Essays in Industrial Organization

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Preface

All of the material in this thesis has been written out of curiosity. This curiosity has been awakened in me when I, still as an undergraduate student, visited the Ph.D. program at the University of California at Berkeley. It made me apply as a doctoral student, and it pushed me to explore new ideas, which – especially during my two years in the intense and inspiring working atmosphere at Université Toulouse 1 with its excellent courses, seminars, guest lectures, and its numerous conferences – were constantly popping up in my mind. Many of these ideas turned out to be not feasible, but some of them did and these are the ones that make up this thesis.

I begin by thanking you, Konrad Stahl, for giving me the chance to start as a doctoral student at Mannheim, for having been my advisor, and for believing enough in me to send me first to Berkeley and later – when you realized that my research entered fields that you were not close to yours – to Toulouse. Thank you for having prepared the way at Mannheim for me to defend my thesis in cotutelle! Thank you also for having given me the courage and the financial means to go and present my work in conferences and workshops! And finally thank you for keeping me cool when my slides were stolen before my first presentation in an international conference! I will always be prepared to give my talk without slides!

If I started understanding that writing an economic model is hard work, which needs a lot of focus (and a lot of patience), this is certainly thanks to Giancarlo Spagnolo, who coauthored my first paper and supervised a second idea during my time at the Universität Mannheim. Thank you, Giancarlo, for having written the word "ugly" on several of my first attempts to write a theoretical economic model! Thank you for having repeatedly told me to put structure on my ideas and to write them down as clearly as possible! Thank you for insisting with me to be at the same time as formal and as intuitive as possible! I hope I approached to some degree the rigor you demanded from me.

If in the end I indeed managed to keep my ideas somewhat simple and – at least to some degree – to find out which ingredient "is guilty of what" in my models, I have to thank Patrick Rey for that. Patrick, I do not know how to thank you for your great advice and I do not know how to express the value it had and has to me! Let me start with thanking you for having been able to see potential in my ideas – and for having told me that there is some – *a long time* before I was able to sense where these ideas were leading me! This way, you encouraged me to work harder, to make the ideas as clear as possible, and finally to see where I was heading. Thank you for your advice on how to tackle the ideas, even though it usually took me some time to

follow your advice: On various occasions, I left your office thinking: "it looks right what you are saying, but let me try to do it first the way I thought to do it". About every single time, in the end, I found myself solving the problems the way you have suggested – because it was the most sensible way to solve them. A huge thank you for giving me the chance to stay in the great environment of Toulouse and for making it possible for me to defend my thesis both, at Universität Mannheim and at Université Toulouse 1! Finally, thank you, Patrick, for teaching me more than Economics. Being in a state of *Zen* was so much easier after leaving your office.

The intense working atmosphere at Université Toulouse 1 and my intention to make up for lost time had an unfortunate drawback for my social life: Aside from few exceptions, my office mates and colleagues at UT1 only saw me in the office. I promise to do better in the future on that front! Thanks for knowing me, greeting me, and smiling at me anyway ;-). I am happy that I had your company in Toulouse! Thank you also for all your answers to my questions! The same way, I would like to thank my fellow students and colleagues at Mannheim, many of whom left at the same time I did. Thank you for being there whenever I had a question, for good joint teaching, and for good company! All the best to you!

A special "Thank you!" goes to Aude Schloesing and to Florence Chauvet! You have made my life at Université Toulouse 1 so much easier by always helping me – whichever situation I was in. Thanks also for listening to my concerns and "cooling me down" when things did not seem to go the way I wanted them to go. You are jewels! Thank you to Marion Börresen for giving me support in various ways at Mannheim until I "betrayed" the chair and went away!

Finally, I would like to thank my mother and my sister for always being there for me, whatever I was doing. Thank you to my parents for teaching me both, to believe in myself and to self-criticize! You do not know how helpful this is!

The greatest amount of debt, however, I would like to acknowledge to you, Simona. Thank you so much for great joint work, for constant support and encouragement, and for being vigorously upset whenever you felt that I have given only 115 instead of 150%! You have often made me go the extra-mile! Knowing that I am not always easy to work with, I thank you all the more for coauthoring two papers and for being willing to go on doing more joint work! And – thank you for loving me and planning a life together!

In the end, money matters. Funding for my research has been provided in these five years by Universität Mannheim, the European Commission in form of a Marie Curie Training Site fellowship and a CEPR fellowship in the RTN "Competition Policy in International Markets", as well as by GREMAQ in form of a post-doctoral fellowship. Thank you to Marc Ivaldi, Bruno Jullien, Michel LeBreton, Patrick Rey, and Konrad Stahl for helping me to access these sources!

I am sad to leave Toulouse for good. One only knows what it means once one has left, but it is possible to get a taste of it recalling the number of excellent seminars and workshops, which are taking place each and every week, as well as all the guest lectures and conferences, which are being held at Toulouse all over the year.

Toulouse, June 2005.

General Introduction

This thesis deals with issues of cooperation in industrial organization. It comprises two main parts. Part I contains chapter 1, which studies the impact of network structures on the sustainability of cooperation or collusion. Part II contains chapters 2 – 4, which deal with the incentives to pursue joint R&D projects in the presence of agency problems.

Chapter 1 of this thesis is devoted to the study of networks of relational (or implicit) contracts. It is based on the paper "Networks of Relations and Social Capital" by Steffen Lippert and Giancarlo Spagnolo. In this chapter, we explore how sanctioning power and equilibrium conditions change under different network configurations and information transmission technologies. In our model relations are the links, and the value of the network lies in its ability to enforce cooperative agreements that could not be sustained if agents had no access to other network members' sanctioning power and information. We identify conditions for network stability and in-network information transmission as well as conditions under which stable subnetworks inhibit more valuable larger networks. In this chapter, we finally provide formal definitions for individual and communities' "social capital" in the spirit of Coleman and Putnam.

Chapter 2, based on the paper "Moral Hazard and the Internal Organization of Joint Research" by Simona Fabrizi and Steffen Lippert (Fabrizi and Lippert, 2005b), analyzes the impact of agency problems on the choice of two entrepreneurs whether to carry out a stand-alone or a joint research project. If the research project is carried out jointly, it can be conducted either by only one of the entrepreneurs' research units, saving on fixed costs, or in joint work by both entrepreneurs' research units, which are considered to be substitutes of a varying degree. Our main results show that joint projects are chosen when they are of high value and/or when they exhibit low degrees of duplication or complementarities between the research units. Agency problems reduce the occurrence of joint projects as they have to be of higher value and/or exploit higher synergies. We also find that joint projects that would make use of potential synergies are chosen too seldomly from a welfare point of view.

In chapter 3, based on the paper "How much efficiency gains and price reductions to put as ingredients into an efficiency defense? 'Quanto Basta'" by Simona Fabrizi and Steffen Lippert, we study the impact of agency problems on merger decisions for firms facing a process innovation project that may be conducted in two competing stand-alone firms or in a merger. We compare the decisions of agent-managed firms with those of owner-managed (or family-run firms) and show that agent-managed firms merge less often in order to exploit synergies and more often for pure market power reasons. Within this framework, we then characterize the errors a competition authority would make when it relies on an efficiency defense using expected unit production cost reductions as a decision criterion whether or not to accept a proposed merger. We show that, due to the systematically different organizational choices of agent-managed firms as compared with owner-managed (family-run) firms, the occurrence of either type of errors (type I and type II) is smaller for agent-managed than for owner-managed firms.

Chapter 4 examines a channel through which a pro-competitive policy may have an impact on managerial incentives to develop new products, one using directly the separation of ownership and control inside the firms. If managers who exert a non-observable effort in the development of new products have private information about the profit maximizing organizational form to do so, the owners would optimally distort the managers' incentives in order to let them reveal their private information. As a consequence, the introduction of a policy favoring competitive stand-alone development of products will not only induce more of that organizational form, but also increase the incentives to innovative under it.

Part I

Cooperation and Collusion in Networks

Chapter 1

Networks of relations and social capital

1.1 Introduction

Relational[1] (or implicit) contracts, informal cooperative arrangements sustained by repeated interaction, are a fundamental governance mechanism for most forms of economic and social interaction. When several long-term cooperative relationships link different agents in a group, these agents and their relationships form *networks of relations*. This paper is an attempt to characterize some of their features.

Sociologists have forcefully argued that, by ignoring the networks of social relationships in which economic transactions are "embedded", economists fail to understand important features of the economic process.[2] Like social relations, economic transactions themselves are seldom isolated exchanges. Most often, they are also part of a relationship, episodes of a history of exchanges of various type itself embedded in a network of other economic and social relationships.[3] This is obviously the case for transactions within organizations – from employment to interactions between units and employees – but also for many of those between organizations, in particular supply relations, including financial ones.[4]

Networks of relational arrangements are not only crucial in developing economies, where explicit contracting is hard: in advanced economic environments, and most prominently in the fast changing one of high-tech industries firms often cooperate to share the high risk and return from their activities. In these industries formal arrangements represent the tip of the iceberg "beneath which lies a sea of informal relations" (Powell et al. 1996). On the one

[1] This chapter is based on the paper "Networks of Relations and Social Capital", written jointly with Giancarlo Spagnolo and circulated as SSE/EFI Working Paper No 570, quoted in this thesis as Lippert and Spagnolo (2005).

[2] The work of Coleman (1988, 1990) and Granovetter (1985) is particularly relevant. For example, the latter writes *"The embeddedness argument stresses instead the role of concrete personal relations and structures (or "networks") of such relations in generating trust and discouraging malfeasance"* (1985, p. 490).

[3] Greif (1993) and Casella and Rauch (2002) discuss the importance of ethnic ties for trade in environments where other enforcement mechanisms are ineffective.

[4] Macaulay (1963) first drew attention on the crucial role plaid by relationships in the economic process; Klein and Leffler (1981) have stressed the importance of long term firm-customer relationships; cornerstones of the formal theory of implicit contracts are Bull (1987) and MacLeod and Malcomson (1989); Baker et al. (2001), Levin (2003) and Rajo (2003) constitute important recent developments.

hand, lacking contractibility over the main ingredients – investments into human capital and knowledge transfers – explicit contracts can only play a limited role.[5] On the other hand, the need for flexibility linked to the fast changing and highly unpredictable environment make rigid explicit contracts dangerous and vertical integration unattractive. High tech firms therefore often establish informal cooperative agreements with several other firms, and these arrangements link them in a common network of relations.[6]

In the Internet, the maintenance of reciprocal peering agreements between Internet Service Providers (ISPs) requires long term cooperative relationships between them, nodes of a network. Our theoretical inquiry also aims at shading light on the viability of peering ISPs networks, relative to the more formal unilateral transit agreements with dominant ISPs or backbone operators.

The interbank market can also be seen as a network of long term relationships, where the links that spread contagion among interdependent financial institutions also induce liquid banks to cooperate and privately bail out illiquid ones (see Leitner, 2004). And social networks have been recently shown to have a pervasive and sometimes negative influence on corporate governance practices (e.g. Kramarz and Thesmar, 2004).

In fact, cooperation is often not for the good: corruption, illegal trade (in drugs, arms and people) and organized crime in general can only rely on relational contracts for the governance of their illegal transactions, which therefore typically take place within networks of tight relations. Similarly, collusive agreements to increase prices or restrain output are forms of illegal (and common) relational contracts. Multiproduct firms at different levels of the production chain, meeting and cooperating/colluding in different input, geographical and product markets form networks of relations that may link many apparently distant and unrelated firms, creating pro-collusive *indirect multimarket contact* where no multimarket contact seems present.

In this paper we describe equilibrium conditions for different architectures of networks of relations under different informational regimes, paying special attention to differences between circular and non-circular architectures. Most of the dilemmas mentioned earlier, from hold-up situations in specific (legal or illegal) exchanges to cheating in cartel agreements or on public good contributions have the strategic features of a Prisoner's Dilemma game, so our basic model is a repeated game in which each agent interact in generic, asymmetric strategic situations with the structure of repeated Prisoner's Dilemmas and can form links – cooperative relationships – with a small subset of the other agents. In our model, the links are the relationships, the network is directed and the links' orientation captures the presence of net gains from cooperation (slack

[5]The experimental work of Fehr et al. (2004) nicely documents the overwhelming importance of long term relationships for specific economic transactions.

[6]Saxenian (1994) reports a highly specialized network-like organization within the computer-industry in Silicon Valley. She argues that networks of informal cooperative information-sharing relations play a crucial role for the success of the district in comparison with Route 128, a competing district close to Boston. In her words, "While they competed fiercely, Silicon Valley's producers were embedded in, and inseparable from, these social and technical networks." It is noteworthy that the informal relations reported by Saxenian are not only of value on their own, they are of special value due to their being part of a network of such relations between engineers. Examining the biotechnology industry, Powell et al. (1996) point out that the "development of cooperative routines goes beyond simply learning how to maintain a large number of ties. Firms must learn how to transfer knowledge across alliances and locate themselves in those network positions that enable them to keep pace with the most promising scientific or technological developments."

of enforcing power in the bilateral relation). We consider three informational assumptions: the benchmark case of complete information, where each agent observes the histories of play of all agents; the opposite case where no information can be transmitted from an agent to the others on their observed history of play; and the case where, while agents meet to transact, they can choose to exchange and pass on received information on the respective histories of play. In this last case we assume that time is required for information to travel from one agent to the other, and allow for different speeds of information circulation within the network. We begin by characterizing sustainable networks where agents can only have relations with two neighbors. We show that when relations are asymmetric, since an agent would only cooperate if she receives some incoming arrows, there is a kind of an "end-network effect" (resembling the "end-game effects" of finitely repeated games), and network structures such as trees are not sustainable. Circular networks overcome this problem, ensuring that all agents' defections would be met with punishment, which provide a clear and intuitive explanation to the importance attributed by sociologists like Coleman (1988, 1990) to the "closure" of social networks.

We then show that the possibility of transmitting information about defections to other agents in the network is never used in equilibrium if enforcement relies on unrelenting "grim trigger" punishment strategies: when this is the case, once an agent deviates, a contagious process eliminates all prospect of future cooperation in the network, which removes all incentives to transmit information. With "forgiving" punishment strategies agents may instead choose to transmit information to keep on cooperating in the rest of the network while punishing multilaterally one deviator. We also find that under imperfect information and unrelenting punishment strategies, bilaterally enforceable relations between some agents may hinder the stability of larger networks containing these agents because these may not be willing to sacrifice their relation to perform their part in the punishment phase that could sustain the larger network. This problem, though, can also be overcome with the use of relenting punishments. In contrast to results in other literatures (e.g. Kranton, 1996; Spagnolo, 2002), in our model improved outside options, like a more efficient spot market, may under certain conditions foster cooperation by making the breakup of a relation in the case of a deviation a credible threat. Extending the analysis to more complex network architectures where agents may have more than two partners/neighbors we provide formal definitions for individual and communities' "social capital" in the spirit of Coleman and Putnam that generalize the definition introduced in Spagnolo (1999a, 2000) based on Bernheim and Whinston's (1990).

In an appendix we also allow agents to exclude 'cheaters' permanently from the network and then close the gap by creating new relations. We identify (quite restrictive) conditions for these strategies to form a sustainable network and show that they may marginally improve over the other strategies considered only if information about agents' history can be transmitted over the network. With full information these strategies do just as well as the others and with no information transmission they cannot sustain a network because of lack of information on whom to link to.

Related Literature. Besides being related to the already mentioned relational contracts literature, this paper contributes to the literature on the emergence and stability of networks. Prominent contributions to this literature - elegantly surveyed in Jackson (2003) - include, among others, Jackson and Wolinsky (1996), who model the emergence and stability of a social networks when agents choose to set up and maintain or destroy costly links using the notion of pairwise stability; Bala and Goyal (2000a) who consider the setup of directed and non-directed links by one agent only; Johnson and Gilles (2000), who introduce a spatial cost structure leading to equilibria of locally complete networks; Bala and Goyal (2000b), who explore the role of communication reliability in networks; and Kranton and Minehart (2000, 2001) who introduce investment and competition after in a buyer-seller network where buyers choose links in a the first stage. Belleflamme and Bloch (2003) model the formation of networks of market-sharing collusive relations between firms. These models focus on agents' decision whether to build and maintain a link or not. The common central question is: Given a value of a network, a sharing rule and the cost of maintaining a link, which networks will emerge in equilibrium, and are they efficient? The underlying game and enforceability problems are left out of consideration.[7] Our approach is complementary. We depart from this literature by explicitly modelling the underlying game, which allows us to study the consequences of its features for the stability of network structures; by focussing on the equilibrium sustainability of network structures rather than on the process of network formation; and by showing that the condition for sustainability of each relation of which a network is composed is generally not independent of the network's architecture.

Related work that explicitly models enforcement problems in communities has mostly focused on random matching games. Kandori (1992), Ellison (1994) and others consider repeated random matching prisoner's dilemma games, showing how much cooperation can be sustained under no information transmission between agents. More recently, a similar framework is used by Dixit (2003a) to study the effects of different types of third-party enforcement, and in Dixit (2003b) to analyze the efficiency of relational vs. explicit governance systems when distance among agents differ, inviting in his conclusion to endogenize information transmission. Groh (2002) extends this approach by including an endogenous decision to pass on information to other agents, hence he is closest to our framework. In contrast to this literature, we consider situations where agents with potentially changing opponents establish long-term relationship with fixed partners (e.g. neighbors). This introduces an important forward induction element into strategic behavior when defecting. We keep Groh's endogenous choice whether to pass on information on past actions and introduce the further possibility to pass on informations received by partners in the underlying game.

Our work is probably closest to the simultaneous and independent work of Haag and Lagunoff (2002) and Vega Redondo (2003).[8] Haag and Lagunoff examine a planner's optimal choice of social linkages - or "neighborhood structure" - when each agent plays symmetric repeated

[7] In a footnote of their introduction, Belleflamme and Bloch write: "In this paper, our focus is on the stability of market sharing agreements, and we assume that these agreements are enforceable. The issue of enforceability of market sharing agreements is an important one, which cannot be answered in traditional models of repeated oligopoly interaction. We leave it for further study." Our work can be seen as a first part of this further study.

[8] We are grateful to Sanjeev Goyal who let us know about these important, complementary papers.

prisoner's dilemma games with those other agents selected to be her neighbors, the agents' discount factors differ and are stochastically determined after the planners' choice, information is assumed to flow along the links, and agents sustain cooperation by a kind of stationary grim trigger strategies. Among other things, they find a trade off between suboptimal equilibrium punishment (due to imperfect monitoring) and excessive social conflict (linked to heterogeneous discount factors). Our approach is similar in so far that we also look at the effect of different network structures on the maximum level of cooperation sustainable. However, our approaches are very different in most other respects. In their model, as in Kranton and Minehart (2000, 2001), the presence of a link is a pre-condition for interaction hence for a cooperative relation. In our model, instead, the link is the relation and there is no link without cooperation. Moreover, we allow for general asymmetries in payoffs, so that the same agent can be very interested in cooperating with one agent but ready to cheat with the other, and consider in detail the effect of different strategies besides grim trigger. Finally, we endogenize information transmission and characterize the relation with different punishment strategies.

Vega Redondo models the evolution of a social network where social relations are idiosyncratic bilateral repeated prisoners' dilemmas with symmetric payoffs, subject to random shocks.[9] In his model, links are created and destroyed by agents depending on the expected net gains from cooperation; information is assumed to flow across the network one link per period; and enforcement power is transmitted to non sustainable relations. As in Spagnolo (1999a, 2000), "social capital" is defined as the slack enforcement power from cooperative relations that can be used to enforce cooperation in other relations where bilateral cooperation is not sustainable. Vega Redondo is mainly interested in the formation and evolution of social networks. He assumes circulation of information in the network and focuses on symmetric situations and grim trigger strategies. In contrast, we do not deal with network formation and evolution but dig more in depth in terms of sustainability of given network structures, allowing for asymmetries, different punishment strategies and agents' choice of whether to pass or conceal information. Among other things, we show that a network of relations may sustain relations none of which is sustainable if agents rely only on bilateral punishment mechanisms; and that information transmission among agents is not consistent with the use of unforgiving strategies such as "grim trigger" or "Nash-reversion".

Finally, our work is also closely related to the theoretical literature on multimarket contact and collusive behavior sparkled by the seminal work of Bernheim and Whinston (1990). In their model, collusion between two firms is fostered by tying collusive behavior in one market to collusive behavior in the other thereby pooling asymmetries in incentive constraints in the two markets.[10] The closest paper within this strand of literature is probably Maggi (1999), who adapts and extends the multimarket contact framework modelling multilateral self-enforcing in-

[9] See also Jackson and Watts (2002), who analyze the process of network formation when agents interact in coordination games.

[10] Spagnolo (1999a) extends the setting to objective functions submodular in payoffs from different markets and shows that multimarket contact may facilitate collusion even in the absence of asymmetries. Matsushima (2001) introduces imperfect monitoring and shows that when firms meet in a sufficient number of markets efficient collusion can be sustained under almost the same conditions as with perfect monitoring.

ternational trade agreements. We generalize and extend the work of Bernheim and Whinston by considering imperfect information and endogenous information transmission, and most importantly by showing that agents/firms can easily exploit *indirect multimarket contact* to sustain otherwise unfeasible cartels where absolutely no multimarket contact is present. We generalize and extend Maggi's work by considering generic strategic situations and generic number of agents and relations, and by characterizing the role of different information transmission mechanisms and punishment strategies on networks stability.

We proceed with the definition of a network of relations in section 1.2. In section 1.3, we derive results for sustainable networks with the restriction of at most two neighbors. We extend these results to situations with more neighbors in section 1.4. Section 1.5 concludes. Appendix A.7 extends the analysis by assuming that in a punishment phase, new relations can be created.

1.2 The model

Interaction There is a set $N = \{1, ..., n\}$ of infinitely lived agents $i \in N$ able to interact in pairs according to a connection structure $\mathcal{C}$ of two element subsets of N, where $ij \in \mathcal{C}$, $i, j \in N$, if they are connected. Denote $\mathcal{C}_i$ the set of connections of agent i. In each period t, connected agents play according to a generic prisoners' dilemma with idiosyncratic payoffs given by the following matrix:

		agent j	
		C^{ji}	D^{ji}
agent i	C^{ij}	$c^{i,j}, c^{j,i}$	$l^{i,j}, w^{j,i}$
	D^{ij}	$w^{i,j}, l^{j,i}$	$d^{i,j}, d^{j,i}$

where $l^{i,j} < d^{i,j} < c^{i,j} < w^{i,j}$ and $l^{i,j} + w^{i,j} < 2c^{i,j}$, $\forall i, j \in N$, $i \neq j$. The stage game is assumed to be constant over time. Note that the assumptions on the payoffs imply the static Nash equilibrium characterized by $\left(D^{ij}, D^{ji}\right)$. One interpretation of agent i's actions C^{ij} and D^{ij} is that agent i is either taking a cooperative action C^{ij} with respect to j, or not taking it, i.e. taking no action at all, D^{ij}.

We can think of C^{ij} as "contributing" to any kind of local public good, "complying" with the terms of any relational agreement, or "colluding"; and to D^{ij} as "don't...". The asymmetric prisoner's dilemma structure captures the essential strategic features of most of the examples discussed in the introduction[11].

