followed in order to ameliorate the overall social welfare impact of privately taken decision on how to conduct R&D

[14] As before, we will focus on $\alpha = 0.01$, $\alpha = 0.35$, $\alpha = 0.49$, and $\alpha = 0.5$, and $\varepsilon \in [-1, 1[$ for our graphical analysis.

projects. The model provides a characterization of under which circumstances society should start supporting research joint ventures, over both stand-alone and cross license agreements; and when cross license agreements should be discouraged.

Our model, thus, provides the testable implication that – keeping everything else equal – non-fundamental R&D projects, i.e. those for which typically the processes are well defined, are more likely to be conducted jointly while fundamental R&D projects, for which the researchers typically enjoy the freedom to design the research processes, are more likely to be conducted in a stand-alone configuration. The first group of projects can be associated with a product innovation which consists of an improvement or adaptation of a product, intermediate input, or service, (e.g. the project of a new minivan to be introduced on the market; or the development of a drug starting from existing chemical entities). While the second one has to do with the more fundamental innovations, or "basic research" to use, once more, the classification given by Aghion et al. (2005). Our results, are therefore orthogonal to theirs. By making explicit the source of *freedom* versus *directedness* they consider, our model is able to explain a different dimension of how R&D projects are conducted - either in a stand-alone, or in a cross license agreement, or in a research joint venture configuration - as well as how they should be conducted from a social standpoint, as a function of their intrinsic nature.

Further research would be to test our theory, as well as to empirically assess the impact of different R&D policies on both private decisions and social welfare as a function of the presence or absence of moral hazard in the way the R&D process can be conducted.

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A Proof of $b_1 = b_2$ for (RJV)

In this appendix, we show that paying equal transfers in the (RJV) case is cost minimizing. To show this, we minimize the expected transfer implementing a certain probability level.

We split the problem into two parts. Let us first minimize the expected cost for the unconstrained problem, i.e. assuming $\min\left\{\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}},1\right\}<1$. Then the joint entity solves the following minimization problem:

$$\min_{b_1,b_2} C\left(RJV\right) = \min_{b_1,b_2}\left[p\left(RJV\right)\left(b_1+b_2\right)\right]$$
$$s.t.\ e_i^{-\varepsilon}\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{\varepsilon}{1-\varepsilon}} b_i = e_i \qquad \forall i \qquad (IC_i)$$

We can rewrite the program expressed in e_i

$$\min_{e_1,e_2} C\left(RJV\right) = \min_{e_1,e_2}\left[p\left(RJV\right)\left(b_1+b_2\right)\right]$$
$$s.t.\quad b_i = e_i^{1+\varepsilon}\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{-\varepsilon}{1-\varepsilon}} \qquad \forall i \qquad (IC_i)$$

we derive the first order conditions

$$\frac{\partial C^u\left(RJV\right)}{\partial e_1} = \left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{\varepsilon}{1-\varepsilon}} e_1^{-\varepsilon}\left(e_1^{1+\varepsilon}\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{-\varepsilon}{1-\varepsilon}} + e_2^{1+\varepsilon}\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{-\varepsilon}{1-\varepsilon}}\right) +$$
$$\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}\left(\left(1+\varepsilon\right)e_1^{\varepsilon}\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{-\varepsilon}{1-\varepsilon}} - \varepsilon e_1\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{-1-\varepsilon}{1-\varepsilon}}\right) +$$
$$\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}\left(-\varepsilon e_2^{1+\varepsilon}\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{-1-\varepsilon}{1-\varepsilon}} e_1^{-\varepsilon}\right) = 0$$

$$\frac{\partial C^u(RJV)}{\partial e_1} = \left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{\varepsilon}{1-\varepsilon}} e_2^{-\varepsilon}\left(e_1^{1+\varepsilon}\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{-\varepsilon}{1-\varepsilon}} + e_2^{1+\varepsilon}\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{-\varepsilon}{1-\varepsilon}}\right) +$$
$$\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}\left((1+\varepsilon)e_2^{\varepsilon}\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{-\varepsilon}{1-\varepsilon}} - \varepsilon e_2\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{-1-\varepsilon}{1-\varepsilon}}\right) +$$
$$\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}\left(-\varepsilon e_1^{1+\varepsilon}\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{-1-\varepsilon}{1-\varepsilon}} e_2^{-\varepsilon}\right) = 0$$