Agents are assumed to interact repeatedly. Time is discrete, and all agents are assumed to share a discount factor $\delta < 1$. For simplicity, we assume additive separability of agents' payoffs across interactions and across time[12]. Agents are assumed to choose actions which maximize their discounted utility.

[11] Matsushima (2001) shows this in detail for *quantity setting oligopolies,* where firms simultaneously choose either a small amount of supply ("cooperation") or a large amount of supply ("defection").

[12] Removing this (standard) assumption, along the lines of Spagnolo (1999a, 1999b), would complicate the analysis but leave all qualitative results unaffected.

Relations and relational networks In this subsection, we define what we mean by a relation and by a network of relations and give some definitions useful for analyzing these networks. We start by defining a relation:

Definition 1.1 (Relation) *Given a strategy profile, two agents i and j share a relation if they repeatedly play C^{ij}, C^{ji}.*

Let $R \subset \mathcal{C}$ denote the set of connections between agents who share a relation and $R_i = \{j | \, ij \in R\}$ the set of agents with whom i shares a relation.

For notational convenience, let g^{ij} denote player i's net expected discounted gains from the relation with player j, i.e. the difference between the discounted payoff from playing $\left(C^{ij}, C^{ji}\right)$ forever and defecting and playing the static Nash equilibrium $\left(D^{ij}, D^{ji}\right)$ forever after

$$g^{ij} \equiv c^{i,j} - \delta d^{i,j} - (1-\delta)\, w^{i,j}.$$

In a standard bilateral repeated game setting both conditions, $g^{ij} \geq 0$ and $g^{ji} \geq 0$, are necessary for a cooperative relation to be sustainable in equilibrium as, in the repeated prisoner's dilemma, Friedman's (1971) grim trigger (or "unrelenting Nash reversion") strategies are optimal in the sense of Abreu (1988). Note also that if $g^{ij} > 0$ player i does not have an incentive to defect from a cooperative agreement in an infinitely repeated prisoners' dilemma where players use optimal punishment strategies; but $g^{ij} < 0$ does not mean that there is no gain for agent i from cooperation with agent j. It just means that agent i would like to deviate and bilateral cooperation is, therefore, not sustainable. We call a relation of player i with player j deficient for player i if $g^{ij} < 0$ and non-deficient for player i if $g^{ij} \geq 0$.

Definition 1.2 (mutual, unilateral, bilaterally deficient relation) *The relation ij is called mutual iff $g^{ij} \geq 0$ and $g^{ji} \geq 0$, it is called unilateral iff either $g^{ij} < 0$ and $g^{ji} \geq 0$ or $g^{ij} \geq 0$ and $g^{ji} < 0$, it is called bilaterally deficient iff $g^{ij} < 0$ and $g^{ji} < 0$.*

We are now in the position to define a network of relations.

Definition 1.3 (Relational network) *A relational network $\mathcal{N}^S = (N, R)$ is a graph consisting of the set of agents N and the set of relations R.*

Definition 1.4 (Sustainable relational network) *A relational network $\mathcal{N}^S = (N, R)$ is sustainable iff the strategy profile prescribing the relations in R is a sequential equilibrium.*

Definition 1.5 (Stable sustainable relational network) *A sustainable relational network $\mathcal{N}^S = (N, R)$ is strategically stable if it fulfills Kohlberg and Mertens' (1986) stability criteria.*

Graphical representation A simple way to represent relational networks is graphical, where a line or an arrow is drawn from agent j to agent i if $ij \in R$. This is standard in the literature. We would like to emphasize, however, that *our graphical representation of relational networks departs from the conventional graphical representation* in the networks formation literature.

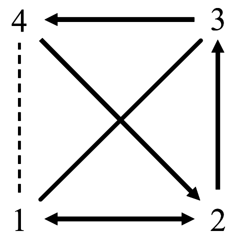


Figure 1.1: Graphical representation of a network of relations

There, an arrow outgoing from a vertex i usually depicts a link sponsored or formed by vertex i. In our graphical representation, on the other hand, the presence of arrows conveys information on the sustainability of relations with optimal bilateral punishments, more specifically on each agent's net discounted gains from defecting from a bilateral relation: We depict a relation $ij \in R$ with $g^{ij} > 0$ by an *incoming arrow* to player i.

A unilateral relation, thus, is depicted by an arc originating from the agent for whom the relation in deficient. A mutual relation is depicted by an incoming arc to both players. A bilaterally deficient relation is just a line. If two agents i, j can take an action w.r.t. each other, i.e. $ij \in \mathcal{C}$, but do not share a relation, i.e. $ij \notin R$, we depict this by a dotted line. Refer to figure 1.1: Agents 1 and 2 share a mutual relation, the relation between 2 and 3 is unilateral – it is deficient for player 2 and non-deficient for player 3 – and agents 1 and 3 share a bilaterally deficient relation. Finally, agents 4 and 1 are connected in the sense that $14 \in \mathcal{C}$, however $14 \notin R$, i.e. $4 \in \mathcal{C}_1$ but $4 \notin R_1$.

Definition 1.6 (mutual, non-mutual, mixed relational network) *A relational network is mutual if it only consists of mutual relations; it is non-mutual if it does not contain mutual relations; and it is mixed if it consists of both, mutual and other relations.*

As we are going to use – to some (limited) extent – graph theoretical language, let us define the used concepts here. In the relational network, agents i and j are called adjacent from/to each other or *directly connected* if $ij \in R$. The set of agents with whom i shares relations are the *neighborhood* of i, denoted by R_i, and $j \in R_i \Leftrightarrow i \in R_j$. Given $\mathcal{N}^S = (N, R)$, the number of agents in N is called the *order* of $\mathcal{N}^S$ and the number of relations in R the *size* of $\mathcal{N}^S$. The number of arcs directed into agent i is called the *indegree* of agent i, denoted by $\text{id}\, i$. The *degree* of vertex i is the number of edges of agent i, denoted $\deg i$. An agent of degree 1 is called end vertex. The network in figure 1.1 is of order 4 and size 5, there is no end vertex, and 2 is a vertex with $\deg 2 = 3$ and $\text{id}\, 2 = 2$. A network is called an $i-j$ *path* if it consists of a finite alternating sequence of agents and links that begins with agent i and ends with agent j, in which each link in the sequence joins the agent that precedes it in the sequence to the agent that follows in the sequence, in which no agent is repeated. An $i-j$ path is called a *cycle* if $i = j$. A cycle of size c is called a $c-$*cycle*.

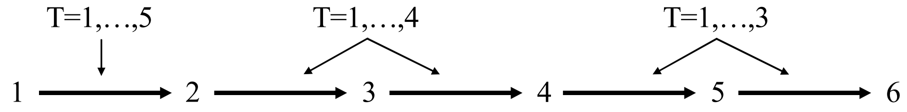


Figure 1.2: Agent 1's possible "observations"

Information structures We will consider the following three informational assumptions. Let H^{ij} be the set of histories in the relation between agents i and j with $\left(a_t^{ij}, a_t^{ji}\right)_{t=1,\ldots,T} \in H^{ij}$.

(**I1**) *Complete Information:* At time τ, each agent $i \in \mathcal{N}^S$ observes

- $(a_t^{mn})_{t=1,\ldots,\tau} \in H^{mn}\ \forall m, n \in \mathcal{N}^S$.

Each agent observes the history of play of all other agents.

(**I2**) *No Information Transmission:* At time τ, each agent $i \in \mathcal{N}^S$ observes

- $\left(a_t^{ij}, a_t^{ji}\right)_{t=1,\ldots,\tau} \in H^{ij}\ \forall j \in R_i$.

Each agent only observes the history of (his own and) his direct opponents' play.

(**I3**) *Network Information Transmission:* At time τ, each agent $i \in \mathcal{N}^S$ observes

- $\left(a_t^{ij}, a_t^{ji}\right)_{t=1,\ldots,\tau} \in H^{ij}\ \forall j \in R_i$ and
- $(a_t^{mn}, a_t^{nm})_{t=1,\ldots,int\left[\tau-\frac{l}{v}\right]} \in H^{mn},\ m \in R_n$, where $\min\left[l\left(i,m\right), l\left(i,n\right)\right] = l$ if there exists an $i-m$ path and if every agent on that path is *willing* to transmit information on their own history as well as messages received.

Under the *Network Information Transmission* mechanism, (**I3**), besides observing the history of his direct opponents' play, in each period each agent i can transmit and receive truthful messages - pieces of hard information - to/from each agent $j \in R_i$ about the histories of play and about messages they received. A message on past behavior can travel over v links per period. We assume that agents only meet when they cooperate, hence information can only be transmitted through existing cooperative relations/links.

For an illustration of the three informational assumptions, consider a non-circular network with 6 agents, call them agent 1 through 6, as in figure 1.2. Suppose first agents use the Network Information Transmission mechanism $(\mathbf{I3})$, and let $v = 2$. Then in $t = 5$, agent 1 observes the full history of his own play starting at $t = 1$ through $t = 5$. Furthermore, he will receive messages from agent 2 about the play between 2 and 3 and thus "observe" actions $\left(a_t^{2,3}, a_t^{3,2}\right)_{t=1,\ldots,4}$. The messages from 2 will also contain his received messages and thus agent 1 will "observe" actions $\left(a_t^{3,4}, a_t^{4,3}\right)_{t=1,\ldots,3}$, $\left(a_t^{4,5}, a_t^{5,4}\right)_{t=1,\ldots,3}$, and so on. Consider now the *Complete Information* case (**I1**). Each agent immediately knows everything that happened between every other two players, that is for example between agents 5 and 6 or between agents 2 and 3. This is of course also a degenerate form of Network Information Transmission mechanism (**I3**) where $\nu \to \infty$. With No Information Transmission (**I2**) each agent only knows the history of his own play, that is agent 1 only knows what happened between agents 1 and 2. This is also an extreme case of the network Information Transmission mechanism (**I3**) where $\nu = 0$.

Our information transmission mechanisms relate to the literature on perfect, public, and private monitoring in the following way. *Complete Information* (**I1**) implies perfect monitoring. *No Information Transmission* (**I2**) implies perfect monitoring for agents i and j on their bilateral history of play, but private monitoring for the same agents on the history of play of other agents and of their neighbors with other neighbors[13]. With the *Network Information Transmission* mechanism (**I3**), a temporal modification of (**I2**) is assumed. Again, refer to figure 1.2 and let $v = 2$ and $t = 5$. There is perfect monitoring for all actions that happened more than 3 periods ago. Actions between agents 5 and 6 from period 4 are assumed to be private w.r.t. agent 1. They are perfectly monitored by agents 6, 5, 4, and 3. The network information transmission regime introduces therefore a space-time neighborhood structure into relational networks, in the sense that perfect monitoring may travel through the network with time. Note also that there is no public monitoring in any of our information structures[14].

There are many situations in which there does not exist an institution that gathers and disseminates immediately information on the behavior of network members, as assumed implicitly in the complete information case (**I1**). In the network information transmission regime (**I3**) we thus suppose that information can only be transmitted through personal contacts of members of the network, and that transmission takes time. We assume that in networks of relations communicating besides interacting is not costly. This, we think, is a reasonable assumption since we have in mind chatting while carrying out one's daily business. We will see that an essential feature of this information structure is that, even though information transmission is costless in itself, agents must be given incentives to actually transmit information. Even with high speeds of information transmission, agents may prefer not to transmit information but rather deviate from their relations to reap short run deviation profits, in which case the potential higher speed of information transmission does not realize nor does it affect the sustainability of the network.

Specificity We assume fully specific relations, i.e. such that if a relation between two agents breaks down, these agents cannot substitute it with relations with other agents (i.e., it is not possible for an agent to substitute a partner with another one)[15]. Little changes (apart from notation) if agents are assumed imperfect substitutes, in the sense that a relation with an agent can be replaced at a finite but high cost with a relation with another agent.

[13] See Mailath and Morris (1999) for an example of private monitoring where the private signal about the other players' actions is imperfect.

[14] For an example of public monitoring, see Green and Porter (1984). They assume that players observe their own actions, but only an imperfect public signal about the actions of the other players.

[15] The most obvious examples of such situations are networks where a geography limits the set of potential partners of each agent, or where agents perform different functions (e.g. they supply different goods/services).

Assumption 1.1 *We restrict our attention to relational networks (equilibria)* $\mathcal{N}^S = (N, R)$, *with* $R = \mathcal{C}$.

We allow for costless substitution in Appendix A.7, so that punishment through exclusion/replacement becomes an option, and find that the results of the present paper continue to apply: relational networks where defecting agents are excluded and the relations shared with them replaced by relations between the defecting agent's former neighbors are either not sustainable, or not strategically stable in the sense of Kohlberg and Mertens (1996).

1.3 Analysis

Most insights can be gained by examining networks with a restricted number of neighbors. For the time being, therefore, we simplify the analysis by focussing on networks with nodes of a maximal *degree of two*, i.e. where each agent can have at most two neighbors[16].

Assumption 1.2 $\deg i \leq 2$.

In section 1.4, we will discuss how the results generalize to more complex networks.

1.3.1 Non-mutual networks

Mutual relations can be sustained by direct bilateral punishments, so if all relations are mutual, a network cannot improve on what agents can sustain bilaterally. A relational network plays a role when it allows to sustain unilateral or bilaterally deficient relations, i.e. relations that would not be sustainable in the absence of a network. In this section, we explore how relational networks can be sustainable even if they do not contain any relation sustainable in the absence of such a network (assumption 1.3). We will show how the network's ability to pool payoff asymmetry and redistribute sanctioning power and information improves on what agents could achieve through bilateral interaction.

Assumption 1.3 *Relational networks do not contain mutual relations.*

Let us start with a necessary condition for multilateral punishment mechanisms in a relational network:

Lemma 1.1 $\mathrm{id}\, i \geq 1\ \forall i \in R$ *is a necessary condition for a relational network to be sustainable.*

Proof. Suppose $i \in R$ and $\mathrm{id}\, i = 0$. Then $g^{ij} \leq 0\ \forall j \in R_i$ and i had an incentive to deviate from all her relations. ■

This is a straightforward generalization of the sustainability condition for a bilateral relational contract: For each contracting party, the net gain from cooperating has to be non-negative. The following proposition follows immediately:

[16] This assumption may represent a time constraint: It is always possible not to take an action w.r.t. someone you are connected to, however, it takes time to indeed take a *cooperative* action.

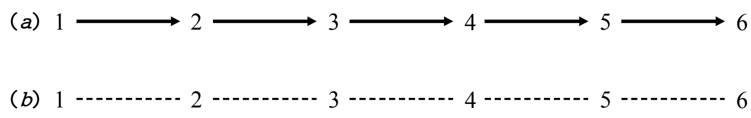


Figure 1.3: Only the empty network (b) is sustainable

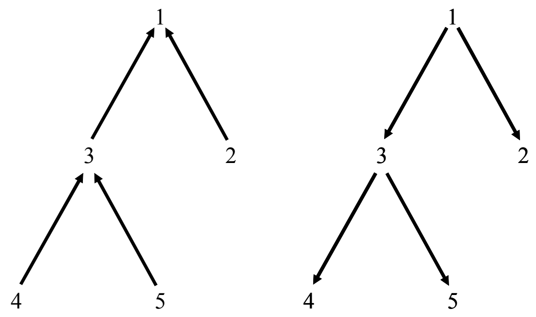


Figure 1.4: Trees

Proposition 1.1 *End-network effect: The only sustainable non-mutual non-circular relational network is the empty one (independent of the discount factor and the information structure).*

As long as all relations are not mutual, they are not sustainable by a multilateral mechanism within a non-circular network. Figure 1.3 illustrates this: Part (a) shows a network that is not sustainable. In that situation, agent 1 always has an incentive to deviate and the only sustainable network is empty, as shown in (b).

Proposition 1.1 highlights an end-network effect much similar to the end-game effect of standard finite games and rather general. Relaxing assumption 1.2 but keeping assumption 1.1, it is straightforward to see that this effect generalizes to *trees* (see figure 1.4 for an intuition), *stars* and any other network forms where there are vertices that have only outgoing arrows.

One way to ensure that the necessary condition from lemma 1.1 is satisfied in a non-mutual network is to "close" the network. If agents 1 and 6 from figure 1.3 shared a unilateral relation that was non-deficient for 1, as in Figure 1.5, then each agent in the network would have an incoming and an outgoing arrow, so that a multilateral punishment mechanism may exploit payoff asymmetries.

To capture this effect, we define below the unrelenting strategy profiles (**S1**) for the *complete information* case (**I1**), and (**S2**) for both, the *no information transmission,* (**I2**) and the *network information transmission* case (**I3**). These strategy profiles can be thought of as a network versions of Friedman's (1971) "grim trigger" strategies.

Strategy profile (**S1**)

1. Each agent $i \in \mathcal{N}^S$ starts playing the agreed upon action vector C^{ij} $\forall i \in \mathcal{N}^{\mathcal{S}}, \forall j \in R_i$.

2. Each player i goes on playing C^{ij} $\forall j \in R_i$ as long as no deviation by any player in the network is observed.

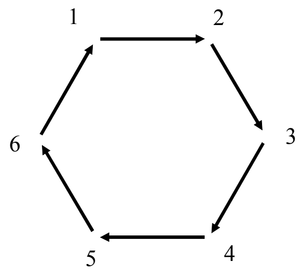


Figure 1.5: Circular unilateral network

3. Every agent i reverts to D^{ij} $\forall j \in R_i$ for ever otherwise.

Strategy and belief profile (**S2**) is a straightforward adaptation of the grim trigger like strategies (**S1**) to an environment without full information.

Strategy and belief profile (S2)

1. Each agent $i \in \mathcal{N}^S$ starts playing the agreed upon action vector C^{ij} $\forall i \in \mathcal{N}^{\mathcal{S}}, \forall j \in R_i$.
2. As long as player i observes every neighbor $j \in R_i$ play C^{ji} she goes on playing C^{ij} $\forall j \in R_j$.
3. If player i observes a neighbor j play D^{ji} in $t = \tau$ she reverts to D^{ij} $\forall j \in R_i$ $\forall t \geq \tau + 1$.

The beliefs players have after observing their neighbors – which we define formally in the appendix – are such that (i) and (iv) they believe that everybody in the network cooperated if they observe cooperation on both sides, (ii) and (v) they believe "anything" consistent if they observe cheating from a neighbor whose net gain from cooperating with them is positive, and (iii) and (vi) they assign an equal probability to the event that any of the other players was the first to deviate in case they observe Cooperate from their neighbor with a positive net gain from cooperation with them and Defect from the neighbor with a negative net gain from cooperating with them. As for parts (iii) and (vi) of the belief structure, a priori a player does not know anything else about any other player than that they are all symmetric w.r.t. their incentives to deviate in their respective bilateral relations. Then the observation that only one neighbor deviated does not provide any further knowledge. Following Bernoulli's "Principle of Insufficient Reason", we, therefore, assume that he assigns an equal probability of any of the other players to have been the first to deviate from $(S2)$ point 1. This assumption in part (iii) of the belief structure is innocent as this observation is part of a dominated deviation.

We can then state the following.

Proposition 1.2 *If the relational network is a c-cycle and agents use unforgiving strategies, then:*

1. *under complete information* (**I1**)*, a non-mutual relational network is sustainable if and only if* $\forall i \in \mathcal{N}^S$ $g^{i,i-1} + g^{i,i+1} > 0$*;*

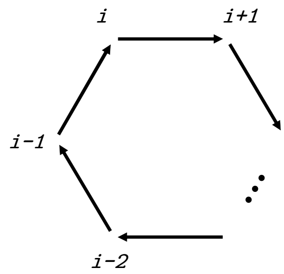


Figure 1.6: Circular unilateral network

2. *under no information transmission* (**I2**)*, a non-mutual relational network is sustainable if and only if* $\forall i \in \mathcal{N}^S$ $\delta^{c-2} g^{i,i-1} + g^{i,i+1} > 0$*; and*

3. *under the network information transmission regime* (**I3**)*, a non-mutual relational network is sustainable if* $\forall i \in \mathcal{N}^S$ $\delta^{c-2} g^{i,i-1} + g^{i,i+1} > 0$*, regardless of the speed of information transmission.*

For the proof of proposition 1.2, refer to figure 1.6. Also note that in a non-mutual network sustained by the above strategies and beliefs, unless there is perfect information the agents' optimal deviation is defecting immediately from deficient relations; and it is to postpone defections from non-deficient relations to the period before the punishment from that neighbor is expected to start.

Proof. *Part 1* of proposition 1.2: *Sufficiency*: Consider (**S1**). Since a deviator faces immediate Nash-reversion from both his neighbors, it is optimal to deviate on both neighbors, and the circular network is a Nash-Equilibrium if $\forall i$ $g^{i,i-1} + g^{i,i+1} > 0$. In the punishment phase, the stage Nash equilibrium is played and therefore a best response. *Necessity*: Since during the punishment phase the agents play their minimax strategy, the punishment phase is infinitely long, and it starts immediately, this is the strongest punishment available to the agents. If cooperation is not possible with these strategies, it will not be possible with other ones.

Part 2 of proposition 1.2: *Sufficiency*: Consider (**S2**). The optimal deviation for an agent i is now first deviating on the deficient relation, that is from his relation with $i+1$, and as late as possible – since deviating from a bilaterally non-deficient relation is a cost – from his other relation. The second deviation should take place after $c-2$ periods. Therefore deviation will not be profitable if

$$\delta^{c-2} g^{i,i-1} + g^{i,i+1} \geq 0 \qquad \forall i \in \mathcal{N}^S \text{ and } \{i-1, i+1\} = R_i.$$

Since every agent i in the network would want to deviate bilaterally from his relation with $i+1$, was it not for the threat of the loss of cooperation in her other relation, after losing this other relation for ever, "infecting" is optimal. This is true for *any* belief about the history of the game. *Necessity*: Since during the punishment phase the agents play their minimax strategy and the punishment phase is infinitely long, this is the strongest punishment available to the agents. As there is no possibility to transmit information on past behavior, it is also not possible to enter a punishment phase on both sides with a faster speed than one agent per period. If cooperation is not possible with these strategies, it will not be possible with other – less strong – punishments.

Part 3 of proposition 1.2: Assume the network information transmission regime (**I3**) and unforgiving strategies. Suppose agent i observes a deviation of his neighbor $i-1$ in his ($i-1$'s) deficient relation. Then, since, due to the unforgiving strategies, there will never be a return to cooperation with $i-1$, the best response of i in his (i's) remaining deficient relation would be to deviate from that relation. Therefore agent i will not make use of her ability to transmit information, leaving only room for the same strategies as under (**I2**).*Q.E.D.* ■

As we see from part 3 of proposition 1.2, an important feature of our model is that the design of the punishment paths interacts with agents' incentives to transmit information. One implication of this is that, even though grim trigger strategies are optimal punishment strategies in all the bilateral relations (i.e. if they rely on bilateral punishment mechanisms), for non-mutual relational networks, the grim trigger-like strategies (**S1**) and (**S2**) are only *optimal* punishment strategies for the *complete information* (**I1**) and the *no information transmission* case (**I2**), respectively. They are optimal because punishment is as strong as possible on both sides, once it arrives there, *and* it arrives on both sides with the smallest possible delay. Under the *network information transmission* regime (**I3**) with high speeds of information transmission instead, i.e. in a world where information can be transmitted via links and this information travels more than one link per period, strategies (**S2**) are *not optimal* anymore. The potentially high speed of information transmission is – individually optimally – not being used, and therefore, punishment "on the other side" arrives later than necessary, reducing the enforcement power of the network. In section 1.3.2, we will introduce a forgiving punishment mechanism that uses information transmission and that we will show to be optimal.