Solving for this problem, leads to two possible candidates for the minimum: $e_i = -e_{-i}$ and $e_i = e_{-i}$. As efforts are defined as non-negative variables, the solution to this problem is unique s.t.

$$e_1 = e_2 = e \qquad \Rightarrow \qquad b_1 = b_2 = b.$$

Whenever $\min\left\{\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}, 1\right\} = 1$, the same condition just found should be true following a limit argument.

B Properties of the Entrepreneurs' Profit Indifference Curves

Lemma 1 *For both the observable and unobservable efforts cases,*

1. *the function $\Delta_\Pi^j(\alpha,\varepsilon)$ has the following properties:*
   - *(a)* $\frac{\partial\left[\Delta_\Pi^j(\alpha,\varepsilon)\right]}{\partial\varepsilon} = 0$,
   - *(b)* $\frac{\partial\left[\Delta_\Pi^j(\alpha,\varepsilon)\right]}{\partial\alpha} < 0$,
   - *(c)* $\Delta_\Pi^j(0.5,\varepsilon) = 0$,
   - *(d) for any* $\alpha < 0.5$, $\Delta_\Pi^u(\alpha,\varepsilon) > \Delta_\Pi^o(\alpha,\varepsilon)$,
   - *(e) for* $\Delta > \Delta_\Pi^j(\alpha,\varepsilon)$, $(CLA) \succ (S)$, *and vice versa for* $\Delta < \Delta_\Pi^j(\alpha,\varepsilon)$;
2. *the function $\widehat{\Delta}_\Pi^j(\alpha,\varepsilon)$ has the following properties:*
   - *(a)* $\widehat{\Delta}_\Pi^j(\alpha,\varepsilon) > 0$ *iff* $\varepsilon \in \left]\underline{\varepsilon}, \widehat{\varepsilon}_\Pi^j\right[$, *with* $0 = \widehat{\varepsilon}_\Pi^o < \widehat{\varepsilon}_\Pi^u < 1$
   - *(b)* $\widehat{\Delta}_\Pi^j\left(\alpha, \widehat{\varepsilon}_\Pi^j\right) = 0$,
   - *(c)* $\frac{\partial\left[\widehat{\Delta}_\Pi^j(\alpha,\varepsilon)\right]}{\partial\varepsilon} < 0$,
   - *(d)* $\frac{\partial\left[\widehat{\Delta}_\Pi^j(\alpha,\varepsilon)\right]}{\partial\alpha} < 0$,
   - *(e)* $\widehat{\Delta}_\Pi^u(\alpha,\varepsilon) > \widehat{\Delta}_\Pi^o(\alpha,\varepsilon)$,
   - *(f) for* $\Delta > \widehat{\Delta}_\Pi^j(\alpha,\varepsilon)$, $(RJV) \succ (CLA)$, *and vice versa for* $\Delta < \widehat{\Delta}_\Pi^j(\alpha,\varepsilon)$;
3. *the function $\widetilde{\Delta}_\Pi^j(\alpha,\varepsilon)$ has the following properties:*
   - *(a)* $\frac{\partial\left[\widetilde{\Delta}_\Pi^j(\alpha,\varepsilon)\right]}{\partial\varepsilon} < 0$,
   - *(b)* $\lim_{\alpha\to 0}\left[\widetilde{\Delta}_\Pi^j(\alpha,\varepsilon)\right] > 0$, $\frac{\partial\left[\widetilde{\Delta}_\Pi^j(\alpha,\varepsilon)\right]}{\partial\alpha} < 0$, *and* $\widetilde{\Delta}_\Pi^j\left(0.5, \widehat{\varepsilon}^j\right) = 0$,
   - *(c)* $\widetilde{\Delta}_\Pi^u(\alpha,\varepsilon) > \widetilde{\Delta}_\Pi^o(\alpha,\varepsilon)$,
   - *(d) for* $\Delta > \widetilde{\Delta}_\Pi^j(\alpha,\varepsilon)$, $(RJV) \succ (S)$, *and vice versa for* $\Delta < \widetilde{\Delta}_\Pi^j(\alpha,\varepsilon)$.