A short comment on the circular form of the network is due. Even though proposition 1.2 is a statement on a particular network architecture, a c-cycle, of course this circular network could be embedded into bigger networks. The strategy profiles (**S1**) or (**S2**) we studied would not conflict with that. Our implicit assumption by concentrating on a c-cycle – if it is embedded into a bigger network – is that the multilateral punishment mechanism (**S1**) or (**S2**) is taken for that particular subnetwork only.

To give an example for circular networks (or subnetworks), one could think of firms located on a (Salop) circle, with different capacities in the left and right market, cooperating/colluding with their neighbors. Coleman (1990) insists on the importance of the "closure" (circularity) of social networks. Giving a graphical representation as in figure 1.7[17], he suggests that if parents (A and B), whose children (a and b) are friends, share a relation, too, as in figure 1.7 part (a), they have more "power" over their children – thanks to what Coleman calls "intergenerational closure" – than if they do not, as in figure 1.7 part (b). Lack of relations among parents makes it more difficult for them to successfully impose/enforce norms on/upon their children. He does not provide a game theoretical foundation for his claim, but our model fits precisely his story.

[17] Note that his representation differs from ours by using two arrows to describe one relation.

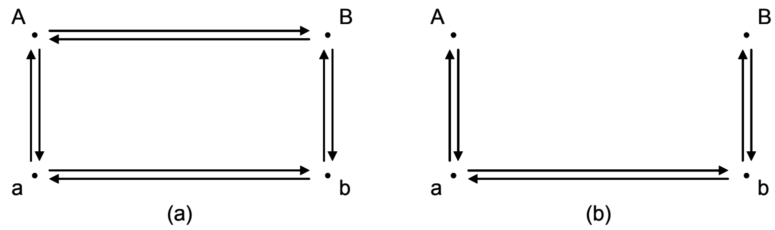


Figure 1.7: Representation of two communities: (a) with and (b) without intergenerational closure (from Coleman, 1990).

1.3.2 Mixed networks

In this section, we will relax assumption 1.3 that excluded mutual relation from the relational networks under consideration. We will explicitly allow for them (assumption 1.4), and study their impact on the sustainability of the various types of relational networks. We proceed examining the consequences of an increase of the stage game payoff $c^{i\cdot}$ of an agent i such that one of his relations becomes a mutual one. Increasing the cooperation payoff $c^{i\cdot}$ of an agent i increases both, the *profitability* of cooperating for this agent as well as the *sustainability* of the relative relation with a bilateral punishment mechanism.

After demonstrating a cooperation-enhancing effect for non-circular networks under information structure (**I1**), we will show that a circular network's ability to pool payoff asymmetry and redistribute sanctioning power under information structures (**I2**) and (**I3**) decreases if the unforgiving punishments from section 1.3.1 are used. When the increase in $c^{i\cdot}$ transforms a non-mutual relation into a mutual one, agent i may lose the incentive to exercise the multilateral punishment strategy, which sustained the network and thus the other bilaterally non-sustainable relations in the network. Subsequently, we will show that forgiving strategies overcome the problem for information structure (**I3**).

Assumption 1.4 *Relational networks contain both, mutual and other relations.*

Non-circular networks with unforgiving punishments

Proposition 1.1 states that there does not exist a non-circular non-mutual network other than the empty one. This is true because there would be an agent having only deficient relations and, thus, an incentive to deviate. If one increases the cooperation payoff $c^{\cdot i}$ of that agent, so that his relation becomes mutual, this incentive to deviate vanishes. Under *full information* a multilateral punishment like (**S1**) can then sustain such a network. Part 1 of proposition 1.3 states that. Part 2 shows that the negative result of Proposition 1.1 remains for the other information transmission mechanisms. And Part 3 shows that the equilibrium in Part 1 does not satisfy reasonable stability criteria put forward by Kohlberg and Mertens (1986). In particular, the equilibrium (**S1**) does not satisfy their *Iterated Dominance* and *Admissibility* criteria and gives thus rise to a forward induction problem.

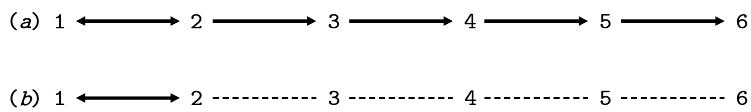


Figure 1.8: Sustainable networks under (a) info structure (**I1**), (b) info structure (**I2**) and (**I3**)

Proposition 1.3 *Suppose* $\deg i \leq 2$. *Then*

1. *under information structure* (**I1**)*, a non-circular relational network* $\mathcal{N}^{\mathcal{S}}$ *is sustainable if*

   (a) $\operatorname{id} i\,|_{\deg i=1} = 1$ *and*

   (b) *for all other agents in the relational network* $g^{i,i-1} + g^{i,i+1} > 0$*, and*

2. *under information structures* (**I2**) *and* (**I3**)*, there exists no sustainable non-circular mixed relational network.*

3. *If the relational network under* (**I1**) *relies on unforgiving punishments, it is not strategically stable.*

Proof. Parts 1 and 2 of proposition 1.3 are straightforward. Part 3 of proposition 1.3: *Unforgiving* punishment in our framework means to play according to (**S1**), i.e. to play D on both sides *forever* if a deviation occurred in the network. Ruling out the play of strictly dominated strategies gives rise to a profitable deviation for each agent i of the mutual subnetwork who is also part of a non-mutual subnetwork. Let agent 2 in figure 1.8 (a) play $D^{2,3}$ and $C^{2,1}$ in a period t. Then reverting to $D^{2,3}$ and $D^{2,1}$ for ever in $t+1$ is part of a strictly dominated strategy for 2. It is strictly dominated by $D^{2,3}$ and $D^{2,1}$ in a period t and reverting to $D^{2,3}$ and $D^{2,1}$ for ever in $t+1$. Thus, if agent 1 observes $D^{2,3}$ and $C^{2,1}$ in t, he can conclude that a rational agent 2 does not want to stick to the multilateral punishment mechanism. Given that 2 played $C^{2,1}$, there exists a focal equilibrium. This focal equilibrium is to switch to a bilateral punishment mechanism, the normal grim trigger strategy. The resulting – stable – equilibrium is the same as the one under ($I2$) and ($I3$), sketched in figure 1.8 (b). This gives rise to a profitable deviation for agent 2. *Q.E.D.* ■

Figure 1.8 illustrates proposition 1.3. Under the *full information* assumption (**I1**), every agent knows the history of every other player and can, thus, enter into a punishment phase. Given this, figure 1.8 (a) is an equilibrium. Under the other information transmission mechanisms, this is not the case, figure 1.8 (a) is not an equilibrium network, while figure 1.8 (b) is.

The sustainability of 1's relation in the absence of a network enables cooperation in the network. However, according to proposition 1.3, the resulting network under (**I1**) is not strategically stable. The mutual interest in cooperation, which made cooperation of all agents in the non-circular network an equilibrium, puts it on weak feet as it makes it unlikely to be selected as the equilibrium played.

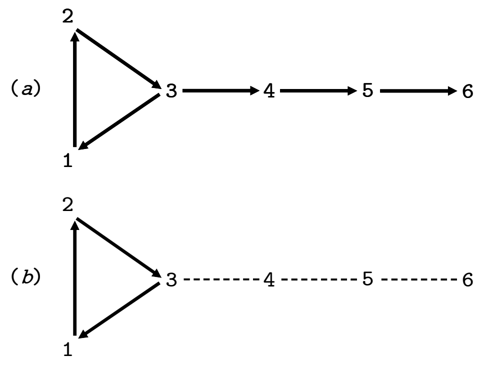


Figure 1.9: Non-circular network with a (possibly) sustainable subnetwork at one end.

Relaxing assumption 1.2 ($\deg i \leq 2$), it is straightforward to see that Proposition 1.3 generalizes to lines that are adjacent to subnetworks which are sustainable in autarky. Assume in figure 1.9 that the subnetwork $(\{1,2,3\},\{12,23,31\})$ is sustainable in autarky, i.e. without making use of possible relations $34, 45, 56$. Then, under (**I1**), strategies (**S1**) make (a) a sustainable network if, in addition, $g^{31}+g^{32}+g^{34}\geq 0$, $g^{43}+g^{45}\geq 0$, and $g^{54}+g^{56}\geq 0$, whereas network (b) is the only sustainable one under (**I2**) and (**I3**), irrespective of the payoffs in the relations 34, 45, and 56.

Remark. *All statements made on mutual relations also apply to subnetworks that are sustainable in the absence of the rest of the network.*

Mixed circular networks with unforgiving punishments

We now turn to circular networks. We will proceed in the same way we did in subsection 4.3.2: Again, we will increase the cooperation payoff $c^{i,\cdot}$ of an agent i's deficient unilateral relation such that it becomes mutual. As in subsection 4.3.2, we will discuss the impact of this change on the sustainability of a network.

Under *full information*, (**I1**), we will retain the results found so far. The equilibrium given by strategies (**S2**) however, relied on the fact that each agent, who was cheated upon by a neighbor, had an incentive to carry out the punishment on the deficient side. If we introduce a mutual subnetwork, there exist agents *who do not have* a deficient relation. Contrary to the full information environment (**I1**), and given that with (**S2**) it is not optimal for agents to transmit information, under the other two information regimes it is not possible to identify the initial deviator. Agents, who are part of a mutual subnetwork, may therefore be reluctant to enter into an punishment phase immediately if they observe a deviation on only one side: They only expect their neighbor to enter the punishment phase with a certain probability. This leads to proposition 1.4.

Proposition 1.4 *In a non-mutual circular relational network of size c with $g^{i,i+1}\leq 0$ and $g^{i,i-1}\geq 0$ $\forall i\in\mathcal{N}^S$, let $\underline{\delta}\equiv\left\{\delta|\, g^{i,i+1}+\delta^{c-2}g^{i,i-1}=0\right\}$. For agent k increase $c^{k,k+1}$ such that $g^{k,k+1}>0$, so that the network becomes mixed.*

1. *Then, under information structure* (**I1**),

   (a) *the resulting relational network is still sustainable*

   (b) *but not strategically stable.*

2. *Denote with* $\underline{\underline{\delta}}$ *the minimum discount factor necessary to sustain the resulting network under* (**I2**) *and* (**I3**) *with strategy and belief profiles* (**S2**). *Then*

   (a) *for sufficiently low* $l^{i,i+1}$ ***or*** *sufficiently high* $w^{i,i+1}$, $\underline{\underline{\delta}} = \underline{\delta}$.

   (b) *for too high* $l^{i,i+1}$ *and too low* $w^{i,i+1}$, (**S2**) *does not result in a sustainable network.*

   (c) *a too low* $w^{i,i+1}$ *results in strategic instability of the network.*

Proof. Part 1 (a): The optimality of the actions during a punishment phase proposed in part 1 of the proof of proposition 1.2 only depend on the strategies played by the deviator and his neighbors being a stage-game Nash equilibrium for the bilateral interaction. Since we have full information, everybody knows everybody else's history and expecting the other to stick to the prescribed strategy (**S1**), would lead to playing D^{ij} whenever a deviation is observed.

Part 1 (b): The proof parallels the one for proposition 1.3 part 3.

Part 2 (a) through (c) we relegate to the appendix. *Q.E.D.* ∎

The intuition for parts 2 (a) and (b) is the following (refer to figure 1.10): With the beliefs specified in (**S2**), if agent i in figure 1.10 observes $D^{i-1,i}$ and $C^{i+1,i}$ in $t = \tau$, he assigns probability $\frac{1}{c-1}$ to the event that any of the other agents in the network deviated first. Then, the bigger the network becomes, the more likely it is a priory that the agent that started the contagious process is an agent other than $i+1$ and $i+2$. Since in this case, $i+1$ will not play $D^{i+1,i}$ until $t = \tau + 2$, and since the net gain from cooperating with $i+1$ is positive for i, for a big size of the network, it is not a best response to play $D^{i,i+1}$ in $t = \tau + 1$. However, for agent i, with probability $\frac{1}{c-1}$ agent $i+1$ started. Because of that, if the loss from playing $C^{i,i+1}$ if $i+1$ plays $D^{i,i+1}$, $l^{i,i+1}$ is high enough, the expected payoff from carrying out the punishment may be higher than the one from going on cooperating for one more period. Furthermore, for agent i, with probability $\frac{1}{c-1}$ agent $i+1$ started. In that case, agent i expects $D^{i+1,i}$ from $t = \tau + 2$ on. Then, if the payoff from playing $D^{i,i+1}$ in $t = \tau + 1$, i.e. $w^{i,i+1}$, is very high in comparison to the payoff from playing $C^{i,i+1}$, agent i might also prefer to punish immediately.

The intuition for part 2 (c) is the following: Strategic stability rules out the belief that agent $i+1$ started and then sticks to the multilateral punishment since this is strictly dominated by having played $D^{i+1,i}$ in $t = \tau$. This only leaves a high $w^{i,i+1}$ as a reason to carry out punishments immediately.

Proposition 1.4 shows a trade-off between profitability and sustainability of cooperation in networks: An agent, who benefits (too) strongly from relations with everybody he is connected to, may hurt cooperation between other agents because he may be unwilling to punish deviants.

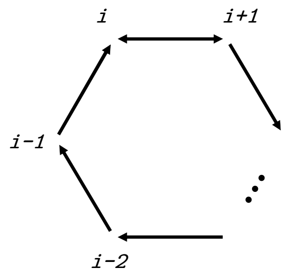


Figure 1.10: Circular network with a mutual relation

Mixed circular networks with forgiving punishments

In this subsection, we will show that harsh, but forgiving punishments lead agents to use the so far unused possibility to transmit information through links (under *network information transmission*, (**I3**)). For high speed of information transmission, these strategies will give rise to equilibrium networks not sustainable with the unrelenting grim trigger-type strategies studied so far. We find that these forgiving punishments are *optimal strategies* under (**I3**) , while grim trigger-type strategies are not even though they are in the repeated prisoner's dilemma.

Remember that under strategy profile (**S2**) agents do not exploit the possibility to transmit information offered by (**I3**), independent of the speed ν. Because of this, the results under (**I2**) and (**I3**) do not differ. Transmitting information cannot be an equilibrium choice with (**S2**) because the punishment phase lasts forever. A defection leads then to a complete breakdown of the relational network during the punishment phase[18], and agents prefer to "grab what they can" before the collapse of the network by defecting/infecting rather than maintaining the relation and transmitting information. The potential of high speed information transmission is therefore left unused.

By rewarding agents for transmitting information instead of infecting their neighbor, it becomes possible to avoid the breakdown of cooperation and to make use of high speeds of information transmission, thereby, relaxing the agents' incentive constraint and allowing a sustainable network for a lower δ than (**S2**). Proposition 1.5 shows this.

For that end, let us define the following strategy profile:

Strategy profile S3

1. All agents start by playing C^{ij} $\forall i \in \mathcal{N}^{\mathcal{S}}, \forall j \in R_i$.

2. As long as agent i observes C^{ji} $\forall j \in R_i$, and as long as no message containing D^{jn} for some $j \in R_i$, agent i goes on playing C^{ij} $\forall j \in R_i$.

3. If agent i observes D^{ji} for any $j \in R_i$ and she received no message about an earlier defection of j, agent i then sends a message about the deviation to her other neighbor

[18]That holds also if one considers a change in (**S2**) such that the reversion to the stage Nash equilibrium does not last forever but only for T periods.

and plays D^{ij} until j and i played D^{ij}, C^{ji} for T_j periods. After that i sends her other neighbor a message about the end of the punishment phase for player j and they go back to 2. thereafter. Each agent truthfully passes on the messages.

4. If a neighbor k of j receives a message about j's initial deviation, she plays D^{kj} until both, she receives the message that D^{ij}, C^{ji} has been played for T_j periods and D^{kj}, C^{jk} has been played for T_j periods. She returns to 2. thereafter.

5. If agent j played D^{ji}, she plays C^{ji} for the next T_j periods, D^{jk} in the period when k receives the information on her initial deviation and C^{jk} for the next T_j periods. She returns to 2. thereafter.

6. If some agent deviates from the actions in 3. – 6., the punishment starts against this agent.

Proposition 1.5 *In a non-mutual circular network of size c with $g^{i,i+1} \leq 0$ and $g^{i,i-1} \geq 0$ $\forall i \in \mathcal{N}^S$, let $\underline{\delta} \equiv \left\{ \delta | \, g^{i,i+1} + \delta^{c-2} g^{i,i-1} = 0 \right\}$. Let $\widetilde{\Delta}$ be the set of δ for which – together with an appropriate T_j, $\forall j \in \mathcal{N}^S$ – (**S3**) constitutes a sustainable non-mutual network with $g^{i,i+1} \leq 0$ and $g^{i,i-1} \geq 0$ under (**I3**) and $\widetilde{\delta} = \min \left\{ \widetilde{\Delta} \right\}$. Then*

(i) $\widetilde{\delta} \leq \underline{\delta}$ with a strict inequality for high speeds of information transmission (for $v > 1$).

(ii) if one substitutes non-mutual subnetworks with mutual ones the network is still sustainable and strategically stable $\forall \delta \in \widetilde{\Delta}$ for any l.

For the proof, which we relegate to appendix , there are four incentive constraints to consider:

1. Every agent has to have an incentive to stick to C^{ij} $\forall j \in R_i$ as long as neither he observes D^{ji} for a $j \in R_i$ nor he receives a message containing D^{jn} for $j \in R_i$. $\left(IC^{CI}\right)$

2. Given one neighbor j of i played $D^{j,i}$, each agent m (including $m = i$ herself) has to have an incentive to send a message containing $D^{j,i}$ to her other neighbor n and stick to $C^{m,n}$. $\left(IC^{CII}\right)$

3. Every neighbor of an original cheater has to have an incentive to carry out the punishment. $\left(IC^{P}\right)$

4. Every original cheater has to agree to be punished. $\left(IC^{LP}\right)$

We first show that $\left(IC^{CII}\right)$ and $\left(IC^{P}\right)$ are never binding. Using $\left(IC^{LP}\right)$ and $\left(IC^{CI}\right)$, we then show that, for a speed of $v = 1$, it is possible to choose a length T_j, $\forall j \in \mathcal{N}^S$, of the punishment period for each agent such that the punishment payoff for her is equivalent to minimaxing her on both sides forever[19], i.e. the strength of the punishment is equivalent to the one for (**S2**). Increasing the speed of information transmission reduces the delay of the

[19] To avoid divisibility problems, one can always assume a public randomization device giving the end of the punishment period for each agent such that in expectation the punishment payoff of the initial deviator is equivalent to minimaxing him forever.

punishment and, thus, relaxes $\left(IC^{LP}\right)$ which in turn gives room to make it more severe. This establishes *(i)*. Since agents are being rewarded for punishing their neighbor, they always have an incentive to do so during a punishment phase even if they want to cooperate bilaterally, which establishes *(ii)*.

Corollary 1.1 *Under* network information transmission (**I3**) *and assumptions 1.1, 1.2, and 1.4, for high enough ν it is possible to find a T_j $\forall j \in \mathcal{N}^S$ such that* (**S3**) *is an optimal punishment mechanism whereas* (**S2**) *is not.*

Proof. Two elements determine the strength of the multilateral punishment mechanism in the network: the payoff after punishment starts on each side, and the promptness with which this punishment starts on each side after a deviation. It is always possible to adjust the length of the punishment phase T_j for each player j such that he receives an punishment payoff equivalent to minimax forever. Furthermore, according to assumption 1.1, $R = \mathcal{C}$, the other neighbor of an agent that first defects can "get to know" about the defection and start the punishment phase at the earliest with the information that travelled through the network. This means that (**S3**) is an optimal punishment mechanism. As for high ν, information transmission is faster than contagion, (**S2**) is not an optimal punishment mechanism for high ν. ■

Punishment with (**S3**) is as strong as possible and as fast as possible, therefore these are the optimal (punishment) strategies in our network. Proposition 1.5 also shows that it is not necessary to have a complete breakdown of cooperation in the network in case of a deviation if information about past actions can be transmitted. The equilibrium is, thus, more robust (against e.g. mistakes) and increases welfare during punishment phases.

Since under perfect information (**I1**) the agent that defects first is known, the complete breakdown of the network in a punishment phase can be avoided through punishments as in (**S3**). These strategies[20] result in the same critical discount factor as for (**S1**), as punishment was immediate on both sides already with (**S1**).

While strategy profile (**S3**) avoids the breakdown of the network due to mutual subnetworks for (**I3**), it can not be used under (**I2**) since it makes use of information transmission. Without information transmission it is impossible to know who deviated first from the equilibrium path and a targeted punishment of only the agent that defects first becomes unattainable.

Up to now, we have not explicitly considered bilaterally deficient relations. It should however be clear at this point that a mixed circular relational network containing bilaterally deficient relations – as for example the network in figure 1.11 – is sustainable with the same strategies discussed above under the same conditions given.

[20] All neighbors $j \in N_i$ of an initial cheater i start playing $D^{j,i}$ until i has played $C^{i,j} \forall j \in N_i$ for T periods and then they go back to plaing $C^{i,j}, C^{j,i}$. In all other games in the network, the players go on playing the cooperative action during the punishment phase for player i. As the initial cheater can always get his minimax payoff forever, which is the payoff from the punishment in (**S1**), the biggest T, for which this strategy profile is an equilibrium, gives him exactly this payoff.

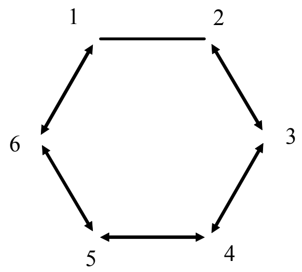


Figure 1.11: Mixed relational network containing only mutual relations except one bilaterally deficient one

1.4 Higher degree networks and social capital

In this section we show that there are generalizations of the results we obtained for the simple relational networks above, allowing for more than two neighbors[21]. For this end, we will use a c-cycle as a basic structure and add a link. We will show how networks of relations that generate "slack enforcement power" for some agents may enable these to sustain cooperation on additional deficient relations, even in *one shot* prisoner's dilemma interactions. We then offer an interpretation of this use of networks of relations as cooperation-enforcement/governance devices for new social dilemmas in terms of the highly debated but somewhat vague concept of "social capital".

In our model, establishing a link always increases the discounted payoff of the agents creating it, as it is always profitable to cooperate. However, regarding the sustainability of the network, though, adding a non-mutual relation has two effects: On the one hand, adding any relation that is not sustainable in autarky uses scarce enforcement power. Thus, there is a limit to adding them. On the other hand, if information travels with delay along the links of the network, or where information cannot "travel" and strategies rely on contagion, new links shorten paths, making multilateral punishments faster.