C Properties of the Social Welfare Indifference Curves

Lemma 2 *For both the observable and unobservable efforts cases,*

1. *the function* $\Delta_W^j(\alpha,\varepsilon)$ *has the following properties:*

   (a) $\frac{\partial\left[\Delta_W^j(\alpha,\varepsilon)\right]}{\partial\varepsilon}=0,$

   (b) $\frac{\partial\left[\Delta_W^j(\alpha,\varepsilon)\right]}{\partial\alpha}<0,$

   (c) $\Delta_W^o(0.5,\varepsilon)=0,$ *but* $\Delta_W^u(0.5,\varepsilon)>0,$

   (d) $\Delta_W^u(\alpha,\varepsilon)>\Delta_W^o(\alpha,\varepsilon),$

   (e) $\exists\underline{\alpha}^j$*, with* $0<\underline{\alpha}^o<\underline{\alpha}^u<\frac{1}{2}$*, such that* $\forall\alpha<\underline{\alpha}^j$*,* $(S)\succ(CLA)\,\forall\Delta$*; and* $\forall\alpha>\underline{\alpha}^j$*, if* $\Delta>\Delta_W^j(\alpha,\varepsilon)$*,* $(CLA)\succ(S)$ *and vice versa for* $\Delta<\Delta_W^j(\alpha,\varepsilon)$*;*

2. *the function* $\widehat{\Delta}_W^j(\alpha,\varepsilon)$ *has the following properties:*

   (a) $\widehat{\Delta}_W^j(\alpha,\varepsilon)>0$ *iff* $\varepsilon\in\left]\underline{\varepsilon},\widehat{\varepsilon}_W^j\right[$*, with* $0=\widehat{\varepsilon}_W^o<\widehat{\varepsilon}_W^u<1,$

   (b) $\widehat{\Delta}_W^j\left(\alpha,\widehat{\varepsilon}_W^j\right)=0,$

   (c) $\frac{\partial\left[\widehat{\Delta}_W^j(\alpha,\varepsilon)\right]}{\partial\varepsilon}<0,$

   (d) $\frac{\partial\left[\widehat{\Delta}_W^j(\alpha,\varepsilon)\right]}{\partial\alpha}<0,$

   (e) $\widehat{\Delta}_W^u(\alpha,\varepsilon)>\widehat{\Delta}_W^o(\alpha,\varepsilon),$

   (f) *for* $\Delta>\widehat{\Delta}_W^j(\alpha,\varepsilon)$*,* $(RJV)\succ(CLA)$*, and vice versa for* $\Delta<\widehat{\Delta}_W^j(\alpha,\varepsilon)$*;*

3. *the function* $\widetilde{\Delta}_W^j(\alpha,\varepsilon)$ *has the following properties:*

   (a) $\frac{\partial\left[\widetilde{\Delta}_W^j(\alpha,\varepsilon)\right]}{\partial\varepsilon}<0,$

   (b) $\lim_{\alpha\to0}\left[\widetilde{\Delta}_W^j(\alpha,\varepsilon)\right]>0,$ $\frac{\partial\left[\widetilde{\Delta}_W^j(\alpha,\varepsilon)\right]}{\partial\alpha}<0,$ *and* $\widetilde{\Delta}_W^j\left(0.5,\widehat{\varepsilon}^j\right)=0,$

   (c) $\widetilde{\Delta}_W^u(\alpha,\varepsilon)>\widetilde{\Delta}_W^o(\alpha,\varepsilon),$

   (d) *for* $\Delta>\widetilde{\Delta}_W^j(\alpha,\varepsilon)$*,* $(RJV)\succ(S)$*, and vice versa for* $\Delta<\widetilde{\Delta}_W^j(\alpha,\varepsilon)$.