In the remainder of the section, we consider for each of the three informational regimes, (**I1**) – (**I3**), the effects of adding to a non-mutual circular network a bilaterally deficient, a unilateral, and a mutual relation, one at a time.

Full information (**I1**) It is straightforward to generalize proposition 1.2 part 1 and we state without proof:

Proposition 1.6 *Assume* (**I1**) *and the strategy profile* (**S1**)*. Then a network is sustainable iff*

$$\sum_{j \in R_i} g^{ij} > 0 \quad \forall i \in \mathcal{N}^{\mathcal{S}}. \tag{1.1}$$

[21] We have done so already in the sections before when we looked at trees, stars, or non-circular networks, one end node of which was an autarkically sustainable subnetwork.

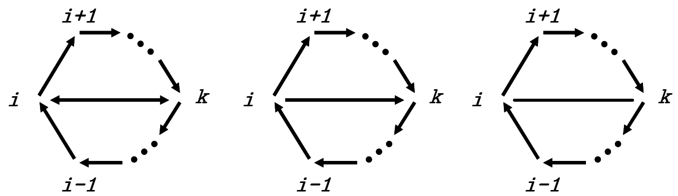


Figure 1.12: Adding a relation to a circular, non-mutual network

As long as (1.1) is satisfied, also bilaterally deficient relations can be sustained in equilibrium. Consider for example figure 1.12 (c). Agents i's and k's being part of the network helps them sustain a bilaterally deficient relation if the sum of the net gains from cooperating for i and k are big enough.

While "grim trigger" strategies (**S1**) are an equilibrium, the forward induction argument of Proposition 1.3 part 3 also applies here as long as (a) there are subnetworks that are sustainable without the rest of the network, and (b) there is a "rest" of the network that is not, i.e. as long as the relation ik that is added to $\mathcal{N}^{\mathcal{S}} \setminus ik$ is not sustainable outside $\mathcal{N}^{\mathcal{S}}$.

To see this, consider first figure 1.12, networks (b) or (c). Since ik is a deficient relation for i, $\mathcal{N}^{\mathcal{S}}$ is only sustainable with (**S1**) if $\mathcal{N}^{\mathcal{S}} \setminus ik$ is sustainable in autarky. If this is the case, then the same stability argument made for mutual subnetworks apply. If e.g., agent i deviates only from her relation with agent k, but not from his other two relations, it induces speculation on future play as under the current strategy profile the deviation is strictly dominated by a simultaneous deviation on all relations. Furthermore there is an equilibrium – $\mathcal{N}^{\mathcal{S}} \setminus ik$ – which (i) Pareto-dominates the continuation equilibrium in the punishment phase of (**S1**) and which is (ii) a focal point after this deviation. This is a profitable deviation, given the agents coordinate on $\mathcal{N}^{\mathcal{S}} \setminus ik$, since $g^{ik} < 0$.

Consider now network (a) with strategy profile (**S1**). If we add a mutual relation ik to a circular network $\mathcal{N}^{\mathcal{S}} \setminus ik$ that is *not sustainable* because $g^{i,i-1} + g^{i,i+1} < 0$ and/or $g^{k,k-1} + g^{k,k+1} < 0$, and if g^{ik} and g^{ki} are big enough such that $\mathcal{N}^{\mathcal{S}}$ is sustainable with (**S1**), the stability argument from proposition 1.3 part 3 applies: agents i and k had a "profitable deviation" from $\mathcal{N}^{\mathcal{S}}$ leaving them with ik.

If instead we add the mutual relation ik to a *sustainable* network $\mathcal{N}^{\mathcal{S}} \setminus ik$, both subnetworks are sustainable in autarky and there is no need to combine them into one multilateral punishment mechanism. Furthermore, under (**I1**), every member of $\mathcal{N}^{\mathcal{S}} \setminus ik$ immediately observes the play of every other player so that there is no delay in punishment that can be reduced by shortening paths through the new relation ik. However, even if players agreed on (**S1**) including ik, the sustainability of both subnetworks rules out the stability argument from Proposition 1.3 part 3.

As in previous sections, with more sophisticated forgiving punishment strategies (**S3**), this forward induction argument vanishes since punishments phases are followed by a return to cooperation that, together with rewards for the punishers provide incentives to punish.

No information transmission (I2) Let us turn to the no information transmission assumption (**I2**) and study sustainable networks using the contagion strategies (**S2**).

Refer to figure 1.12, first considering network (a). Obviously, if both subnetworks ik and $\mathcal{N}^{\mathcal{S}}\setminus ik$ were sustainable in autarky, treating the subnetworks separately and adding ik to $\mathcal{N}^{\mathcal{S}}\setminus ik$ results in a sustainable network.

If, on the other hand, $\mathcal{N}^{\mathcal{S}}\setminus ik$ is not sustainable on its own, adding ik might help sustain the network for two reasons. First, if $\mathcal{N}^{\mathcal{S}}\setminus ik$ is not sustainable because $g^{i,i+1}+\delta^{c-2}g^{i,i-1}<0$ and if $g^{i,i+1}+\delta^{m-2}g^{i,k}+\delta^{c-2}g^{i,i-1}>0$, where m is the size of the subnetwork $\{i,i+1,...,k\}$, adding ik will result in a sustainable network if both, i and k have, given their beliefs, an incentive to contribute to a multilateral punishment using their mutual relation. Second, if $\mathcal{N}^{\mathcal{S}}\setminus ik$ is not sustainable because $g^{j,j+1}+\delta^{c-2}g^{j,j-1}<0$, adding ik may result in a sustainable network under the same condition because the delay with which the punishment reaches j is shorter.

Proposition 1.7 *Let a network $\mathcal{N}^{\mathcal{S}}$ consist of a non-mutual circular network of size c, $\mathcal{N}^{\mathcal{S}}\setminus ik$, with $g^{i,i+1}\leq 0$ and $g^{i,i-1}\geq 0$ $\forall i\in\mathcal{N}^{\mathcal{S}}\setminus ik$ and a mutual relation ik between two non-adjacent agents. Let $\underline{\delta}\equiv\left\{\delta|\, g^{i,i+1}+\delta^{c-2}g^{i,i-1}=0\right\}$ $\forall i\in\mathcal{N}^{\mathcal{S}}\setminus ik$. Let $\widehat{\Delta}$ be the set of δ for which $\mathcal{N}^{\mathcal{S}}$ is sustainable with* (**S2**) *and beliefs specified in appendix A.5 and let $\widehat{\delta}=\min\left\{\widehat{\Delta}\right\}$. Then* for $l^{i,k}$ *and* $l^{k,i}$ small enough *or* $w^{i,k}$ *and* $w^{k,i}$ big enough, $\widehat{\delta}<\underline{\delta}$.

Proof. Assume (**S2**) and the beliefs specified in appendix A.5. As in the proof of proposition 1.4, by assuming $l^{i,k}$ and $l^{k,i}$ low enough or $w^{i,k}$ and $w^{k,i}$ big enough, i's (k's) expected profit from playing C^{ik} (C^{ki}) after having observed agent $i-1$ ($k-1$) deviate is smaller than if they not only play $D^{i,i+1}$ ($D^{k,k+1}$), i.e. infect agent $i+1$ (agent $k+1$), but also $D^{i,k}$ ($D^{k,i}$), i.e. infect also agent k (agent i). Therefore punishment sets in earlier and a lower discount factor is needed to sustain $\mathcal{N}^{\mathcal{S}}$. *Q.E.D.* ■

Again, if i's (k's) loss from playing C^{ik} (C^{ki}) if k (i) plays D^{ki} (D^{ik}) or the gain from playing D^{ik} (D^{ki}) if k (i) plays C^{ki} (C^{ik}) is big, the expected payoff from not punishing is relatively low and the agents sharing the mutual relation are willing to contribute to a collective punishment mechanism.

Consider now networks (b) and (c). Here, adding the relation ik, which is unilateral (bilaterally deficient), involves a trade-off. On the one hand, punishment will be faster, which relaxes the incentive constraint for each agent in $\mathcal{N}^{\mathcal{S}}\setminus ik$ and makes the network sustainable for lower discount factors. On the other hand, one agent (two agents) will have to sustain one deficient relation more, which tightens the incentive constraint for this agent (these agents). The set of discount factors for which the network is sustainable may therefore expand or shrinks with the addition the new relation, depending on parameter values.

The conditions for sustainability of the network, which we give together with the belief structure in appendix A.5, are a straightforward generalization of the conditions we had for the simple network with $\deg(i)\leq 2$.

Network information transmission (I3) Let us now turn to the network information transmission assumption (**I3**). Consider first network (a) from figure 1.12. Given the feasibility of information transmission, consider strategies (**S3**) which make use of it. For network (a) to be sustainable, the incentive constraints for agents other than i and k, are equivalent to the ones given in appendix A.4 with one change: Since the ways are shorter, the delay with which punishment sets in is shorter as well, making it easier to sustain the network. As an example for the incentive constraints for agents i and k, we give the ones for i in appendix A.6. Again, the sustainability conditions from appendix A.4 generalize.

Consider networks (b) and (c). Again, adding the relation ik, which is unilateral (bilaterally deficient), involves a trade-off. On the one hand, punishment will be faster, which relaxes the incentive constraint for each agent in the network and makes the network sustainable for lower discount factors. On the other hand, one agent (two agents) will have to sustain one deficient relation more, which tightens the incentive constraint for this agent (these agents). It is, thus, not clear whether the set of discount factors for which the network is sustainable increases or shrinks with adding the additional relation.

Social Capital Consider again figure 1.12 (c). We stated above that agents i's and k's being part of the network may help them sustain a bilaterally deficient relation between them. This is the case if the sum of the net gains from cooperating for i and k from their other relations are large enough, i.e. if they dispose of sufficient *slack enforcement power* to enforce the additional relation.

Suppose the circular network $\{i, i+1, ..., k-1, k, k+1, ..., i-1, i\}$ is a social network, i.e. the relations in it are *social relations*, and suppose the bilaterally deficient relation between i and k is a *one-shot prisoner's dilemma,* say an occasional business transaction where each agent can "hold up" the other. Then the slack enforcement power from our social network, used to govern a one-shot business interaction, is much like what Coleman (1990) defines as *social capital*:

> Social capital is defined by its function. It is not a single entity, but a variety of different entities having two characteristics in common: They all consist of some aspect of social structures, and they facilitate certain actions of individuals who are within that structure. Like other forms of capital, social capital is productive, making possible the achievement of certain ends that would not be attainable in its absence. Like physical capital and human capital, social capital is not completely fungible, but is fungible with respect to certain activities. A given form of social capital that is valuable in facilitating certain actions may be useless or even harmful for others. Unlike other forms of capital, social capital inheres the structure of relations between persons and among persons. It is lodged neither in individuals nor in physical implements of production.

"...*social capital* inheres the *structure of relations* between persons and among persons" and it makes "possible the achievement of certain ends that would not be attainable in its absence." This is a micro-perspective on social capital. Our model allows for a formal definition for social capital à la Coleman:

Definition 1.7 *(Social capital à la Coleman): Take a sustainable social network* $\mathcal{N}^S$ *with* $i, k \in \mathcal{N}^S$*. Then we define the* ***individual social capital*** i *and* k *can draw upon for a one-shot business interaction* ik *as*

$$sc_{ik} = \left(\max \left\{ w^{ik} - c^{ik}, w^{ki} - c^{ki} \right\} \middle| C^{ik}, C^{ki} \text{ is equilibrium in a MPM containing } \mathcal{N}^S \text{ and } ik \right).$$

The social capital agent i can draw on from being part of a social network is defined as the slack enforcement power usable to enforce cooperation-compliance in other interactions in need of governance through an *MPM* (multilateral punishment mechanism)[22]. With complete information (**I1**), this is only a player specific definition as it is equivalent to the sum of his net gains from cooperation in all his social relations $sc_{ik} = \min \left\{ \sum_{j \in R_i} g^{ij}, \sum_{j \in R_i} g^{kj} \right\}$. For the other information regimes, the extent to which existing relations in a social network can facilitate "the achievement of certain ends“ for an agent depends not only on his net gains from cooperation, i.e. how much he has to loose in his social relations. Since the delay with which an eventual punishment sets in matters, it also depends on *partners' locations* in the network.

Reviewing "(game-)theoretical questions stimulated by a reflection on social capital", Sobel (2002) identifies two ways in which Coleman's (1990) network closure or – put differently – "dense social networks make enforcement of group cooperative behavior more effective": First by creating "common knowledge of information", and second by increasing "the quality and reliability of third-party monitoring needed to enforce cooperative dynamic equilibria." With this paper, we offer an additional explanation of why closure might be important for the enforcement of cooperative behavior, the pooling of payoff asymmetries.

Robert Putnam (1995) takes another perspective on social capital. For him, the concept "refers to the collective value of all 'social networks' and the inclinations that arise from these networks to do things for each other." This is a macro-perspective on social capital, which, translated into our model, lead to the following formal definition:

Definition 1.8 *(Social capital à la Putnam): Take a sustainable social network* $\mathcal{N}^S$ *with* $i, k \in \mathcal{N}^S$*. Then we define the* ***social capital of a society*** *as the average individual social capital in that society*

$$\frac{1}{n \operatorname{card}(R_i)} \sum_{i \in \mathcal{N}^S} \sum_{k \in R_i} sc_{ik}.$$

The conclusion to be drawn from our model for the construction of aggregate measures of social capital is: If there is full information about the actions of economic agents, it suffices to

[22] This is a definition of social capital that quantifies it by its returns. A similar approach has been taken by Fernandez et al. (2000), who measure the returns to bonusses paid to current employees who successfully refer new employees out of their personal network. Fernandez et al. (2000) refer to the bonus paid to the employees as the company's "social capital investment" and to the net cost savings they obtain in their recruitment process as "the return to social capital". In our opinion, these references are, however, misleading. What the authors call "investment in social capital" should be termed more appropriately *the employees' return to their social capital*: The investment has been done by the employees themselves, and is not quantified by the firm's referral bonus. Furthermore, the net cost savings of the firm in the hiring process, which the authors label as "the returns to social capital", is more appropriately *the firm's return to the bonus paid to its employees.* It is part of, but not the whole, return to the investment in social capital. It reflects the relative bargaining power between employees and the firm in sharing the return to social capital.

have a measure of the average sum of the net gains from cooperation per person from social relations in the economy. However, if this is not the case, as in most real world situations, in addition, a measure of the density of the network should be used.

Information transmission as social capital We would like to emphasize that the value of the social network may also rest in the enforcement of the transmission of information on the history of interactions with outsiders. If the outsiders interact repeatedly with changing members of the network, transmission of information on the history of the play in these interactions through the network may help facilitate cooperation in them. In that sense, our model is a microfoundation of Kandori's (1992) *attaching a label to a cheater* by the members of the social network and of Sobel's second reason of why dense networks help enforce cooperative behavior – by increasing "the quality and reliability of third-party monitoring needed to enforce cooperative dynamic equilibria", an insight, which – to his knowledge – no one had formalized precisely in a game-theoretic model. The fact that such a transmission of information in a society is of economic value has been shown in variuos studies, among others in Acemoglu and Zilibotti (1999).

1.5 Conclusion

Each of us is involved in networks of long term relationships of different kinds and with different parties. Networks of social and economic relations include colluding firms, industrial districts, interbank markets as well as criminal/terrorist organizations. In this paper we have tried to clarify how the structure of such networks of relations affects the feasible equilibrium pattern of interaction.

In our model, agents maintain long term self-enforcing relations thanks to the information circulation and the enforcement/sanctioning power ensured by a network of such relations. We identify equilibrium conditions for different architectures of such networks, paying special attention to differences in these conditions for circular and non-circular architectures. The basic framework is that of repeated games between fixed partners with three basic information structures: complete information, no information, and information transmission through the network's links.

We show that if agents cannot discipline themselves within a certain relation, the pooling of asymmetries in payoffs across the network may allow them to sustain the relation under all three informational assumptions. We find an end-network effect, i.e. that a non-circular network or subnetwork is not sustainable. We find that the possibility to transmit information about a defection through the links in the network is not exploited in equilibrium if enforcement relies on unforgiving punishment phases. More complex punishment strategies induce agents to use information transmission, and to keep on cooperating in the rest of the network while punishing a defection (which increases efficiency and decreases the discount factor necessary to sustain the network). If information can be transmitted via the network, grim trigger strategies, therefore, cease to be optimal punishments as they do not use the possibility to transmit information to punish cheaters faster. Having self-sustaining relations in the network turns out to hurt cooperation with imperfect information, because agents may then not be willing to perform the prescribed punishment after a defection. When information can be transmitted, the network may be sustained using strategies that reward the punisher and encourage information transmission.

We model relations as cooperative agreements in generic infinitely repeated prisoners' dilemmas forming the links of the network of relations. The model is general enough to capture numerous economic and social situations. We provide a microfoundation to Granovetter's (1985) idea of "embeddedness" according to which, by ignoring the social background in which economic transactions are embedded, economists fail to understand important features of the economic process. Our end-network effect, i.e. the finding that a non-circular network or subnetwork is not sustainable, provides a clear explanation of why "closure" of social networks is so important for social capital, as argued by Coleman (1988) and (1990). Finally, we drew some conclusions about sensible measures of social capital in a network of relations, both on an individual and an aggregate level.

Immediate applications of our model include the organization of inter-firm relations in industrial districts, the enforcement of collusive behavior in business networks, interbank relations and the effects of "social capital" on the governance of economic and social interactions (as discussed by Coleman (1988, 1990), Putnam (1993) and Greif (1993) and formalized by Spagnolo (1999b)). In her much acclaimed book, Saxenian (1994) attributes a large part of Silicon Valley's success to a special culture of cooperation in that industrial district, which stems from a common background of the early workforce in that area. We believe our model offers a complementary explanation how social networks may facilitate information circulation in a community.

Appendix

A.1 Strategy and belief profile (S2)

1. Each agent $i \in \mathcal{N}^S$ starts playing the agreed upon action vector C^{ij} $\forall i \in \mathcal{N}^{\mathcal{S}}, \forall j \in R_i$.

2. As long as player i observes every neighbor $j \in R_i$ play C^{ji} she goes on playing C^{ij} $\forall j \in R_j$.

3. If player i observes a neighbor j play D^{ji} in $t = \tau$ she reverts to D^{ij} $\forall j \in R_i$ $\forall t \geq \tau + 1$.

(i) $a_t^{j,j+1}, a_t^{j+1,j} = C^{j,j+1}, C^{j+1,j}$ and $a_t^{j,j-1}, a_t^{j-1,j} = C^{j,j-1}, C^{j-1,j}$ $\forall t = 1, ..., \tau$, they believe $a_t^{k,l}, a_t^{l,k} = C^{k,l}, C^{l,k}$, $\forall kl \in R$, $\forall t = 1, ..., \tau$,

(ii) $a_\tau^{j+1,j} = D^{j+1,j}$ and $a_\tau^{j-1,j} = D^{j-1,j}$ or $a_\tau^{j+1,j} = C^{j+1,j}$ and $a_\tau^{j-1,j} = D^{j-1,j}$ with $g^{j,j+1} < 0$ they can have any belief consistent with this observation,

(iii) $a_\tau^{j+1,j} = D^{j+1,j}$ and $a_\tau^{j-1,j} = C^{j-1,j}$ with $g^{j,j+1} < 0$, they assign an equal probability $\Pr\left(a_t^{k,l} = D^{k,l} \wedge a_t^{k,l} = C^{m,n} \forall m \neq k\right), t \leq \tau, \forall k \neq j$.

For agents j with $\mathrm{id}(j) = 2$, beliefs are such that if they observe[23]

(iv) $a_t^{j,j+1}, a_t^{j+1,j} = C^{j,j+1}, C^{j+1,j}$ and $a_t^{j,j-1}, a_t^{j-1,j} = C^{j,j-1}, C^{j-1,j}$ $\forall t = 1, ..., \tau$, they believe $a_t^{k,l}, a_t^{l,k} = C^{k,l}, C^{l,k}$, $\forall kl \in R$, $\forall t = 1, ..., \tau$,

(v) $a_\tau^{j+1,j} = D^{j+1,j}$ and $a_\tau^{j-1,j} = D^{j-1,j}$ they can have any belief consistent with this observation,

(vi) $a_\tau^{j+1,j} = D^{j+1,j}$ and $a_\tau^{j-1,j} = C^{j-1,j}$ or $a_\tau^{j+1,j} = C^{j+1,j}$ and $a_\tau^{j-1,j} = D^{j-1,j}$, they assign an equal probability $\Pr\left(a_t^{k,l} = D^{k,l} \wedge a_t^{k,l} = C^{m,n} \forall m \neq k\right), t \leq \tau, \forall k \neq j$.

A.2 Proposition 1.1

Proof. A network has been defined non-circular if for no agent $i_1 \in \mathcal{N}^S$ there exists a path $\{i_1, i_2, ..., i_k\}$ with $i_1 = i_k$. It has been defined non-mutual if $g^{ij} > 0 \Leftrightarrow g^{ji} \leq 0$. In such a network, there would have to be either an agent e at the end vertex with $\mathrm{od}\, e = 1$ or an agent m in the middle with $\mathrm{od}\, m = 2$. Since we assumed $\deg i \leq 2$, there will not be any punishment from *other* neighbors and agent $e's$ or agent $m's$ dominant strategy is to defect from the relation. *Q.E.D.* ■

A.3 Proposition 1.4

First we proof that with an unforgiving punishment, cooperation may break down if we replace a unilateral relation with a mutual one. We then show that for $U^i\left(C^{ij}, D^{ji}\right)$ in the mutual relation small enough, the set of equilibria will not shrink.

Proof. Part 2 (a) and (b). Consider strategies (**S2**) and beliefs as outlined above. Suppose, we are in the situation of figure 1.10 with agents i and $i+1$ forming a mutual subnetwork. Consider the following defection: Agent $i+1$ plays $D^{i+1,i+2}$ and after $c-2$ periods goes on playing $C^{i+1,i}$. After $c-2$ periods, say in period $t = \tau$, agent i observes $D^{i-1,i}$ and $C^{i+1,i}$. Playing $D^{i,i+1}$ in $t = \tau + 1$ is rational for agent i only if she expects $i+1$ to play $D^{i+1,i}$ in $t = \tau + 1$. Whether she expects this to happen, depends on her beliefs on who started the deviation. Agent i may have three possible beliefs about who defected initially.

(a) Agent $i+1$ started and deviated only from his relation with $i+2$. If agent $i+1$ after his initial deviation sticks to the strategies prescribed, he will play $D^{i+1,i}$ in $t = \tau + 1$. Then it is in i's best interest to play $D^{i,i+1}$ as well. In the expected discounted payoff, this receives a bigger weight, the lower $l^{i,i+1}$.

(b) Agent $i+2$ started: Then $i+2$ would infect $i+1$ in $t = \tau + 1$, thus, no matter what agent i plays in $t = \tau + 1$, agent $i+1$ will play $D^{i+1,i}$ in $t = \tau + 2$. Therefore it is better to have a deviation profit in $t = \tau + 1$ and play $D^{i,i+1}$. In the expected discounted payoff, this receives a bigger weight, the higher $w^{i,i+1}$.