D Comparison between Profit and Social Welfare Indifference Curves

The relationships between the profit-indifference curves and the social welfare-indifference curves are described in Lemmas 3 and 4.

Lemma 3 *For the no moral hazard case, the profit-indifference curves and the social welfare-indifference curves have the following properties:*

1. $\Delta_\Pi^o(0.5,\varepsilon)=\Delta_W^o(0.5,\varepsilon)$, $\widehat{\Delta}_\Pi^o(0.5,\varepsilon)=\widehat{\Delta}_W^o(0.5,\varepsilon)$, $\widetilde{\Delta}_\Pi^o(0.5,\varepsilon)=\widetilde{\Delta}_W^o(0.5,\varepsilon)$;

2. $\forall\alpha \in \left]\underline{\alpha}^o, \overline{\alpha}\right[$*, with* $\overline{\alpha}$ *such that* $\Delta^o_\Pi(\alpha,\varepsilon) = \Delta^o_W(\alpha,\varepsilon)$*,* $\Delta^o_\Pi(\alpha,\varepsilon) < \Delta^o_W(\alpha,\varepsilon)$ *and* $\forall\alpha \in \left]\overline{\alpha}, 0.5\right[$*,* $\Delta^o_\Pi(\alpha,\varepsilon) > \Delta^o_W(\alpha,\varepsilon)$*;*
3. $\widehat{\Delta}^o_\Pi(\alpha,0) = \widehat{\Delta}^o_W(\alpha,0)$ *and,* $\forall\varepsilon \in \left]\underline{\varepsilon}, 0\right[$ *and* $\forall\alpha \neq 0.5$*,* $\widehat{\Delta}^o_\Pi(\alpha,\varepsilon) > \widehat{\Delta}^o_W(\alpha,\varepsilon)$*,*
4. $\forall\alpha \neq 0.5$*,* $\widetilde{\Delta}^o_\Pi(\alpha,\varepsilon) > \widetilde{\Delta}^o_W(\alpha,\varepsilon)$*.*

Lemma 4 *For the moral hazard case, the profit-indifference curves and the social welfare-indifference curves have the following properties:*

1. $\Delta^u_\Pi(0.5,\varepsilon) \neq \Delta^u_W(0.5,\varepsilon)$*,* $\widehat{\Delta}^u_\Pi(0.5,\varepsilon) \neq \widehat{\Delta}^u_W(0.5,\varepsilon)$*,* $\widetilde{\Delta}^u_\Pi(0.5,\varepsilon) \neq \widetilde{\Delta}^u_W(0.5,\varepsilon)$*;*
2. $\forall\alpha \in \left]\underline{\alpha}^u, 0.5\right[$*,* $\Delta^u_\Pi(\alpha,\varepsilon) < \Delta^u_W(\alpha,\varepsilon)$*;*
3. $\widehat{\Delta}^u_\Pi(\alpha,\widehat{\varepsilon}^u_\Pi) = \widehat{\Delta}^u_W(\alpha,\widehat{\varepsilon}^u_W) = 0$*, with* $\widehat{\varepsilon}^u_\Pi = \widehat{\varepsilon}^u_W = \widehat{\varepsilon}^u$*, and* $\forall\varepsilon \in \left]\underline{\varepsilon}, \widehat{\varepsilon}^u\right[$*,* $\widehat{\Delta}^u_\Pi(\alpha,\varepsilon) > \widehat{\Delta}^u_W(\alpha,\varepsilon)$*,*
4. $\widetilde{\Delta}^u_\Pi(\alpha,\varepsilon) > \widetilde{\Delta}^u_W(\alpha,\varepsilon)$*.*

E Figures

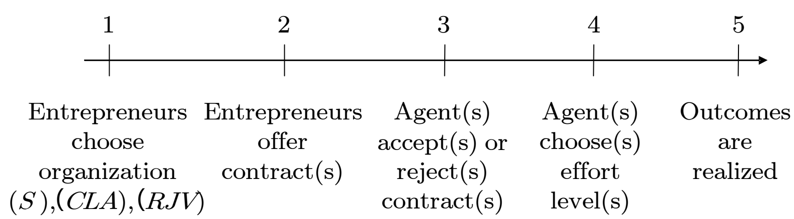
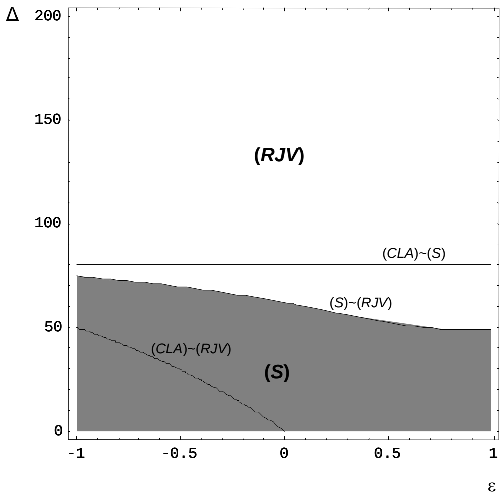


Figure 1: Timing



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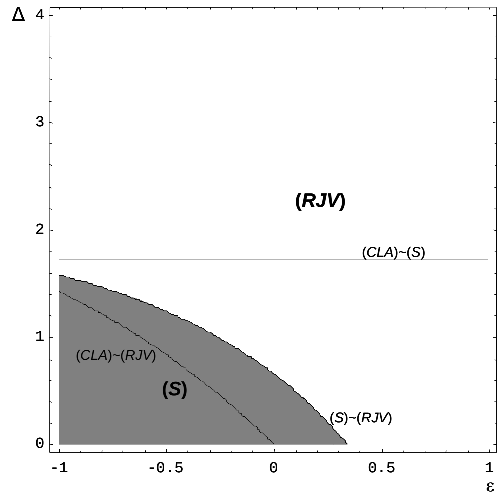

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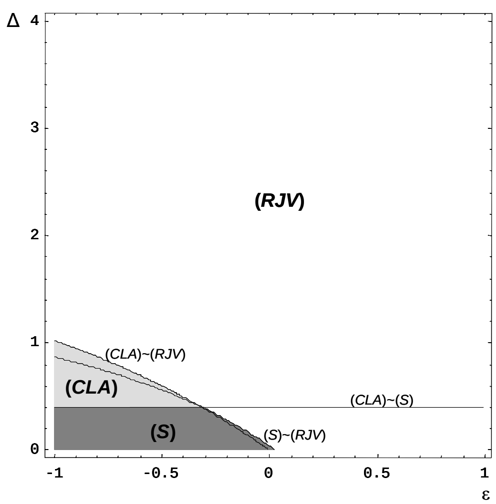

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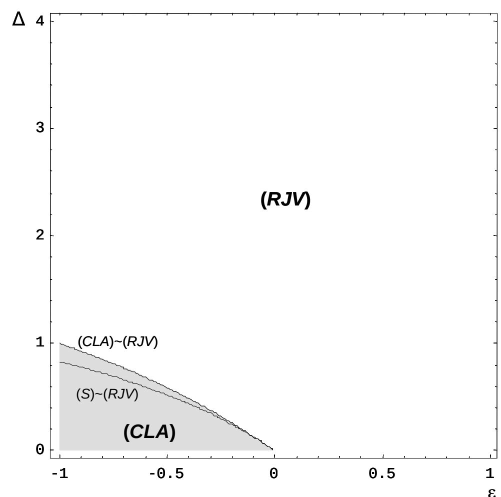

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Figure 2: Equilibrium Research Organization for Observable Efforts