[23] We will need this part of the belief structure only when we consider mixed networks. In unilateral networks, by definition there are no agents with an indegree of two.

(c) An agent $m \in \mathcal{N}^S \setminus \{i, i+1, i+2\}$ started: The earliest period when $i+1$ would be infected by $i+2$ would be $\tau+2$. Thus i will expect $i+1$ to play $C^{i+1,i}$ at least until $t = \tau + 2$. Since we assumed $g^{i,i+1} > 0$, for this belief it is *not* a best response to play $D^{i,i+1}$ in $t = \tau + 1$.

Since agent i does not have any information, a consistent belief is that cases (a) and (b) have occurred with probability $\frac{1}{c-1}$ and case (c) with probability $\frac{c-3}{c-1}$. If c gets large, therefore, the expected payoff for agent i from deferring the punishment phase by one period may become positive.

This in turn delays the expected punishment date of an initial deviator, which leads to a breakdown of the network if $l^{i,i+1}$ is not small and $w^{i,i+1}$ is not big.

Part 2 (c). The proof parallels the one for proposition 1.3 part 3. *Q.E.D.* ■

A.4 Proposition 1.5

For notational convenience the following definition will be useful.

Definition 1.9 *We define a function*

$$\theta(c,v) \equiv \begin{cases} \max\left\{\frac{c-2}{v}, 1\right\} & \text{if } int\left(\frac{c-2}{v}\right) = \frac{c-2}{v} \\ \max\left\{int\left(\frac{c-2}{v}+1\right), 1\right\} & \text{if } int\left(\frac{c-2}{v}\right) \neq \frac{c-2}{v} \end{cases}.$$

This function maps the order of the cycle c and the speed of information transmission v into the strictly positive natural numbers and indicates the period in which an information about play between agents i and $i+1$ in period 0 reaches agent $i-1$.

In the proof we first consider the incentive constraints for agents in the network not to deviate from cooperation in phase I (IC^{CI}), from cooperation with their other neighbor in phase II that is if one neighbor cheated (IC^{CII}), from punishing the original cheater in phase II (IC^{P}), and from letting the others punish when she deviated in the first place (IC^{LP}). In a second step we show that $\widetilde{\delta} \leq \underline{\delta}$. It is shown that IC^{CII} and IC^{P} are never binding, so we can concentrate on IC^{CI} and IC^{LP}. For a speed of $v = 1$, by an appropriate choice of the length of the punishment, the conditions for cooperation can be made equivalent to the ones for (**S2**). Increasing the speed then relaxes IC^{LP} which gives room to make punishment more severe, which establishes (i): $\widetilde{\delta} \leq \underline{\delta}$. Since agents are being rewarded for punishing their neighbor, they always have an incentive to do so during a punishment phase even if they want to cooperate bilaterally, which establishes (ii). If T is chosen such that punishment is as hard as playing minimax strategies with both neighbors forever, this is the hardest punishment possible. Since here information transmission is used, every mean to decrease the delay before punishment on both sides sets in is used. This establishes the corollary.

Proof. The following incentive constraints are to be satisfied:

1. (IC^{CI}) For each agent i, playing $D^{i,i+1}$ in $t=0$ and $D^{i,i-1}$ in $t = \theta(c,v)$, which is her best deviation, yields $w^{i,i+1}$ in $t=0$, $l^{i,i+1}$ for the following T_i periods and $c^{i,i+1}$ thereafter,

as well as $c^{i,i-1}$ until $t = \theta(c,v) - 1$, $w^{i,i-1}$ in $t = \theta(c,v)$, $l^{i,i-1}$ for the following T_i periods and $c^{i,i-1}$ thereafter. Playing $C^{i,i+1}$ and $C^{i,i-1}$ forever yields $\frac{1}{1-\delta}\left(c^{i,i+1} + c^{i,i-1}\right)$. Summing up leads to $\left(IC^{CI}\right)$, which is the condition for (**S3**) to be a Nash equilibrium.

$$IC^{CI} \equiv \left(c^{i,i+1} - w^{i,i+1}\right) + \sum_{t=1}^{T_i} \delta^t \left(c^{i,i+1} - l^{i,i+1}\right)$$
$$+ \delta^{\theta(c,\nu)}\left(c^{i,i-1} - w^{i,i-1}\right) + \sum_{t=\theta(c,\nu)+1}^{\theta(c,\nu)+T_i} \delta^t \left(c^{i,i-1} - l^{i,i-1}\right) \geq 0$$
$$\forall i \in N^{\mathcal{S}},\ i+1, i-1 \in R_i.$$

2. (IC^{CII}) Suppose that in period $t = 0$, agent $i-1$ played $D^{i-1,i}$.

   (a) Suppose $\theta(c,v) \geq T_{i-1} - 1$. Then nothing changes in the trade-off in his interactions with $i+1$ from IC^{CI}. In his interactions with $i-1$, i will already have returned to the cooperative phase, which means he will give up $c^{i,i-1}$ for T_i periods by infecting $i+1$. Thus, i is in the same situation as if he never had been cheated on by $i-1$, which means $IC^{CII} = IC^{CI}$.

   $$IC^{CII} = IC^{CI} \qquad if\ \theta(c,v) \geq T_{i-1} - 1,$$

   (b) Suppose now $\theta(c,v) < T_{i-1} - 1$. Again nothing changes in the trade-off in his interactions with $i+1$ from IC^{CI}. Thus the first line of IC^{CII} coincides with the first line in IC^{CI}. If in $t = 1$, agent i plays $D^{i,i+1}$ instead of sticking to cooperation and just sending a message, this results in agent $i+1$ sending a message that reaches agent $i-1$ in $t = \theta(c,v)+1$. This yields agent i a utility of $l^{i,i-1}$ until $t = \theta(c,v)+T_i+2$. By sticking to cooperation, she would have had a utility of $w^{i,i-1}$ from $t = \theta(c,v)+1$ until $t = T_{i-1}$ and of $c^{i,i-1}$ from $t = T_{i-1}+1$. This difference constitutes the second and third line of IC^{CII}.

   $$IC^{CII} \equiv \left(c^{i,i+1} - w^{i,i+1}\right) + \sum_{t=1}^{T_i} \delta^t \left(c^{i,i+1} - l^{i,i+1}\right)$$
   $$+ \sum_{t=\theta(c,\nu)+1}^{T_{i-1}-1} \delta^t \left(w^{i,i-1} - l^{i,i-1}\right) + \sum_{t=T_{i-1}}^{\theta(c,\nu)+T_i} \delta^t \left(c^{i,i-1} - l^{i,i-1}\right) \geq 0$$
   $$\forall i \in N^{\mathcal{S}},\ i+1, i-1 \in R_i \qquad if\ \theta(c,v) < T_{i-1} - 1,$$

   Since

   $$IC^{CI} - IC^{CII} = \begin{cases} \sum_{t=\theta(c,\nu)}^{T_{i-1}-1} \delta^t \left(c^{i,i-1} - w^{i,i-1}\right) < 0 & \forall \theta(c,v) < T_{i-1} - 1 \\ 0 & \forall \theta(c,v) \geq T_{i-1} - 1 \end{cases},$$

   whenever IC^{CI} holds, IC^{CII} is satisfied.

3. (IC^P) Suppose agent i receives the message that agent $i+1$ deviated in their relation with one of their other neighbors. Then agent i has to have an incentive to punish him. Since $w^{i,j} > c^{i,j}$ together with $\left(IC^{CI}\right)$, this is always the case.

4. (IC^{LP}) Suppose in period $t = 0$, agent i played $D^{i,i+1}$. Then he has to agree to playing $\left(C^{i,i+1}, D^{i+1,i}\right)$ for T_i periods instead of his minimax strategy forever. After having played $D^{i,i+1}$ in $t = 0$, for agent i sticking to punishment strategies means incurring $l^{i,i+1}$ for T_i periods and $c^{i,i+1}$ thereafter. It furthermore means $w^{i,i-1}$ in $t = \theta(c, v)$, $l^{i,i-1}$ for the following T_i periods and $c^{i,i-1}$ thereafter. Deviating from punishment strategies yields $d^{i,i+1}$ forever, $w^{i,i-1}$ in $t = \theta(c, v)$ and $d^{i,i-1}$ forever thereafter. The difference between these utilities is represented by $\left(IC^{LP}\right)$.

$$
\begin{aligned}
IC^{LP} \equiv & \sum_{t=0}^{T_i-1} \delta^t \left(l^{i,i+1} - d^{i,i+1}\right) + \sum_{t=T_i}^{\infty} \delta^t \left(c^{i,i+1} - d^{i,i+1}\right) \\
& + \sum_{t=\theta(c,\nu)}^{\theta(c,\nu)+T_i} \delta^t \left(l^{i,i-1} - d^{i,i-1}\right) + \sum_{t=\theta(c,\nu)+T_i+1}^{\infty} \delta^t \left(c^{i,i-1} - d^{i,i-1}\right) \geq 0 \\
& \qquad \forall i \in \mathcal{N}^{\mathcal{S}},\ i+1, i-1 \in R_i.
\end{aligned}
$$

Constraint $\left(IC^{CI}\right)$ consists of addends that are either strictly increasing in δ or strictly positive. Constraint $\left(IC^{LP}\right)$ is strictly increasing in δ for $\delta \in (0, 1)$. Both conditions do not hold for a δ close to 0. They do hold strictly for a δ close enough to 1, thus there exists a $\widetilde{\delta}$ for which both constraints hold. Therefore under the conditions stated, strategy (**S3**) is subgame perfect for $\delta > \widetilde{\delta}$.

Since $l^{i,j} < d^{i,j}$, it is possible to fix a T_i $\forall i$ such that $IC^{LP} = 0$[24]. Given that T_i, assume $v = 1$, such that $\theta(c, v) = c - 2$. For this, IC^{CI} is satisfied for all δ that satisfy $\delta^{c-2} g^{i,i-1} + g^{i,i+1} \geq 0$. Now consider $v > 1$. Again, it is possible to fix a T_i $\forall i$ such that $IC^{LP} = 0$. That ensures the same strength of the punishment. But now the punishment in the non-deficient relation sets in earlier which reduces the value of the deviation and therefore for $v > 1$, $\widetilde{\delta} < \underline{\delta}$.

Since agents are being rewarded for punishing their neighbor, they always have an incentive to do so during a punishment phase even if they want to cooperate bilaterally, which establishes (ii).

If T_i is chosen for each agent i such that the punishment is as hard as playing minimax strategies with both neighbors forever, this is the hardest punishment possible. Since here information transmission is used, every mean to decrease the delay before punishment on both sides sets in is used. This establishes the corollary. *Q.E.D.* ■

[24] That means that the punishment is as strong as if the deviator was punished with infinite reversion to the static Nash equilibium.

A.5 Belief structure and sustainability conditions for section 1.4, information regime (I2)

For networks (a), (b), and (c) from figure 1.12, we assume the following beliefs:

For agents $j \notin \{i, k\}$, beliefs are such that

(i) if they observe cooperation on both sides, they believe that all agents in the network cooperated so far,

(ii) if they observe a deviation on both sides, they believe that the neighbor with whom they share their deficient relation was the first to deviate, and

(iii) if they observe a deviation only from the agent with whom they share their non-deficient relation, they give an equal probability to the event that any of the other players was the first to deviate.

For agents i and k, beliefs are such that

(iv) if they observe cooperation from all neighbors, they believe that all agents in the network cooperated so far,

(v) if they observe a deviation by all neighbors, they believe that everybody in the network deviated,

(vi) if i (if k) observes agent $i-1$ (agent $k-1$) deviate, but the other neighbors cooperate, agent i (agent k) gives an equal probability to the event that any agent $j \in \{k, k+1, ..., i-1\}$ (any agent $j \in \{i, i+1, ..., k-1\}$) was the first to deviate,

(vii) if i (if k) observes agents $i-1$ and k (agents $k-1$ and i) deviate, but the other neighbor cooperate, he believes that agent k (agent i) was the first to deviate,

$(viii)$ if i (if k) observes agent k, agent $i+1$, or both, agents k and $i+1$, (agent i, agent $k+1$, or both, agents i and $k+1$) deviate, but the other neighbors cooperate, agent i (agent k) gives an equal probability to the event that any agent $j \in \{i+1, i+2, ..., k\}$ (any agent $j \in \{k+1, k+2, ..., i\}$) was the first to deviate, and

(ix) if i (if k) observes agents $i-1$ and $i+1$ (agents $k-1$ and $k+1$) deviate, but the other neighbor cooperate, agent i (agent k) gives an equal probability to the event that any agent $j \in \mathcal{N}^{\mathcal{S}} \setminus i$ (any agent $j \in \mathcal{N}^{\mathcal{S}} \setminus k$) was the first to deviate.

Let $\mathcal{N}^{\mathcal{S}} \setminus ik$ be of size c and the subnetwork $\{i, i+1, ..., k-1, k, i\}$ be of size m. Then for the beliefs given, information structure (**I2**), and $l^{i,k}$ and $l^{k,i}$ low $\mathcal{N}^{\mathcal{S}}$ is sustainable iff

$$g^{i,i+1} + \delta^{m-2}\left(g^{i,k} + \delta^{c-m} g^{i,i-1}\right) \geq 0$$

$$g^{k,k+1} + \delta^{c-m}\left(g^{k,i} + \delta^{m-2} g^{k,k-1}\right) \geq 0$$

$$g^{j,j+1} + \delta^{m-2} g^{j,j-1} \geq 0 \quad \forall j \in \{i+1, ..., k-1\}$$

$$g^{j,j+1} + \delta^{c-m} g^{j,j-1} \geq 0 \quad \forall j \in \{k+1, ..., i-1\}$$

A.6 Sustainability conditions for agent i in section 1.4, information regime (I3)

Refer to figure 1.12. We give the conditions exemplary for agent i.

1. $\left(IC_i^{CI}\right)$ During a cooperation phase, it must be profitable for i to play $C^{i,i+1}, C^{i,k}, C^{i,i-1}$ at any time, which yields $c^{i,i+1}$, $c^{i,k}$, and $c^{i,i-1}$ in each period, instead of choosing his best deviation ("static" best reply), which would be to play $D^{i,i+1}$ in $t=0$, $D^{i,k}$ in $t=\theta(m,\nu)$, and $D^{i,i-1}$ in $t=\theta(c,\nu)$ and then to face a T_i- period punishment during which he has to endure payoffs of only $l^{i,i+1}$, $l^{i,k}$, and $l^{i,i-1}$. Such a deviation is not profitable iff

$$IC_i^{CI} \equiv \left(c^{i,i+1}-w^{i,i+1}\right)+\sum_{t=1}^{T_i}\delta^t\left(c^{i,i+1}-l^{i,i+1}\right) + \delta^{\theta(m,\nu)}\left(c^{i,k}-w^{i,k}\right)+\sum_{t=\theta(m,\nu)+1}^{\theta(m,\nu)+T_i}\delta^t\left(c^{i,k}-l^{i,k}\right) + \delta^{\theta(c,\nu)}\left(c^{i,i-1}-w^{i,i-1}\right)+\sum_{t=\theta(c,\nu)+1}^{\theta(c,\nu)+T_i}\delta^t\left(c^{i,i-1}-l^{i,i-1}\right)\geq 0.$$

2. $\left(IC_i^{CII}\right)$ Suppose that agent $i-1$ deviated in $t=-1$. Agent i has to have an incentive to pass on this information in $t=0$ to both his neighbors, $i+1$ and k, instead of infecting his neighbors $i+1$ in $t=0$ and k in $t=\theta(m,\nu)$ and then facing the punishment prescribed against himself. Again, we have to distinguish two cases depending on the speed of information transmission.

   (a) If $T_{i-1}-1<\theta(c,\nu)$, then the information that i did not pass on the info, but cheated instead against $i+1$, reaches $i-1$ *after* i and $i-1$ have gone back to cooperation. Therefore,

   $$IC^{CII} = IC^{CI} \qquad \forall\theta(c,v)\geq T_{i-1}-1.$$

   (b) If $T_{i-1}-1\geq\theta(c,v)$, then the information that i did not pass on the info, but cheated instead against $i+1$, reaches $i-1$ *after* i and $i-1$ have gone back to cooperation. That means that i looses punishment profits $w^{i,i-1}$ for a number of periods equal to the difference between $T-1$ and $\theta(c,\nu)$. Therefore,

$$IC_i^{CII} \equiv \left(c^{i,i+1}-w^{i,i+1}\right)+\sum_{t=1}^{T_i}\delta^t\left(c^{i,i+1}-l^{i,i+1}\right) + \delta^{\theta(m,\nu)}\left(c^{i,k}-w^{i,k}\right)+\sum_{t=\theta(m,\nu)+1}^{\theta(m,\nu)+T_i}\delta^t\left(c^{i,k}-l^{i,k}\right) + \sum_{t=\theta(c,\nu)+1}^{T_{i-1}-1}\delta^t\left(w^{i,i-1}-l^{i,i-1}\right)+\sum_{t=T_{i-1}}^{\theta(c,\nu)+T_i}\delta^t\left(c^{i,i-1}-l^{i,i-1}\right)\geq 0 \qquad \forall\theta(c,v)<T_{i-1}-1.$$

Again, we see that

$$\left(IC^{I}-IC^{II}\right)=\begin{cases}\sum_{t=\theta(c,\nu)}^{T_{i-1}-1}\delta^{t}\left(c^{i,i-1}-w^{i,i-1}\right)<0 & \forall\theta\left(c,v\right)\geq T_{i-1}-1\\ 0 & \forall\theta\left(c,v\right)<T_{i-1}-1\end{cases}.$$

Thus, $\left(IC^{I}\right)$ holds implies that $\left(IC^{II}\right)$ holds. Agent i also always has an incentive to punish a deviator immediately, thus, the equivalent to $\left(IC^{P}\right)$ always holds. We have to verify that $\left(IC^{LP}\right)$ holds.

3. (IC^{P}) Suppose agent i receives the message that agent $i+1$ (agent k) deviated in their relation with one of their other neighbors. Then agent i has to have an incentive to punish them. Since $w^{i,j}>c^{i,j}$ together with $\left(IC^{CI}\right)$, this is always the case.

4. $\left(IC^{LP}\right)$ Lastly, agent i has to have an incentive to let his neighbors carry out the punishment on him if he deviated. He can ensure himself a payoff of $d^{i,i+1}$, $d^{i,k}$, and $d^{i,i-1}$ forever by playing $D^{i,i+1}$, $D^{i,k}$, and $D^{i,i-1}$ forever. This limits the punishment available to the community.

$$\begin{aligned}IC_{i}^{LP}\equiv&\sum_{t=0}^{T_{i}-1}\delta^{t}\left(l^{i,i+1}-d^{i,i+1}\right)+\sum_{t=T_{i}}^{\infty}\delta^{t}\left(c^{i,i+1}-d^{i,i+1}\right)\\&+\sum_{t=\theta(m,\nu)+1}^{\theta(m,\nu)+T_{i}}\delta^{t}\left(l^{i,k}-d^{i,k}\right)+\sum_{t=\theta(m,\nu)+T_{i}+1}^{\infty}\delta^{t}\left(c^{i,k}-d^{i,k}\right)\\&+\sum_{t=\theta(c,\nu)+1}^{\theta(c,\nu)+T_{i}}\delta^{t}\left(l^{i,i-1}-d^{i,i-1}\right)+\sum_{t=\theta(c,\nu)+T_{i}+1}^{\infty}\delta^{t}\left(c^{i,i-1}-d^{i,i-1}\right)\geq0\end{aligned}$$

By choosing an appropriate T_i, the punishment can again be made as hard as in the contagious equilibrium (with strategies (**S2**) and the respective beliefs). With $\nu>1$, due to a faster punishment, the discount factor necessary to sustain the network will again be lower than with (**S2**).

A.7 Sustainable networks with creation of new links

In this appendix, we consider the permanent exclusion of an agent from the relational network together with the assumption that the remaining members close the gap in it by establishing a new relation.

As before, we examine exclusion for the three information transmission regimes. We will define exclusion, and then show that only for the network information transmission (**I3**), exclusion equilibria may sustain networks with lower discount factors than the mechanisms examined before. This is true, however, only under quite restrictive conditions.

Definition 1.10 (Punishment by exclusion) *We define punishment by exclusion as the permanent choice of a cheater's neighbors in the relational network to play the non-cooperative action w.r.t. the cheater and their permanent choice to play the cooperative action w.r.t. each other.*

As in section 1.3, we suppose assumption 1.2 ($\deg(i) \leq 2$) holds. Contrary to section 1.3, however, we assume that every two agents of the relational network are able to interact with each other:

Assumption 1.5 $\exists ij \in \mathcal{C}\ \forall i, j \in \mathcal{N}^S$, $i \neq j$.

We assume that it is impossible to find an agent outside the network in order to substitute for an agent in the network. One could think of a specific group of agents exchanging a kind of service for which it is impossible to find providors outside the community:

Assumption 1.6 *If* $\nexists ij \in R$ *for some* j *then* $\nexists ik \in \mathcal{C}$ *for any* $k \in \mathcal{N}^S$.

As in section 1.3.1, we want to explore the possibility to sustain relations through the network which would otherwise be non-sustainable, i.e. we presuppose assumption 1.3. In addition, we assume that agents can have at most one relation with each other, i.e. are not able to exploit direct multimarket contact:

Assumption 1.7 $\forall i, j\ \exists$ *one and only one* $ij \in \mathcal{C}$.

The way we defined punishment by exclusion, defections are deterred by the creation of a new relational network. The consequence is that, if this new relational network is not sustainable, there is no deterrence. Therefore, also a deviation from it – if the same punishment is applied – has to be deterred by the existence of yet another sustainable relational network. Strategies will, thus, feature a recursive element. Given this recursive nature of exclusion and given assumptions 1.3 and 1.7, strategies have to include at some point in time other punishments as well. We therefore define strategies (**S4**) and (**S5**) for the (**I1**) and (**I2**) information transmission structures, respectively, such that the punishment depends on the size of the remaining network, making the assumption that the punishment changes to defection with all neighbors if the residual network is triangular.

Strategy profile (S4)

1. Players $k \in \mathcal{N}^{\mathcal{S}}$ start by playing $C^{kj}\ \forall k \in \mathcal{N}^{\mathcal{S}}, \forall j \in R_k$.
2. Each player k goes on playing $C^{kj}\ \forall j \in R_k$ as long as no deviation by any player in the network is observed.
3. If an agent i played $D^{i,j}$,
   (a) her neighbors $j \in R_i = \{i+1, i-1\}$ will play $D^{j,i}$ forever
   (b) if $size\left(\mathcal{N}^{\mathcal{S}}\right) > 3$, $\mathcal{N}^{\mathcal{S}}_{-i} \equiv \mathcal{N}^{\mathcal{S}} - \{i, i-1; i, i+1\} + \{i-1, i+1\}$, her neighbors $j \in \{i+1, i-1\}$ will form a link $i-1, i+1$ and all agents $k \in \mathcal{N}^{\mathcal{S}}_{-i}$ go to point 1.
   (c) if $size\left(\mathcal{N}^{\mathcal{S}}\right) = 3$, every agent k reverts to $D^{kj}\ \forall j \in R_k$ forever.

Strategy profile (S5)

1. Every agent $k \in \mathcal{N}^S$ starts with $C^{k,j}$ with all neighbors k and transmits info on history as well as received info.
2. ...goes on with $C^{i,j}$ as long as he observes $C^{k,j}$ and he does not observe $C^{i,k}$ with i being not a neighbor
3. If $size\left(\mathcal{N}_{-j}^S\right) \geq 3$, and
   (a) if k observes $D^{j,k}$ without having played $D^{k,\cdot}$ before, he will
      i. play $D^{k,j}$ forever
      ii. play $C^{k,i}$ w.r.t. j's other neighbor i
   (b) if an agent i not being a neighbor of k observes $C^{k,i}$, he will
      i. play $D^{i,j}$ with $j \in R_k$ forever
      ii. play $C^{i,k}$ starting from the next period
   (c) all agents $k \in N_{-j}^S$ go to point 1
4. If $size\left(\mathcal{N}^S\right) = 3$ and if k observes $D^{j,k}$, or if k played $D^{k,j}$ before, he plays $D^{k,j}$ $\forall j \in R_k$ forever after.

Note again that a closure of the relational network – after excluding a defector – by agents who formerly did not share a relation requires that there are $ij \in \mathcal{C}$ with $ij \notin R$. Furthermore, there will be additional conditions to fulfill for these strategies to be an equilibrium.

Proposition 1.8 *Suppose assumptions 1.2–1.3 and 1.5–1.7.*

1. *Assume the perfect information transmission regime* (**I1**). *Let* $\widehat{\delta} \equiv \left\{\delta |\, g^{i,i-1} + g^{i,i+1} = 0\right\}$. *Let* $\widehat{\widehat{\delta}}$ *be the minimum discount factor necessary to sustain a network with* (**S4**)*under* (**I1**). *Then*
   (a) $\widehat{\delta} = \widehat{\widehat{\delta}}$ *provided that all potential relations between network member that are not currently links in the network are mutual for* $\widehat{\delta}$.
   (b) *the network is not strategically stable.*
2. *Assume the no information transmission regime* (**I2**). *Then there is no relational network sustained by exclusion.*
3. *Assume the network information transmission regime* (**I3**). *Let* $\widetilde{\Delta}$ *be the set of* δ *for which – together with an appropriate* T_j $\forall j$ – (**S3**) *constitutes a sustainable non-mutual network with* $g^{i,i+1} \leq 0$ *and* $g^{i,i-1} \geq 0$ *under* (**I3**) *and* $\widetilde{\delta} = \min\left\{\widetilde{\Delta}\right\}$. *Let* $\widetilde{\widetilde{\Delta}}$ *be the set of* δ *for which* (**S5**) *constitutes a sustainable non-mutual network with* $g^{i,i+1} \leq 0$ *and* $g^{i,i-1} \geq 0$ *under* (**I3**) *and* $\widetilde{\widetilde{\delta}} = \min\left\{\widetilde{\widetilde{\Delta}}\right\}$. *Then*

(a) *if $l^{i,i-2}$ is not too small, if ν is not too high, and if all potential relations between members of the network, which are not links in the network, are* mutual *for $\widetilde{\widetilde{\delta}}$, $\widetilde{\widetilde{\delta}} < \widetilde{\delta}$.*

(b) *the network is not strategically stable.*

(c) *the strategy profile* (**S5**) *is the optimal cooperative strategy profile in the class of strategy profiles with exclusion.*

Proof. *Part 1.:* We first give the conditions for sustainability of the network assuming optimal deviations given the punishment.

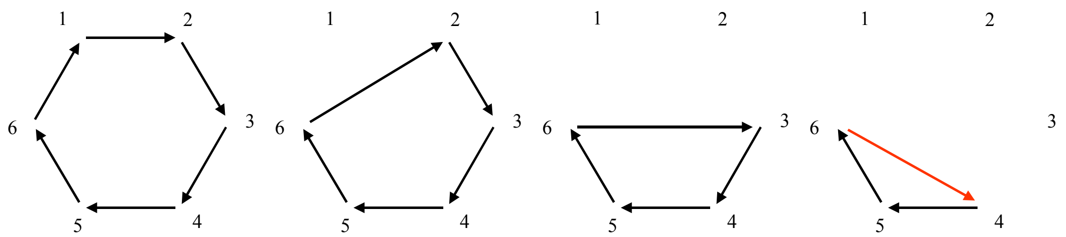
i. For any $i \in \mathcal{N}^{\mathcal{S}}$ we must have
$$g^{i,i+1} + g^{i,i-1} \geq 0.$$

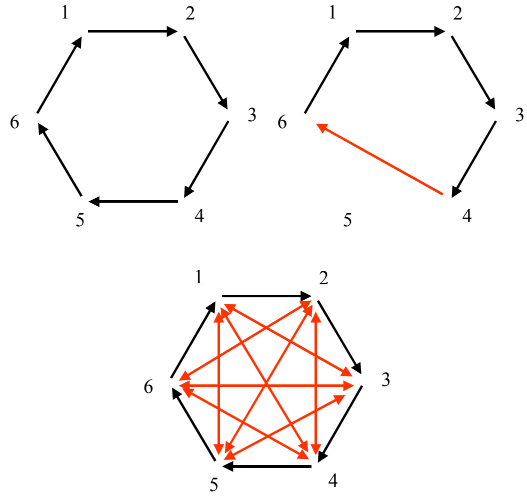
ii. For $i-1$ and $i+1$, we need
$$\begin{aligned} g^{i-1,i+1} + g^{i-1,i-2} &\geq 0 \\ g^{i+1,i+2} + g^{1+1,i-1} &\geq 0. \end{aligned}$$

iii. Points i. and ii. must hold for any member of any network $\mathcal{N}^{\mathcal{S}}_{-i}$ and any member of any reduced network thereof except the triangular networks. In the triangular one, only i. has to hold.

Part 1. (a): (**S1**) punishes a deviation immediately with the strongest possible punishment, i.e. the one that gives the cheater his minimax payoff forever. It is, therefore, not possible to decrease the delay until punishment takes place and the strengh of the punishment.

Condition ii. together with iii. imply that not only $g^{i+1,i-1} > 0$, but also $g^{i+2,i-1} > 0$, $g^{i+3,i-1} > 0$, and so on. To see this, consider the following figures. The first row represents the consequences of the deterrance of a deviation of agent 1, then 2, and then 3. We see, that the relation of 4 with 6 has to be non-deficient for 4. The second row represents the consequences of a deterrance of a deviation of agent 4. We see now that the relation of 4 with 6 has to be non-deficient for 6. The consequence is that all agents inside the circle have to potentially have mutual relations. Thus, if they are for $\widehat{\delta}$, then $\widehat{\delta} = \widehat{\widehat{\delta}}$.





Part 1 (b).: If all $ij \notin R$ have to be mutual, this has consequences for the strategic stability of the equilibrium as shown in proposition 1.4.

Part 2.: In order to be able to link to the neighbor of the neighbor who cheated on a player, this player has to know who is the neighbor of that cheater. This requires information on the history of his neighbor's play, which he does not have under (**I2**).

Part 3.: Again, we first give the conditions for sustainability of the network. As before, we assume optimal deviations given the punishment.

i. No agent has to have an incentive to deviate from the cooperative action:

$$g^{i,i+1} + \delta g^{i,i-1} \geq 0.$$

ii. An agent i who has been cheated on by an agent $i-1$ has to have an incentive to play $C^{i,i+1}$ and $C^{i,i-2}$:

$$g^{i,i+1} + (1-\delta)\, l^{i,i-2} + \delta c^{i,i-2} - d^{i,i-2} \geq 0,$$

iii. and to go on playing that in the next period:

$$g^{i,i+1} + \delta g^{i,i-2} \geq 0.$$

iv. Any agent $i-2$ who observes $C^{i,i-2}$ from a member of the network who is not his neighbor has to have an incentive to play $C^{i-2,i}$:

$$g^{i-2,i} + \delta g^{i-2,i-3} \geq 0.$$

v. Points i. through iv. must hold for any member of $\mathcal{N}^{\mathcal{S}}$ and of any network $\mathcal{N}^{\mathcal{S}}_{-i}$ and any member of any reduced network thereof except the triangular networks. In the triangular ones, only i. has to hold.

Part 3. (a): In this equilibrium, permanent Nash reversion of $i+1$ arrives immediately. Permanent Nash reversion of $i-1$ arrives after one period. With strategy profile (**S3**), a punishment of $i+1$ as strong as permanent Nash reversion arrives immediately. The punishment of $i+1$ as strong as permanent Nash reversion arrives after $\theta(c,\nu)$ periods. Since $\theta(c,\nu)$ is decreasing in ν, for low ν condition i. is less strict than the equivalent condition for (**S3**).

Conditions iii. through v. imply, similarily to conditions ii. and iii. from Part 1. of this proposition, that all potential relations between members of the network, which are not links in the network, have to be *mutual*.

Condition ii. is only less stringent than condition i. if $l^{i,i-2}$ is not too low.

Part 3 (b).: As conditions iii. through v. imply that all potential relations between members of the network, which are not links in the network, have to be *mutual*, it is possible to deviate suboptimally in a network $\mathcal{N}_{-i}^{\mathcal{S}}$ which makes a punishment of an agent in that mutual relation by the other agent in that mutual relation a dominated action.

Part 3 (c).: As the creation of the links between neighbors is immediate, punishment sets in as soon as possible. This punishment involves minimax strategies forever and is thus as hard as possible. *Q.E.D.* ■

Let us briefly comment on these results. First, with exclusion punishments, it is only possible to improve over the strategies defined before for the Network Information Transmission Case (**I3**). For (**I1**), these strategies do just as well, and for (**I2**), there is no punishment by exclusion for lack of information whom to link to. Second, as a deviation of any member of the network has to be deterred by a sustainable other network, this results in certain conditions on the interaction structure. These *certain conditions* are quite restrictive: all potential relations between members of the network, which are not links in the network, have to be mutual. This causes the network to be not strategically stable, and thus (**S4**) and (**S5**), respectively, unlikely to be chosen as equilibrium strategies. In addition, for the Network Information Transmission Regime (**I3**) the loss from playing C if your partner plays D has to be not too low, and the speed of information transmission has to be not too high. This condition on $l^{\cdot}$ would be relaxed if one allowed for the potential relations, which would have to be mutual, to exist in the first place, i.e. if one was to give up the "time constraint" $\deg(i) \leq 2$. Third, with (**S4**), as with restitution punishments, agents enjoy the advantage of avoiding the breakdown of the network during a punishment phase. Thus, there is a utility gain compared with (**S1**). However, compared to restitution punishments (similar to (**S3**)), the neighbors of a cheater lose utility – a payback of the damages is not done. Furthermore, if the network fulfills any other function, such that the size of the network matters for overall welfare, there is a loss in welfare compared to restitution punishments due to the exclusion of the cheater.

Part II

Agency Problems and Joint R&D

Chapter 2

Moral hazard and the decision to do joint research

2.1 Introduction

A number[1] of research and development intensive industries, such as the software, biotechnology, the automobile, the electronics industry and many others have seen a strong increase in joint research and development projects. These joint projects may take the form for example of research joint ventures (RJVs), alliances, or bilateral agreements. The value created in these joint projects is often considerable and of high social interest. For this reason, there have been public programs set up by several governments and supranational authorities to support them. The EU for example does so within the "*European Framework Programs*". Out of the 363 million euro spent on "*Promotion of Innovation and Encouragement of SME*[2] *Participation in R&D*" within the 5th edition of these "*European Framework Programs*" from 1998 until 2000, the EU devoted 200 million euro to "*Joint innovation/SME activities*". The relevance of this phenomenon explains the interest in studying the formation mechanisms, to analyze the rationale, possible failures, duration, and not least the impact on social welfare of joint projects.

Our leading example will be the pharmaceutical industry. Joint projects in this industry may cover various stages of the innovation process, ranging from basic research, such as inventing new chemical entities (NCE) up to the development of new final products, such as drugs, including performing the necessary tests to get them approved by regulatory authorities (such as the *Food and Drug Administration,* FDA, in the US)[3]. In this industry, research projects – joint and stand-alone – are typically carried out by research units[4]. The choice of whether to form an RJV, i.e. the choice of the organizational form to carry out research, on the other hand, is usually taken by the owners of the company and not by the research units. This implies an

[1] This chapter is based on the paper "Moral hazard and the internal organization of joint research", written jointly with Simona Fabrizi and circulated as UPV FAEII Working Paper 2003-10, quoted in this thesis as Fabrizi and Lippert (2005b).

[2] Small and medium sized enterprises.

[3] See Pammolli (1996) for a discussion on R&D in the pharmaceutical industry.

[4] In our paper, we will refer to these research units as managers who carry out the research for the owners (or entrepreneurs).

agency problem, the consequence of which for the formation of joint research agreements – to our best knowledge – has not been studied to date. This paper is an attempt to study the consequences from these agency problems for the formation of RJVs.

Most of the recent literature that studies the underlying incentives to enter into joint projects as well as the conditions for their stability, concentrates on economic agents taking these decisions as if they were also responsible for carrying out the research. There is usually no separation between ownership and control. Therefore, possible conflicts between who takes the decision on whether to conduct a joint research and who might affect the outcome of the research are not accounted for[5].

Our model departs from the traditional owner-manager view, by explicitly considering the impact of principal-agent relations on formation and internal organization of RJVs by allowing owners to decide whether to conduct a project alone or jointly, under both, the owner-manager and the principal-agent assumptions. Research units will be responsible of conducting the projects: their effort – alternatively observable or unobservable – determines in our model the probability of success of the projects. A joint project can be conducted by only one owner's research unit or (in an extension) both owners' research units (agents) together. In the latter case, our analysis will allow for these units to be substitutes to a varying degree. The model assesses the impact of agency problems on the owners' decisions to carry out a stand-alone or a joint project and whether to use possible synergies between research units.

To our best knowledge, there is one study of joint research that takes an explicit agency approach, Pastor and Sandonís (2002). However, the authors do not consider incentives to enter joint research projects: comparing cross-licensing agreements with research joint ventures 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. The underlying assumption in their work is that each research unit's success is essential, both for the cross-licensing and for the research joint venture cases. By contrast, allowing for several degrees of substitution between research units (managers) involved in the joint project in order to reach a success, we are able to characterize the decisions whether to join and how to do so as a function of these different degrees of substitution and the value possible to create in the research projects.

By accounting for possible substitutability, duplication, or complementarity of the agents' efforts in the functional form of the probability of success, we also depart from the team production literature[6] where the success of a task assigned to each agent is fundamental for the success of a given project. In our model, interactions between agents allow for potential synergies. However, results will show that synergies are not necessarily exploited in equilibrium. This

[5]For example, Espinosa and Macho-Stadler (2003) consider the endogenous formation of partnerships by firms in a double sided moral hazard context, i.e. each firm has to decide its level of production with which to contribute to the overall output of the partnership. Each owner has an incentive to free-ride on other owners by deciding how much (unobservable) effort to put into the overall production of the partnership. However, an owner-managers view on the problem is adopted, i.e. each owner is at the same time his own agent.

[6]See, for example, Holmström (1982) or Itoh (1991).

is a consequence of a trade-off between the potential enhanced probability of success of the joint project for a given effort and the increased cost of providing the optimal incentive compatible contracts to be offered to both research units.

Another aspect of our model consists of endogenizing the cost associated with conducting a research project. An often proposed argument to explain the forming a partnership is the ability that share fixed costs that would have to be incurred by each party separately otherwise. These fixed costs savings encompass research costs, savings on assets such as avoiding to replicate laboratories, as it is argued in Harrigan (1986). The relative benefits of enjoying a success, either alone or jointly, provides the rationale for private decisions whether to run a joint or a stand-alone project. In our model the endogenized cost of conducting a research project can be considered to play an equivalent role as, in standard models, the fixed costs may play.

In order to concentrate on agency problems coming from moral hazard we abstract from several potentially interesting aspects such as from the fear of disclosing private know-how within a joint project, from market power considerations, and from the bargaining process underlying the determination of the sharing rule for the joint projects' benefits and costs.

The potential trade-off between staying alone and joining when there is the fear of disclosing each firm's private know-how within a joint project has been considered by Pérez-Castrillo and Sandonís (1996).

The abstraction from market power considerations (in the sense that the overall potential value of the market that projects can target does not depend on whether they join or not) suits situations where a success pays off a well defined value, which can be appropriated, totally or partially, by the author of this success. Examples are R&D projects leading to the patenting of the invention/innovation, or to the approval of a certain drug targeting a potential market. While the overall value of the market is kept fixed, we distinguish in our analysis between *independent* and *common market* projects. This separation is meant to capture both the cases where a stand-alone project is not facing a rival, and the one where it does. Having conducted a successful stand-alone project will pay off a fixed value independent of whether the other entrepreneur succeeded if this projects targeted independent markets. Taking our leading example of the pharmaceutical industry, one could think of a market which is segmented due to regional regulatory constraints that do not allow an innovator to use a patent in another country than the one where the innovation was obtained because it needs to be approved in either segment and approval in one is not a guarantee for approval in the other segment. If the projects aim at a common market on the other hand, a success would have to be shared with the other entrepreneur if his project succeeds as well.

Finally, concerning the bargaining, we assume an exogenous equal sharing of costs and benefits of the joint projects. This simplification is made in order to focus on the impact of agency problems on decision whether to join and how to join between equally important partners in the joint project.

Results will show that the decision to pursue joint projects is always taken between firms facing independent markets, no matter whether research units are affected by moral hazard behavior or not. However, for both, observable and unobservable efforts, under the common market assumption, firms start preferring staying alone as long as the value of the overall market to be targeted is not high enough, and/or if the degree of duplication is not too high. The *more competitive* the environment, the more likely the firms pursue a *stand-alone* project. When entrepreneurs face agency problems, that is, when it is more costly to implement a certain probability of success, the value of the overall market to be targeted has to be higher than under observable efforts for entrepreneurs to pursue a joint project. The additional agency costs may induce the parties to stay alone even if they would otherwise have chosen to conduct the project jointly either with one or both units. Our results show that moral hazard, and thus, an increase of the component that inflates the cost of producing an innovation, *is not* a factor that drives firms to share it necessarily, i.e. to share a "fixed" cost, as it is usually considered. Given that the wage to be paid to the research management can be adjusted implementing the optimal wage contract associated with each case, firms decide to stay alone in some situations where they would have shared costs without moral hazard. In particular, the occurrence of joint projects where both units are kept is decreased systematically as higher complementarities are needed to sustain this configuration against either stand-alone or a joint project with one unit.

The analysis of the impacts of privately taken decisions over the social welfare, will show that conflicts arise under the moral hazard assumption where joint projects keeping both research units would be preferred socially, but privately firms prefer either to join keeping only one unit or not to join at all. Too few socially desirable joint projects exploiting synergies are observed.

The work is organized as follows. In section 2 we describe the setup of the model. Section 3 is devoted to the analysis of the equilibrium organization arising if only one entrepreneurs' research unit is kept. We will compare the results for the situation without moral hazard with the results in a principal agents framework. In section 4, we allow the entrepreneurs to keep both research organizations, making it possible to enjoy synergies. We will perform the same comparisons as in section 3. Section 5 concludes and discusses possible extensions of the model.

2.2 The Model

In this section, we describe the stand-alone configuration for both, projects targeting *independent markets* - or market segments - (I) and those targeting a *common market* (C), as well as the joint research configuration. We will describe the characteristics of the projects, the utility of the agents' conducting them, as well as the probability of success attached to the projects.

Entrepreneurs' projects Let two entrepreneurs pursue a project, which potentially leads to an innovation that targets a market, the overall value of which is Δ. The projects can be pursued by each entrepreneur as stand-alone projects, denoted by (S), or in a joint venture together with the other entrepreneur as a joint project, denoted by (J).

The market is assumed to be exogenously segmented into two parts, each of which is of equal value $\frac{\Delta}{2}$. In the stand-alone situation, we distinguish two cases regarding the accesibility of the two segments by the entrepreneurs. They may be able to access only one segment of the market, distinct from the segment accessed by the other; in this case we will refer to stand-alone projects targeting independent markets or market segments[7], denoted by $(S|\,I)$. They may on the other hand be able to access both segments of the market; in this case we will refer to stand-alone projects targeting a common market[8], denoted by $(S|\,C)$. A stand-alone project targeting independent markets, is assumed to pay off $\frac{\Delta}{2}$ to each entrepreneur in the case of his success[9]. A stand-alone project targeting a common market, pays off Δ to a successful entrepreneur if he is the only one succeeding, or $\frac{\Delta}{2}$ to each of them if both are succeeding[10]. Whenever entrepreneurs decide to conduct a joint project (J), its success is assumed to lead to a success to be used in both segments of the market[11], paying off Δ. In case of failure, any project pays off zero.

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 each entrepreneur employs initially one agent (research unit, division, etc.). If the entrepreneurs combine their assets for a joint project, we assume that they keep one of their two research units or agents[12]. This assumption will be relaxed in an extension to this model in order to analyze the exploitation of potential synergies.

Any time the project is conducted jointly, we further assume that a new entity is founded. We refer to this entity as the *joint entity*. We assume that entrepreneurs share the costs and the benefits of conducting the joint project equally.

Summarizing the assumptions made, we can write the different payoffs $R(\cdot)$ associated with the stand-alone situation:

$$R_i\,(S|\,I) = \begin{cases} \frac{\triangle}{2} & \textit{with } \Pr = p_i\,(S) \\ 0 & \textit{with } \Pr = 1 - p_i\,(S)\,, \end{cases}$$

$$R_i\,(S|\,C) = \begin{cases} \triangle & \textit{with } \Pr = p_i\,(S)\,(1 - p_{-i}\,(S)) \\ \frac{\Delta}{2} & \textit{with } \Pr = p_i\,(S)\,p_{-i}\,(S) \\ 0 & \textit{with } \Pr = 1 - p_i\,(S)\,, \end{cases}$$

[7] An example for projects targeting independent markets, i.e. where entrepreneurs may be initially present in only one segment, is the case where only the "home" entrepreneur knows the regulatory framework of its country, which is a necessary condition to get an approval for the innovation there. The "foreign" entrepreneur does not know the regulatory framework of the for him "foreign" country and therefore, an innovation for that segment is valueless for him.

[8] An example for projects targeting a common market independent markets, is the case where both entrepreneurs have access to - or can develop for - both segments: this is possible either because they were initially present in both segments; or because each of them was initially present only in one segment, but they decide to conduct a joint project – and thus share the necessary knowledge for obtaining approval in their respective segments.

[9] This comes from the assumption of equally sized segments.

[10] The assumption of sharing the value in case both entrepreneurs succeed is taken for simplification: It can be shown that our results do not change qualitatively if we assume that a success of both entrepreneurs in the common markets situation destroys value, i.e. if the value to be appropriated by each entrepreneur were smaller than $\frac{\Delta}{2}$.

[11] The underlying assumption for this is that a project success in one segment can be easily translated into a success in the other segment: e.g. given the now common knowledge about the regulatory frameworks of each respective separate market, joining firms can tailor the project such that its scientific success ensures it to be used in both segments.