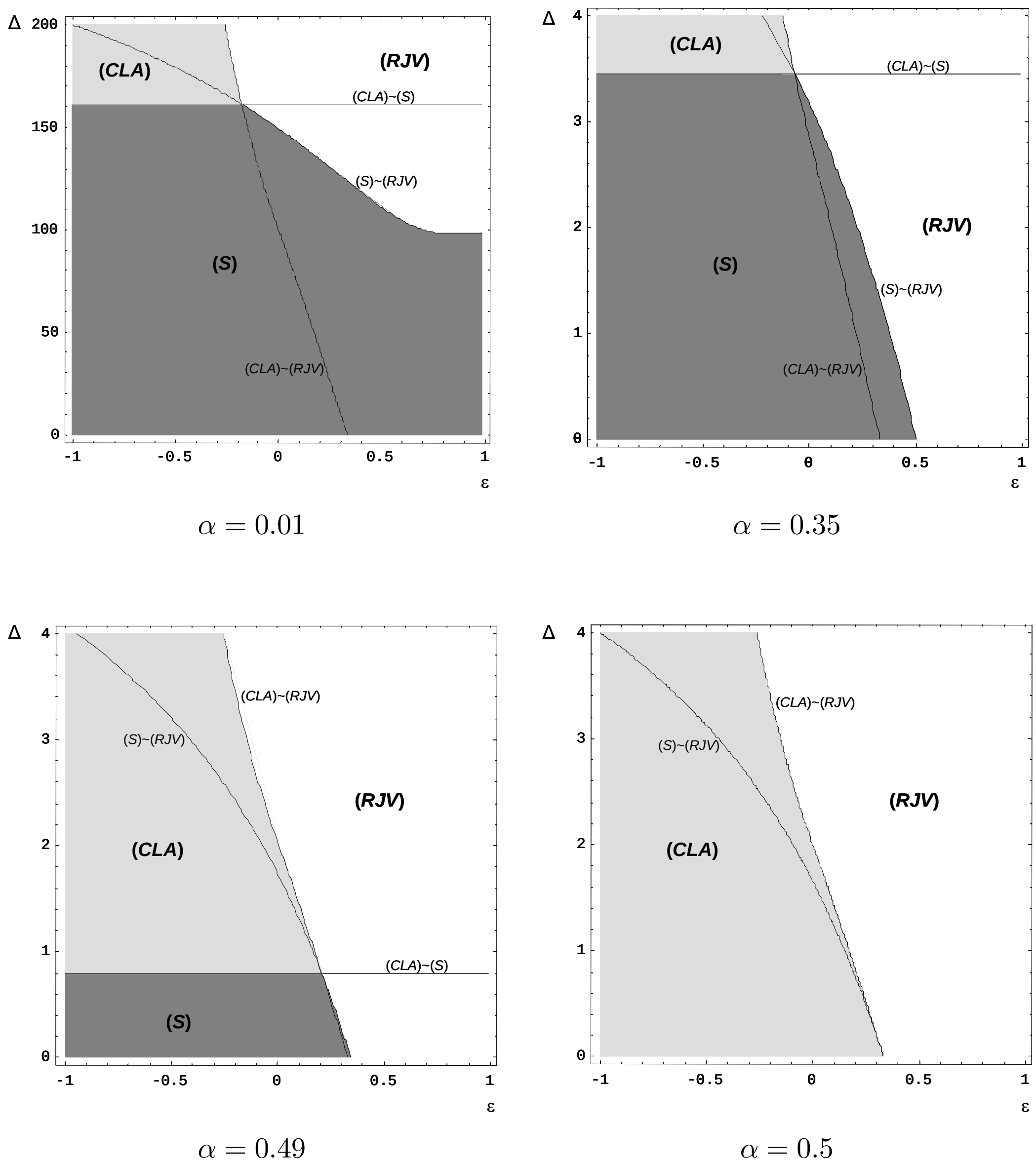


Figure 3: Equilibrium Research Organization for Unobservable Efforts