[12] We are implicitly assuming that each agent has embedded the scientific knowledge/capability to conduct the project alone.

where $p_i(S)$ and $p_{-i}(S)$ are the probabilities of success of firms i and $-i$, respectively. Similarly, we can write the payoffs associated with a joint project:

$$R(J) = \begin{cases} \triangle & \textit{with } \Pr = p(J) \\ 0 & \textit{with } \Pr = 1 - p(J), \end{cases}$$

where $p(J)$ is the probability of success of the joint project.

Agents Agents affect the probability of success of the project they conduct through their effort. We consider both, the cases where the agents exert an observable, contractable effort e_i and where they exert a non observable, therefore not-contractable, 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, however, agents are protected by limited liability. We assume the agents' utility to be additively separable between effort and money,

$$U_i = u_i(t_i) - c_i(e_i) = t_i - \frac{1}{2}e_i^2.$$

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:

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

In the joint case (J) we will drop the index i while referring to the transfer an agent receives from the joint entity.

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 as[13]:

$$\begin{aligned} p_i(S) &= e_i \\ p(J) &= e \end{aligned}$$

The underlying assumption is that an agent is as productive carrying out a joint project as he is carrying out a stand-alone project. This assumption may be questionable for the situation in which stand-alone projects target independent markets, as the common project has twice the

[13] We will derive the optimal contracts not taking into account any restrictions on the parameters Δ and ε such that the probability of success is well defined, e.g. smaller than 1. If the unrestricted solution specified a probability level greater than one, entrepreneurs would not be able to increase the probability of success over the value of one by paying a higher transfer. They would, therefore, optimally specify an implemented effort and a transfer such that the probability is exactly equal to one. In the following analysis, we provide the unrestricted solutions for the optimally implemented efforts and transfers, however, it is always possible to verify that the results are unaltered by allowing for the restriction on the exogenous parameters to bind.

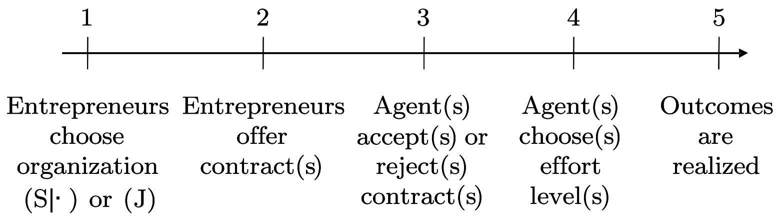


Figure 2.1: Timing

scale of the stand-alone project. We keep it in order to focus on another trade-off which would be unaffected by changing this assumption.

Timing Given that the target of stand-alone projects (independent markets or a common market) is exogenously taken ex ante, the actions of the different players can be summarized as follows:

1. Entrepreneurs simultaneously decide whether they want to invest in a joint or in a stand-alone project.
2. Entrepreneurs offer contract(s) to the agent(s) involved in the project(s).
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.

2.3 Equilibrium organization

2.3.1 Observable efforts

The goal of this section is to provide a benchmark analysis of the optimal organizations either when the agents' efforts are observable and therefore it is possible to make the transfer contingent to the exerted effort[14].

This benchmark will be compared to the parallel analysis when the efforts are not observable[15]. Comparisons will allow us to assess the impact of the separation between ownership and control – entrepreneurs have the power to decide whether to join, but agents affect the real outcome of that decision – on the privately chosen configuration and on the social welfare.

[14] Or, seeing it differently, when we have an owner-manager, i.e. an entrepreneur who could provide that effort alone, as if the he was also the manager. An example could be the case of a biotech firm funded by the biotechnician that is conducting the research himself. In this case of the analysis, we will adhere to the formulation that corresponds to the entrepreneur(s) having full control over their agent'(s) efforts. However, doing so, the alternative interpretation of the owner-manager case just given remains valid.

[15] This may happen any time the entrepreneur is not able to conduct the project alone, but needs the agent(s) and he is not able to judge whether the agent(s) behaved or not, but he can simply observe the result of his actions, either a success or a failure.

Stand-alone (S)

In this section we consider the case in which each entrepreneur conducts the project alone, employing one agent each. Here only the effort of this agent determines the probability of success of the project[16], i.e. $p_i(S) = e_i$. However, as outlined in the model setup, in our analysis, a success allows to access either one or both segments of a market depending on whether the project targeted a independent or a common market. For this reason, in the following analysis we distinguish between these two possible projects.

Independent Markets (I) We first assume that the projects target independent market segments. This means that, when the entrepreneur is successful, he enjoys $\frac{\Delta}{2}$, regardless of the success or failure of the other entrepreneur. Each entrepreneur pays out a transfer that lets the agent break even.

Therefore, each entrepreneur solves the following maximization problem:

$$\max_{e_i} \Pi_i \left(S \middle| I \right) = \max_{e_i} \left[e_i \frac{\Delta}{2} - t_i \right]$$

$$s.t. \qquad t_i - \frac{1}{2} e_i^2 \geq 0 \qquad (IR)$$

$$t_i \geq 0. \qquad (LL)$$

It is straightforward to show that the solution to this problem gives:

$$\begin{aligned} e_i^o \left(S \middle| I \right) &= e^o \left(S \middle| I \right) = p^o \left(S \middle| I \right) = \frac{\Delta}{2} \quad \text{and} \\ t_i^o \left(S \middle| I \right) &= t^o \left(S \middle| I \right) = \frac{1}{2} \left(\frac{\Delta}{2} \right)^2 , \end{aligned}$$

where the superscript o denotes the profit-maximizing solution in the *observable* efforts case. The implemented contract leads for each entrepreneur to an expected profit of:

$$\Pi^o \left(S \middle| I \right) = \frac{1}{2} \left(\frac{\Delta}{2} \right)^2 .$$

Common Market (C) We now assume that entrepreneurs target a common market. According to our assumptions, if only one entrepreneur succeeds, he will be able to appropriate the whole value of the market, Δ; however, if both entrepreneurs succeed, they will have to share this value equally, appropriating each $\frac{\Delta}{2}$. Again, each entrepreneur pays out a transfer that lets the agent break even.

Each entrepreneur, thus, solves the following maximization problem:

$$\max_{e_i} \Pi_i \left(S \middle| C \right) = \max_{e_i} \left[e_i \left(\left(1 - e_{-i} \right) \Delta + e_{-i} \frac{\Delta}{2} \right) - t_i \right]$$

$$s.t. \qquad t_i - \frac{1}{2} e_i^2 \geq 0 \qquad (IR)$$

$$t_i \geq 0, \qquad (LL)$$

[16] Alternatively, the entrepreneur conducts the project alone facing the same disutility of effort as the agent would.

the solution to which gives the equilibrium efforts and transfers:

$$\begin{aligned} e_i^o\left(S|\,C\right) &= e^o\left(S|\,C\right) = p^o\left(S|\,C\right) = \frac{2\Delta}{\Delta+2} \quad \text{and} \\ t_i^o\left(S|\,C\right) &= t^o\left(S|\,C\right) = \frac{1}{2}\left(\frac{2\Delta}{\Delta+2}\right)^2, \end{aligned}$$

where, again, the superscript o denotes the profit-maximizing solution in the *observable* efforts case. The expected net profit for each entrepreneur is:

$$\Pi^o\left(S|\,C\right) = \frac{1}{2}\left(\frac{2\Delta}{\Delta+2}\right)^2.$$

Joint research (J)

In this subsection, we assume that entrepreneurs decide to pursue the research project jointly. In this world, the project is targeting the whole (common) market. When two entrepreneurs invest into a joint project, as assumed, they form a new entity and let one agent run the project alone. We also assumed that the joint entity offers a transfer to their agent, and that entrepreneurs share equally the cost of the transfer, as well as the payoff of the project.

In the (J) case, the probability of success of the joint project is $p(J1) = e$. As assumed, in case of success, both segments of the market are covered, giving rise to a value of Δ.

Therefore, the joint entity's maximization problem is

$$\begin{aligned} &\max_e \Pi\left(J1\right) = \max_e \left[e\Delta - t\right] \\ &s.t. \qquad t - \frac{1}{2}e^2 \geq 0 \qquad (IR) \\ &\qquad\qquad t \geq 0. \qquad (LL) \end{aligned}$$

As in the previous subsection we can derive the following solution to this problem

$$\begin{aligned} e^o\left(J1\right) &= p^o\left(J1\right) = \Delta, \\ t^o\left(J1\right) &= \frac{\Delta^2}{2}, \end{aligned}$$

and each entrepreneur/principal expects a profit equal to

$$\Pi^o\left(J1\right) = \frac{1}{2}\left(\frac{\Delta^2}{2}\right).$$

Optimal organizational form for observable efforts

We are now able to draw some conclusions about the chosen organizations when efforts are observable. The following table summarizes the results found above:

Configurations	$(S\|\,I)$	$(S\|\,C)$	(J)
$\Pi^o\left(\cdot\right)$	$\frac{1}{2}\left(\frac{\Delta}{2}\right)^2$	$\frac{1}{2}\left(\frac{2\Delta}{\Delta+2}\right)^2$	$\left(\frac{\Delta}{2}\right)^2$
$p^o\left(\cdot\right)$	$\frac{\Delta}{2}$	$\frac{2\Delta}{\Delta+2}$	Δ

The comparison between the different levels of profits (and social welfare) lead to the following proposition.

Proposition 2.1 *Under the owner-manager assumption (alternatively: for observable efforts),*

(i) in the independent markets case, entrepreneurs always invest jointly,

(ii) in the common markets case, entrepreneurs invest jointly and keep one agent if

$$\Delta > 2\sqrt{2} - 2,$$

and invest in a stand-alone project otherwise.

When entrepreneurs are facing an independent markets world, they always choose to pursue a joint project. The reason is that the choice of a joint as opposed to that of a stand-alone project only affects the expected cost of implementing *a given* probability of success p: this cost is shared in (J) whereas it is not shared in $(S|\,I)$. It does *not* affect the expected payoffs of implementing *a given* probability of success p an entrepreneur faces: it is always $p\frac{\Delta}{2}$.

In contrast, when entrepreneurs face a common market, entrepreneurs choose a joint project only if the value of the market is high enough. To give an intuition about how firms take their decision between staying alone or pursuing a joint project in the common markets case, we need to distinguish between two effects, one coming from the differences in expected payoffs and another from differences in expected costs, associated with one configuration instead of the other.

First, the expected payoffs associated with $(S|\,C)$ and $(J1)$ for *the same given* probability of success, p, are respectively $p\,(1-p)\,\Delta + p^2\frac{\Delta}{2} = p\,(2-p)\,\frac{\Delta}{2}$ and $p\frac{\Delta}{2}$. In other words, the expected payoff for this probability is higher in $(S|\,C)$ than in $(J1)$. Second, for *the same given* probability of success, p, the costs in $(S|\,C)$ and $(J1)$ are respectively $\frac{p^2}{2}$ and $\frac{1}{2}\frac{p^2}{2}$. This means that it is more costly in $(S|\,C)$ than in $(J1)$ to implement *the same given* probability of success, p. The enhanced payoffs that choosing $(S|\,C)$ against $(J1)$ ensures, conflict with the higher costs associated to this choice. Enhanced payoffs and cost savings go in opposite directions, and which of them outweighs the other depends on the level of a given implemented probability.

When examining the *optimally* implemented probabilities of success and, thus, the expected payoffs (before transfers) as a function of Δ, it is possible to note several points. First, the optimal implemented probabilities associated with (J) and $(S|\,C)$ are *not the same*: for any Δ, in $(J1)$ they are systematically higher than in $(S|\,C)$. Second, the probability of success in (J) is a linear increasing function in Δ, making the expected payoffs a quadratic function in Δ. The probability of success in $(S|\,C)$ on the other hand, is a *concave* increasing function in Δ. This reflects that with an increasing probability of success of the single project the competing project also succeeds more often and that therefore the probability that one entrepreneur enjoys a success alone decreases. For lower Δ values, success alone is more likely and outweighing the cost disadvantage, makes stand-alone the preferres option. For higher Δ values, success of both projects is more likely and therefore the cost disadvantage becomes more important and the joint project is chosen.

Note that, in sections 2.3.1 and 2.3.1, we derived the optimal contracts not taking into account any restrictions on the parameter Δ such that the associated probabilities of success are well defined, e.g. smaller than 1. For example, for $\Delta = 2$, the unrestricted solution for the stand-alone cases specifies an effort level $e_i^o\left(S|\cdot\right) = 1$ and, thus, implements a probability of success of $p_i^o\left(S|\cdot\right) = 1$. For $\Delta > 2$, the unrestricted solution would specify a probability of success greater than one. Similarly, for the (J) organization, the unrestricted solutions would specify a probability of success greater than one for $\Delta > 1$. Therefore, we should not be allowed to make comparisons for $\Delta > 1$. However, for $\Delta > 1$ and $\Delta > 2$, respectively, entrepreneurs know that they cannot increase the probability of success by implementing an higher effort, i.e. even by paying higher transfers. Therefore, they restrict themselves to pay a transfer that implements a probability of one for all higher values of Δ. Therefore, for $\Delta > 1$, $e^o\left(J\right) = 1$ and $t^o\left(J\right) = \frac{1}{2}$ and for $\Delta > 2$, $e_i^o\left(S|\cdot\right) = 1$ and $t_i^o\left(S|\cdot\right) = \frac{1}{2}$. The results of our comparisons have been obtained, taking these (restricted) contracts into consideration.

2.3.2 The principal-agent case

In this section we consider the entrepreneurs' decisions with regard to the organizational choice and the optimal contracts under the assumption that agents efforts are not observable. Contracts cannot be made contingent on the level of these efforts, but only on the verifiable success or failure of the project.

Within this context, we replicate the analysis made in the previous section in order to derive the optimal contracts and the internal organization chosen by the entrepreneurs, as functions of Δ in a similar way as we did for the observable efforts case. Results will allow us to discuss the impact of agency problems on the decisions of whether to enter a joint project.

Stand-alone (S)

As before, we distinguish between the independent and common market projects when we derive optimal contracts. Again, if entrepreneurs decide to invest in a stand-alone project, its probability of success is $p_i(S) = e_i$.

Efforts are not observable, so that entrepreneurs have to provide their agents with incentives to let them exert an effort. In this case, agent i gets a positive bonus, b_i, in case of success of the project he conducts and zero otherwise (as discussed in the setup of the model). Given this type of contract, agent i's maximization program is:

$$\max_{e_i} U_i = \max_{e_i}\left[e_i b_i - \frac{1}{2}e_i^2\right],$$

the solution to which gives the incentive compatibility constraint (IC):

$$e_i = b_i. \qquad (IC)$$

Entrepreneurs will take this constraint into account when they decide about the contract to offer to their agents. Notice that, no matter whether the markets are independent or common, the incentive compatibility constraint to be taken into account by the entrepreneurs stays the same.

Independent Markets (I) Each entrepreneur solves for the following problem:

$$\max_{b_i} \Pi_i \left(S | \, I \right) = \max_{b_i} \left[e_i \frac{\Delta}{2} - e_i b_i \right]$$
$$s.t. \quad e_i = b_i \qquad (IC)$$
$$e_i b_i - \frac{1}{2} e_i^2 \geq 0 \qquad (IR)$$

As a solution, the bonus received by either agent is the same, and, given the (IC), corresponds to the implemented probability of success:

$$b_i^u \left(S | \, I \right) = b^u \left(S | \, I \right) = \frac{\Delta}{4} = p^u \left(S | \, I \right).$$

The superscript u denotes the profit-maximizing solution in the *unobservable* efforts case. Note that the induced probability of success is *half* the one that an owner-manager would have chosen. Each entrepreneur's expected profit is:

$$\Pi^u \left(S | \, I \right) = \left(\frac{\Delta}{4} \right)^2.$$

Common Market (C) Each entrepreneur, solves the following maximization problem:

$$\max_{b_i} \Pi_i \left(S | \, C \right) = \max_{b_i} \left[e_i \left(\left(1 - e_{-i} \right) \Delta + e_{-i} \frac{\Delta}{2} \right) - e_i b_i \right]$$
$$s.t. \qquad e_i = b_i \qquad (IC)$$
$$e_i b_i - \frac{1}{2} e_i^2 \geq 0. \qquad (IR)$$

In equilibrium, the implemented efforts and the bonuses chosen are:

$$e_i^u \left(S | \, C \right) = e^u \left(S | \, C \right) = p^u \left(S | \, C \right) = \frac{2\Delta}{\Delta + 4} \quad \text{and}$$
$$b_i^u \left(S | \, C \right) = b^u \left(S | \, C \right) = \frac{2\Delta}{\Delta + 4},$$

where, again, the superscript u denotes the profit-maximizing solution in the *unobservable* efforts case. Note that the implemented probability of success is *more than half* the one chosen under observable efforts. This is due to a strategic effect between the owners. This leads to an expected net profit for each entrepreneur of:

$$\Pi^u \left(S | \, C \right) = \left(\frac{2\Delta}{\Delta + 4} \right)^2.$$

Joint research (J)

We know that, if entrepreneurs decide to invest in a joint-one agent project, its success probability is $p(J) = e$. Again, entrepreneurs face a (IC) constraint that comes from the agent's utility maximization problem corresponding to the one of the stand-alone case above. The incentive compatibility constraint is therefore the same where the index i has been dropped:

$$e = b.$$

Thus, the joint entity solves:

$$\max_b \Pi(J) = \max_b [e\Delta - eb]$$
$$s.t. \quad e = b \qquad (IC)$$
$$eb - \frac{1}{2}e^2 \geq 0, \qquad (IR)$$

which gives the following results:

$$\begin{aligned} b^u(J) &= \frac{\Delta}{2} \text{ and} \\ e^u(J) &= p^u(J) = \frac{\Delta}{2} = \frac{p^o(J)}{2}. \end{aligned}$$

Here the induced probability of effort is *half* the one that an owner-manager would have chosen. Given the equal sharing rule between entrepreneurs after joining forces, the implemented effort and chosen bonus determines a per entrepreneur profit of:

$$E\Pi^u(J) = \frac{1}{2}\left(\frac{\Delta}{2}\right)^2.$$

Optimal organizational form for unobservable efforts

We are now able to draw some conclusions about the privately chosen organizations under the unobservable efforts assumption. Results obtained in the previous sections are summarized in the following table:

Configurations	$(S\|I)$	$(S\|C)$	(J)
$\Pi^u(\cdot)$	$\left(\frac{\Delta}{4}\right)^2$	$\left(\frac{2\Delta}{\Delta+4}\right)^2$	$\frac{1}{2}\left(\frac{\Delta}{2}\right)^2$
$p^u(\cdot)$	$\frac{\Delta}{4}$	$\frac{2\Delta}{\Delta+4}$	$\frac{\Delta}{2}$

A comparison of the different outcomes, leads to the following propositions:

Proposition 2.2 *Under the principal-agents assumption, (alternatively: for unobservable efforts),*

(*i*) *in the independent markets case, entrepreneurs always invest jointly,*

(*ii*) *in the common markets case, entrepreneurs invest jointly if*

$$\Delta > 4\left(\sqrt{2} - 1\right),$$

and invest in a stand-alone project otherwise.

As before, when entrepreneurs are facing a independent markets world, there are only effects on the expected cost side. Even though the magnitude of these costs is changed, due to the incentive compatible contracts to be offered to the agents, their relative difference makes still entrepreneurs prefer to join over staying alone. Therefore, all comments made in the observable efforts case apply here as well.

In a similar way, when entrepreneurs face a common market, the two effects identified in the observable efforts case appear again. If the value of the market is high enough, i.e. $\Delta > 4\left(\sqrt{2}-1\right)$, (J) is preferred to $(S|\,C)$. A similar choice was taken under the observable efforts assumption, but for a lower level of Δ, remember that (J) prevailed over $(S|\,C)$ for $\Delta > 2\left(\sqrt{2}-1\right)$.

Note that, as for the observable efforts case, we derived the optimal contracts not taking into account any restrictions on the parameter Δ such that the associated probabilities of success are well defined, e.g. smaller than 1. As before, the results of the comparisons have been obtained taking into account the contracts for all values of Δ.

When one compares the results obtained in this section with the ones obtained under the observable efforts case, one finds the implications of moral hazard in our model. On the one hand, the value of the market necessary to make the option of joining with one agent preferred over staying alone shift upwards: it is higher under the moral hazard assumption than without moral hazard. Staying alone is now preferred to joining with either one or two agents more often.

Introducing moral hazard changes the cost side of the model: It makes the implementation of *the same given* probability of success, p, in both, $(S|\,C)$ and (J) twice as expensive: the cost of implementing p in $(S|\,C)$ is now $bp = p^2$ and the cost of implementing p in (J) is $\frac{1}{2}bp = \frac{1}{2}p^2$. The difference in these costs is therefore also twice as big as under observable efforts. This effect would, *prima facie*, speak in favor of observing more often a sharing of the costs under (J). However, under moral hazard the optimal implemented probabilities of success are, as under the observable efforts case, not the same and they are reduced as compared to the observable efforts case. In (J) the optimal implemented probability of success is one half of that in the situation with observable efforts, while the one in $(S|\,C)$ is more than one half the one under observable efforts, even though reduced. This difference in the change of the implemented probabilities, makes the relative cost savings associated to (J) as compared to the enhanced expected payoffs of staying alone, not as high as before. The option $(S|\,C)$ is now preferred more often over (J).

Corollary 2.1 *Moral Hazard causes entrepreneurs to choose to conduct stand-alone research (weakly) more often.*

2.4 Extension: Synergies between research units

Until now, we assumed that entrepreneurs employ only one of their research units/agents in a joint project. This way, it is impossible to use synergies or complementarities coming from a possible interaction of these units with each other. In this section, we will lift this assumption.

There are two consequences from this organizational form except for the possible use of synergies. One is that entrepreneurs can now coordinate the contracts given to the agents. This is a consequence that favors letting the agents work together and it is present in both, the cases with observable and unobservable efforts. However, in the case of unobservable efforts, there is also a consequence unfavorable to such a project. There is now only one statistic for the effort of two agents, whereas in the stand-alone configuration as well as in the joint projects dealt with so far, there was one statistic per agent. This should make it more expensive to let these agents work together.

2.4.1 The joint research model with synergies

Entrepreneurs now have the choice to keep either one or both their reseach units if they opt for a joint project. If they keep one unit/agent, we will refer to a joint-one agent project, denoted as before (J). If the entrepreneurs decide to keep both agents, we will refer to a **j**oint-**b**oth agents project, denoted by (JB).

In the following, we will only note the changes and additions to model as presented in section 2.2, which are coming from considering this extension.

Entrepreneurs' Projects We assume the revenues in a (JB) project to be

$$R\,(JB) = \begin{cases} \triangle & \textit{with } \Pr = p\,(JB) \\ 0 & \textit{with } \Pr = 1 - p\,(JB)\,, \end{cases}$$

where $p\,(JB)$ is the probability of success associated to the (JB) project.