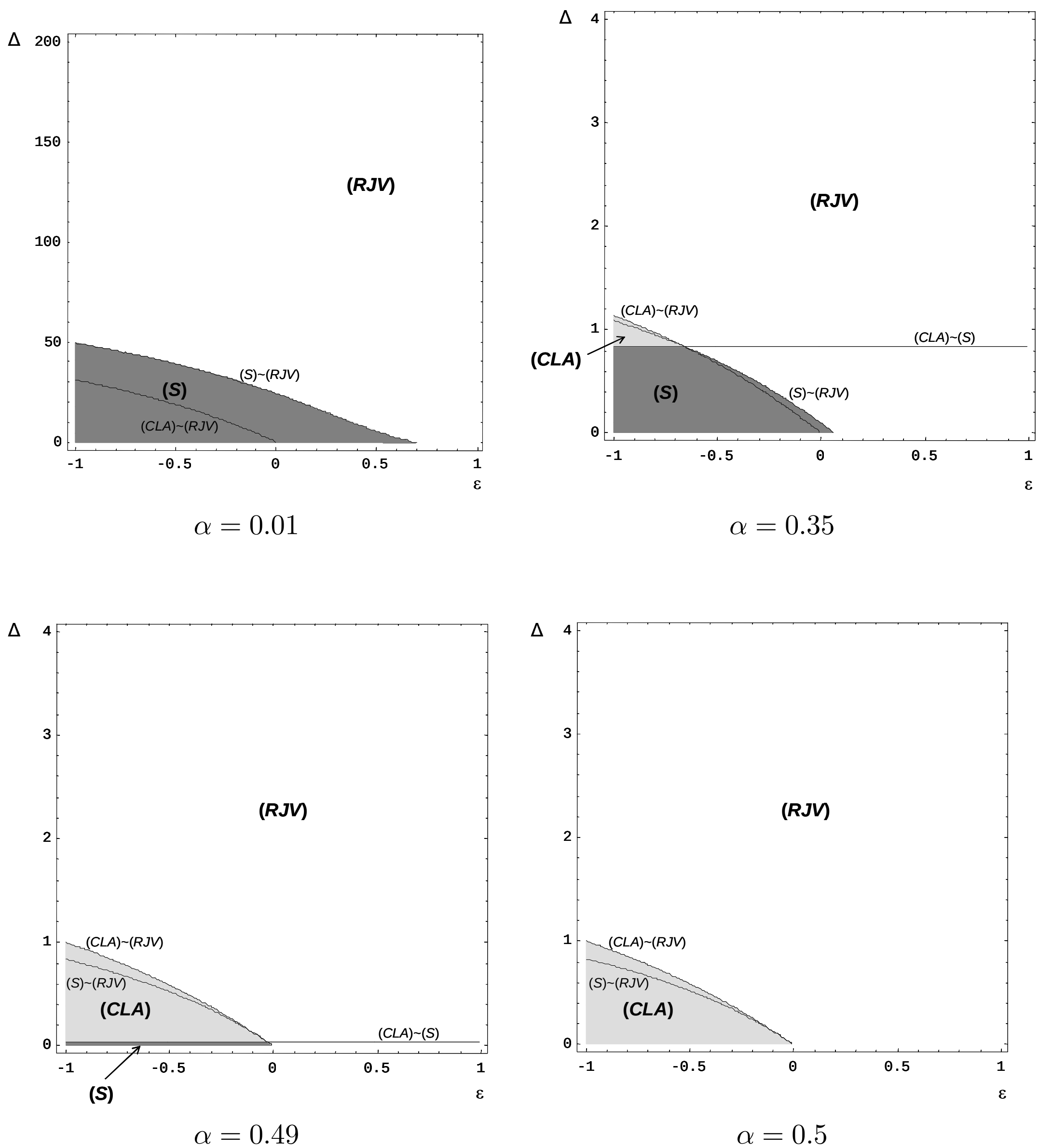
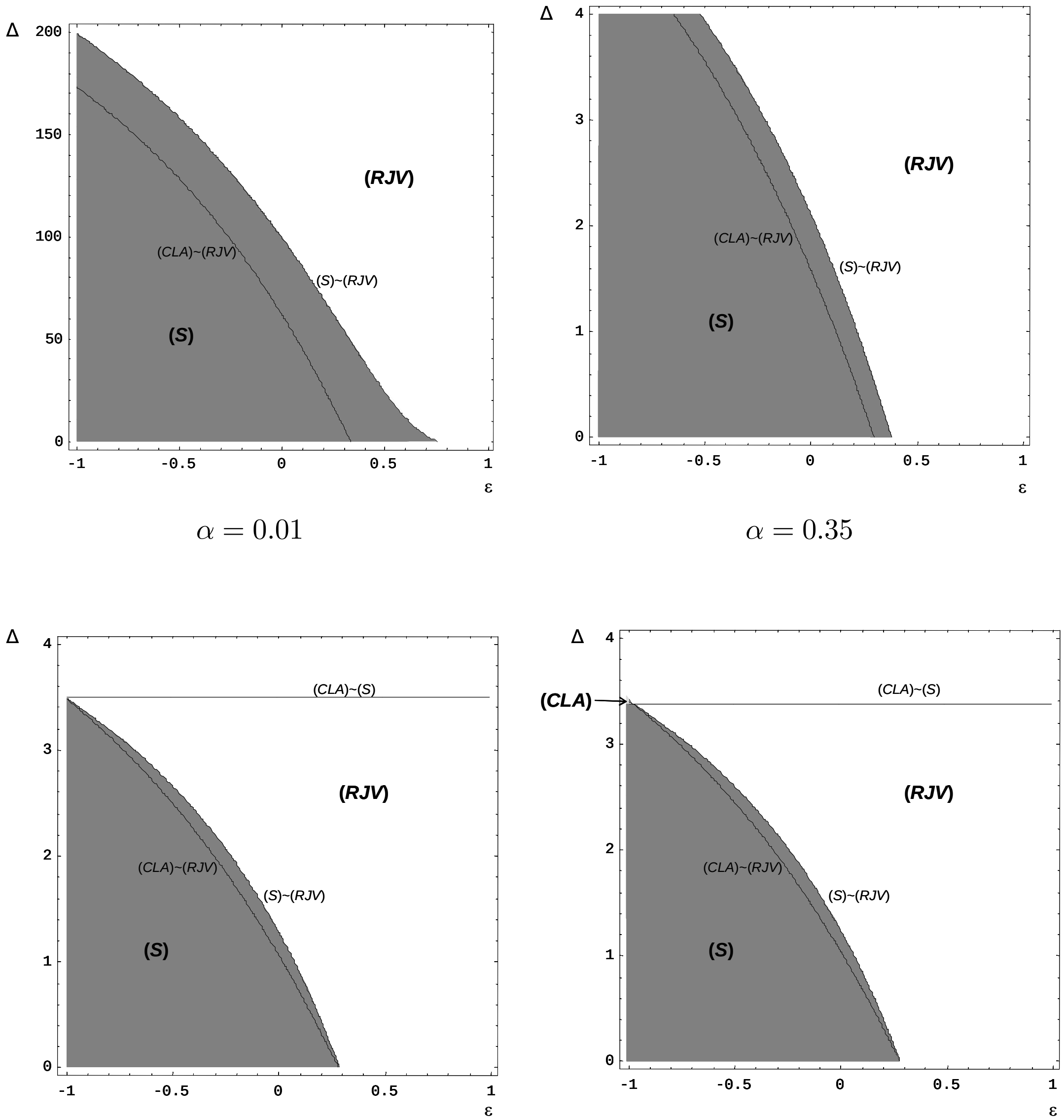


Figure 4: Welfare Impact for Observable Efforts



$\alpha = 0.01$ $\alpha = 0.35$

$\alpha = 0.49$ $\alpha = 0.5$

Figure 5: Welfare Impact for Unobservable Efforts