Agents In a (JB) project, we impose equal transfers to both agents[17]. However, giving equal wages for equal jobs would emerge in equilibrium as the result of the minimization of the cost of implementing a given probability of success in (JB). This result is shown in appendix B.1. Given the limited liability of the agents, the transfers are

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

Probability of success We define the probability of success in a (JB) project as

$$p(JB) = \left(e_1^{1-\varepsilon} + e_2^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}} \leq 1.$$

Note that the probabilities of success in projects conducted by one agent in a special case of that probability where one of the efforts is set to zero.

[17] This may be due to legal constraints which oblige owners to pay comparable wages/transfers for comparable jobs. It could also be in the interest of the entrepreneurs to let their agents follow the project jointly in order not to loose part of the tacit knowledge that agents may acquire during the development of the project itself. Furthermore, giving an incentive contract to only one of the two agents will reduce this case to the (J) case.

The parameter $\varepsilon \in [\underline{\varepsilon}, 1[$ determines the way agents' efforts interact with each other depending on the technology possibilities attached to a given project. We restrict the ε below in order to fulfill second order conditions of the entrepreneurs' optimization problems. We restrict ε to be below one for continuity reasons. Results are not driven by this assumption. Furthermore, a restriction above is needed to justify the assumption that agents are able to conduct the project alone. For $\varepsilon \longrightarrow \infty$, the agents' efforts would become perfect complements, which would conflict with that assumption.

Allowing for positive values of this parameter we can still consider situations where for some projects agents exhibit some complementarities. Think about a project that lets the agents acquire information while exerting an effort together. This information needs to be shared between the two agents and it is crucial for making the project successful.

The technology parameter can also be negative. A negative ε accounts for the degree to which the agents' efforts are duplicates.

Finally, if $\varepsilon = 0$, agents' efforts are perfect substitutes. An example for this case is a project, which can be divided into two parts that may each partially contribute to the overall success of the project and which are assigned each to a different agent. Here no agent's effort overlaps the one of the other and the probability of success is determined by the overall amount of effort exerted by the two agents.

Timing The timing is the same as before, except that in 1, the entrepreneurs choose between $(S|\cdot)$, (J), and (JB).

2.4.2 Observable efforts

Joint-two agents (JB)

In the (JB) case, the probability of success becomes a function of both agents' efforts so that $p(JB) = \left(e_1^{1-\varepsilon} + e_2^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}$. As cost minimization requires that the joint entity proposes to each agent exactly the same contract[18], we show results here as if the constraint was imposed from the beginning. Again it is assumed that in case of success both segments of the market are covered, giving rise to a value of Δ.

Therefore, given that we take $t_1 = t_2 = t$, the joint entity's maximization problem is:

$$\max_t \Pi(JB) = \max_t \left[\left(e_1^{1-\varepsilon} + e_2^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}} \Delta - 2t\right]$$

$$s.t. \qquad t - \frac{1}{2}e_i^2 \geq 0 \qquad \forall i \qquad (IR)$$

$$t \geq 0 \qquad \forall i. \qquad (LL)$$

[18] The proof is given in appendix B.1.

This problem leads to the following results:

$$\begin{aligned} e_i^o(JB) &= e^o(JB) = 2^{\frac{\varepsilon}{1-\varepsilon}}\Delta, \\ p^o(JB) &= 2^{\frac{1+\varepsilon}{1-\varepsilon}}\Delta, \\ t^o(JB) &= 2^{\frac{3\varepsilon-1}{1-\varepsilon}}\Delta^2. \end{aligned}$$

For the (JB) case, we get a per entrepreneur expected profit of:

$$\Pi^o(JB) = \frac{1}{2}\left(2^{\frac{2\varepsilon}{1-\varepsilon}}\Delta^2\right).$$

Optimal organizational form for observable efforts

Comparison of the expected profits reveals the following results.

Lemma 2.1 *For any Δ, (JB) is privately preferred to (J) for $\varepsilon \in \left]-1,1\right[$.*

This result in very intuitive: a higher ε means higher synergies as the agents' efforts become more complementary and less duplicating. Lemma 2.1 implies that for $\varepsilon \in \left]-1,1\right[$, the relevant joint organization for which to make comparisons with the stand-alone organization is (JB). If agents efforts are stronger duplicates, the relevant joint organization is (J).

Lemma 2.1 and proposition 2.1 imply the following result:

Proposition 2.3 *Under the owner-manager assumption (alternatively: for observable efforts),*

(i) in the independent markets case, entrepreneurs always invest jointly,

(a) for $\varepsilon \in \left]-1,1\right[$, they keep both agents,

(b) for $\varepsilon \notin \left]-1,1\right[$, they keep one agent,

(ii) in the common markets case,

(a) for $\varepsilon \in \left]-1,1\right[$, entrepreneurs invest jointly and keep both agents if

$$\Delta > 2^{-\frac{2\varepsilon-1}{1-\varepsilon}} - 2,$$

and invest in a stand-alone project otherwise,

(b) for $\varepsilon \notin \left]-1,1\right[$, entrepreneurs invest jointly and keep one agent if

$$\Delta > 2\sqrt{2} - 2,$$

and invest in a stand-alone project otherwise.

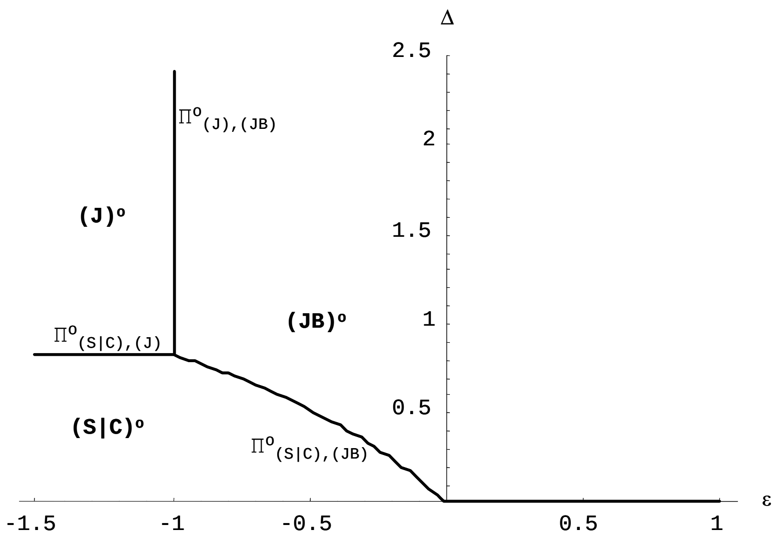


Figure 2.2: Optimal configurations for observable efforts.

If projects target *independent markets*, entrepreneurs joint for any Δ and ε and they do so with the (JB) organization if $\varepsilon \in]-1, 1[$.

Results *for the common market case* are shown graphically in figure 2.2. The $\Pi^o_{(S|C),(JB)}$ is the indifference curve of relevant combinations of Δ and ε above which $(J2)$ is preferred to $(S|C)$; similarly, $\Pi^o_{(S|C),(J)}$ is the indifference curve for the relevant combinations of the same parameters above which profits in (J) are higher than the ones in $(S|C)$; and, finally, for the relevant parameters combinations the indifference curve $\Pi^o_{(J),(JB)}$ separates the left(right) area where profits in (J) are higher(lower) than in (JB). Therefore, these three curves depict three regions: area $(S|C)^o$, $(J)^o$, and $(JB)^o$, where firms prefer $(S|C)$, (J), and (JB), respectively.

Again, a joint project is preferred to a stand-alone project if Δ is high enough. However, a higher ε may substitute for the market value of the invention: $\forall \varepsilon \in]-1, 1[$, the cutoff value of Δ for (JB) is smaller than the one for $(J) : 2^{-\frac{2\varepsilon-1}{1-\varepsilon}} - 2 < 2\sqrt{2} - 2$ and it becomes 0 for $\varepsilon \in [0, 1[$.

2.4.3 Unobservable efforts

Joint-two agents (JB)

In the unobservable efforts world, the contracts offered by the entrepreneurs have to fulfill the (IC) constraint, one for each of their employed agents. Furthermore, we again assume that the entrepreneurs share equally the bonuses to be paid to them, as well as the potential value coming from the joint project.

Each agent maximizes his own utility w.r.t. his own effort taking as given the one of the other agent. The first order conditions of these problems determine each agent's reaction function. When taken together, the reaction functions lead to the (IC) constraint to be taken into account by the joint entity when solving for the optimal implemented contract to be offered to the agents.

The agents' maximization problems are:

$$\max_{e_1} U_1 = \max_{e_1} \left[\left(e_1^{1-\varepsilon} + e_2^{1-\varepsilon} \right)^{\frac{1}{1-\varepsilon}} b - \frac{1}{2} e_1^2 \right] \quad \text{and}$$
$$\max_{e_2} U_2 = \max_{e_2} \left[\left(e_1^{1-\varepsilon} + e_2^{1-\varepsilon} \right)^{\frac{1}{1-\varepsilon}} b - \frac{1}{2} e_2^2 \right],$$

the first order conditions of which are:

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

The Nash solution to the agents' problems gives the (IC) constraint:

$$e_1 (JB) = e_2 (JB) = e (JB) = 2^{\frac{\varepsilon}{1-\varepsilon}} b. \tag{IC}$$

The probability of success for the joint-two agents case, compatible with the (IC) constraint, can be rewritten as:

$$p(JB) = 2^{\frac{1+\varepsilon}{1-\varepsilon}} b,$$

and each agent's (IR) constraint as:

$$p(JB)b - \frac{1}{2} \left[e (JB) \right]^2 \geq 0.$$

The joint entity solves, therefore, for:

$$\begin{aligned} &\max_b \Pi (JB) = \max_b \left[p(JB) (\Delta - 2b) \right] \\ &s.t. \quad e (JB) = 2^{\frac{\varepsilon}{1-\varepsilon}} b \qquad \forall i \qquad (IC) \\ &p(JB)b - \frac{1}{2} \left[e (JB) \right]^2 \geq 0 \qquad \forall i \qquad (IR) \end{aligned}$$

The optimal bonus each agent receives is:

$$b^u (JB) = \frac{\Delta}{4}$$

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

$$\begin{aligned} e^u (JB) &= 2^{\frac{\varepsilon}{1-\varepsilon}} \frac{\Delta}{4} \quad \text{and} \\ p^u(JB) &= 2^{\frac{1+\varepsilon}{1-\varepsilon}} \frac{\Delta}{4} = \frac{p^o (JB)}{4}. \end{aligned}$$

The probability induced by these contracts is equal to one fourth the one chosen by owners-managers. This is a bigger relative reduction between the observable and the unobservable efforts case than in the (J) configuration. It reflects the fact that there is now only *one* statistic for *two* agents' efforts.

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

$$\Pi^u (JB) = \frac{1}{2} \left(2^{\frac{2\varepsilon}{1-\varepsilon}} \left(\frac{\Delta}{2} \right)^2 \right).$$

Optimal organizational form for unobservable efforts

Comparison of the expected profits reveals the following results.

Lemma 2.2 *For any Δ, (JB) is privately preferred to (J) for $\varepsilon \in]0,1[$.*

As before, a higher ε means higher synergies as the agents' efforts become more complementary and less duplicating and lemma 2.2 implies that for $\varepsilon \in]0,1[$, the relevant joint organization for which to make comparisons with the stand-alone organization is (JB). If agents efforts are duplicates ($\varepsilon \leq 0$), the relevant joint organization is (J).

The reduced range of ε for which a (JB) project is chosen over a (J) project as compared to the observable efforts case reflects again the fact that in (JB) there is only *one* statistic for *two* agents' efforts. It is relatively more costly to use a (JB) organization than a (J) organization in order to implement a given probability of success under moral hazard.

Lemma 2.2 and proposition 2.2 imply the following result:

Proposition 2.4 *Under the principal-agents assumption, (alternatively: for unobservable efforts),*

(*i*) *in the independent markets case, entrepreneurs always invest jointly,*

  (*a*) *for $\varepsilon \in]0,1[$ they keep both agents and*

  (*b*) *for $\varepsilon \notin]0,1[$ they keep one agent;*

(*ii*) *in the common markets case,*

  (*a*) *for $\varepsilon \in]0,1[$, entrepreneurs invest jointly and keep both agents if*

$$\Delta > 4\left(2^{\frac{-\varepsilon}{1-\varepsilon}}\sqrt{2}-1\right),$$

  and invest in a stand-alone project otherwise,

  (*b*) *for $\varepsilon \notin]0,1[$, entrepreneurs invest jointly and keep one agent if*

$$\Delta > 4\left(\sqrt{2}-1\right),$$

  and invest in a stand-alone project otherwise.

Again, if projects target *independent markets*, entrepreneurs join for all Δ and all ε and they do so with a (JB) organization if $\varepsilon \in]0,1[$.

Results *for the common market case* are shown graphically in figure 2.3. In this figure, $\Pi^u_{(S),(JB)}$, $\Pi^u_{(S),(J)}$ and $\Pi^u_{(J),(JB)}$ represent the relevant indifference curves as the ones under the observable efforts case. The superscript u refers to the unobservable case we are describing now. As before, these three curves depict three regions: one, where firms prefer $(S|\,C)$, one, in which firms prefer (J), and, one, where the (JB) configuration is chosen.

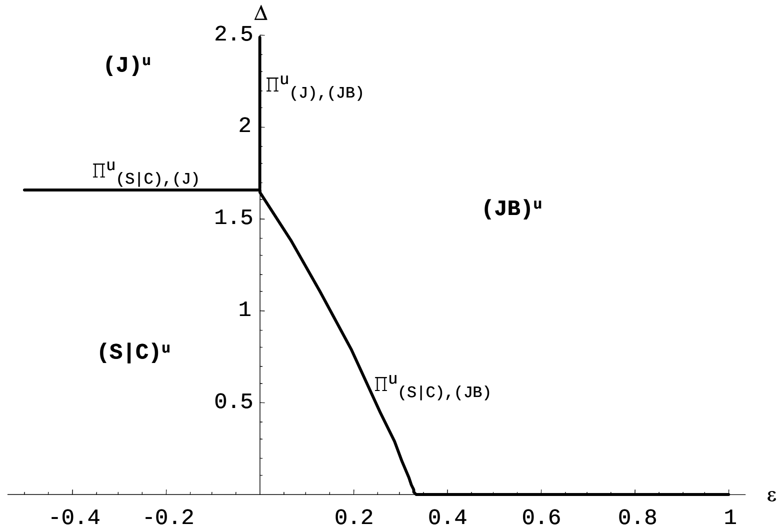


Figure 2.3: Privately chosen configurations for unobservable efforts.

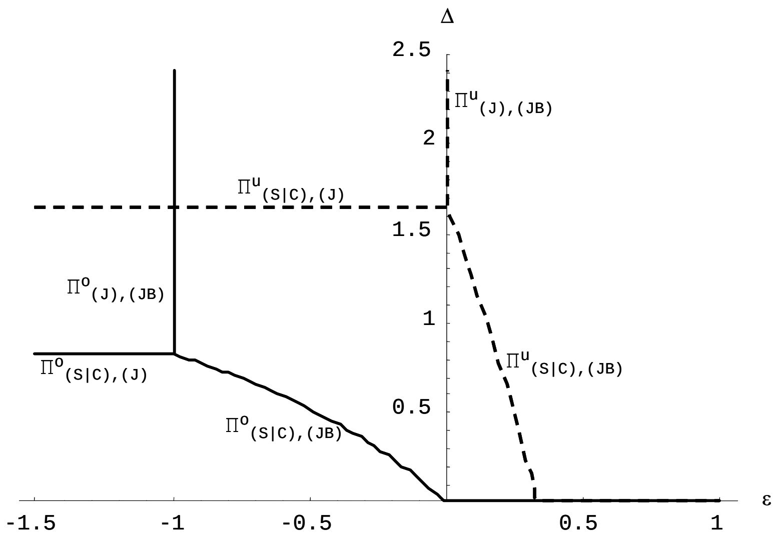


Figure 2.4: Comparison of equilibrium configurations with and without moral hazard

Figure 2.4 compares results obtained in this section with the ones obtained under the observable efforts case. The solid lines depict the private indifference curves for the observable efforts case, whereas the dashed lines depict those for the unobservable one. The graph shows that there are two implications of moral hazard for the equilibrium organization in our model. On the one hand, as already mentioned and motivated, joining with two agents is chosen only for higher complementarities. On the other hand, as before, the value of the market necessary to make the option of joining with one agent preferred over staying alone shift upwards: it is higher under the moral hazard assumption than without moral hazard. Staying alone is now preferred to joining with either one or two agents more often.

Welfare

In this section, we would like to highlight some welfare implications. Let us first define the measure of social welfare $W(\cdot)$ we will use for each of the different environments we consider. Social welfare is assumed to consist of both the entrepreneurs' expected net profits and the agents' expected utility, equivalent therefore to the sum of the expected gross profits and the disutility of agents' efforts, i.e.:

$$\begin{aligned} W\left(S|\cdot\right) &= \begin{cases} W(S|\,I) = (e_1+e_2)\,\frac{\Delta}{2} - \frac{1}{2}e_1^2 - \frac{1}{2}e_2^2 \\ \\ W(S|\,C) = (e_1+e_2-e_1e_2)\,\Delta - \frac{1}{2}e_1^2 - \frac{1}{2}e_2^2, \end{cases} \\ W(J) &= e\Delta - \frac{1}{2}e^2, \text{ and} \\ W(JB) &= \left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}\Delta - \frac{1}{2}e_1^2 - \frac{1}{2}e_2^2, \end{aligned}$$

respectively for the stand-alone independent markets and common markets, and for the joint-one agent or two-agents cases.

Proposition 2.5 summarizes the analysis of the induced welfare in the three organizations for both, the independent markets and common market assumption.

Proposition 2.5 *Under the principal-agents assumption, (alternatively: for unobservable efforts),*

(i) *in the independent markets case,*

- (a) *the private decision to invest jointly is welfare improving as compared to staying alone;*
- (b) *for $\varepsilon \in \,]-0.125, 0[$, (J) is privately chosen whereas (JB) would have been socially preferable;*

(ii) *in the common markets case,*

- (a) *if the joint configuration is chosen, this is always welfare improving as compared to staying alone;*

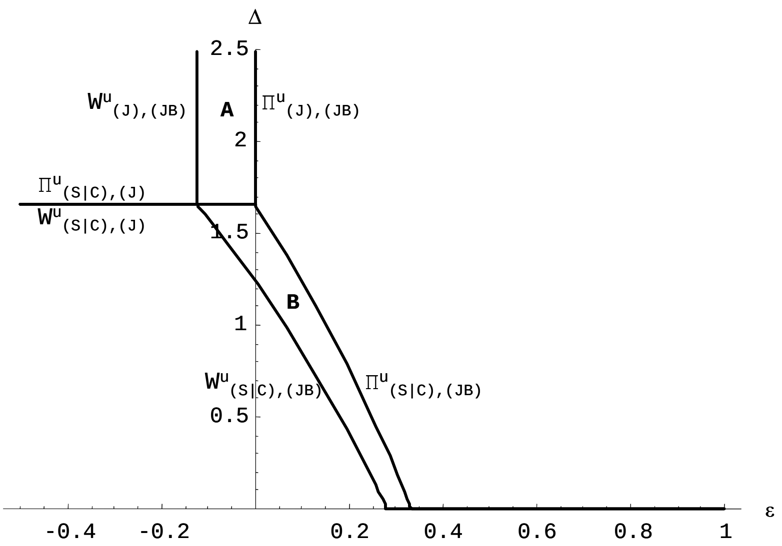


Figure 2.5: Privately and socially preferred configurations for unobservable efforts.

(b) however

b1 for $\varepsilon \in \left]-0.125, 0\right[$ *and* $\Delta > 4\left(\sqrt{2}-1\right)$, (J) *is privately chosen whereas* (JB) *would have been socially preferable;*

b2 for $\Delta \in \left]0, 4\left(\sqrt{2}-1\right)\right[$ *and* $4\left(2^{\frac{1-2\varepsilon}{1-\varepsilon}}\sqrt{\frac{3}{7}}-1\right) < \Delta < 4\left(2^{\frac{-\varepsilon}{1-\varepsilon}}\sqrt{2}-1\right)$, $(S|\,C)$ *is privately chosen whereas* (JB) *would have been socially preferable.*

The main message of the welfare analysis is: under moral hazard, there are too few joint projects in which synergies between the entrepreneurs' research units are exploited as compared to the social preferences. If projects target independent markets, entrepreneurs choose instead of the socially preferred (JB) the (J) organization. If projects target a common market, for high values of the market, entrepreneurs choose instead the (J) organization, for lower values of the market, they choose instead the (S) configuration.

Figure 2.5 describe the possible conflicts between the privately and the socially preferred configurations. The curves $W^u_{(S|C),(JB)}$, $W^u_{(S|C),(J)}$ and $W^u_{(J),(JB)}$ added to the graph from figure 2.3, divide the regions where respectively $(S|\,C)$ is socially preferred to (JB), or (J), or (J) is socially preferred to (JB).

In the figure, we have highlighted the two areas of conflict described above. In area A entrepreneurs choose to join with one agent, while joining with two would have been socially preferred. This happens for high enough values of the market, i.e. $\Delta > 4\left(\sqrt{2}-1\right)$, and low levels of agents' efforts duplication, i.e. $\varepsilon \in \left]-0.125, 0\right[$. This conflict is of the same nature as the one observed under the independent market assumption. It derives from the fact that joining with two agents is more costly privately than socially as entrepreneurs face higher costs coming from the informational rent to be paid to agents. In area B entrepreneurs pursue a stand-alone project, while, again, a joint project where both agents were kept would have been socially preferred instead. This happens for values of the markets smaller than for area A, combined with efforts that are slight duplicates up to slight complements.

2.5 Conclusion

In this paper, we have introduced agency problems into the RJV formation literature, departing from the traditional owner-managers view. This way, we have given an alternative rationale for joint research projects through optimal implemented contracts. The model proposed has explained the difference in the internal organizations of joint projects between the situations in which there are owner-managers as compared to when there is a principal-agent relation between the owner(s) and the agents carrying out the research.

Our results have shown that in the owner-manager case, research is always conducted jointly for projects targeting independent markets (or market segments), but only for sufficiently high values of the market or high enough synergies between agents for projects targeting a common market (or common market segments). When owners face agency problems instead, the decision of going jointly is taken only for higher values of the market and/or higher synergies. We have shown that owners choose less often to let both their units work together if they face moral hazard than otherwise. It has also been shown that for agents' efforts that range from slight duplicates to slight complements there exist a conflict: privately entrepreneurs either decide to stay alone or to join with only one agent, but socially a joint project with both agents would have been preferred. Entrepreneurs choose too seldomly to make use of possible synergies between agents as compared to what would be socially desirable.

Our results suggest that support should be offered to joint projects, provided that they combine research units and, thereby, exploit synergies.

Results have been obtained taking an exogenously fixed overall value of the market, either independent or common. We have argued that making this assumption was not allowing us to look at any market power effects within our analysis. A clarification on the role of this assumption is now possible. When considering the common markets assumption we have let the projects become rivals. This way, an intermediate case between the no competition at all (the one of the independent markets) and the full competition one, which would correspond to a subsequent stage where firms might have had to compete on the market for selling a produced good had they not chosen to join, has been allowed for. In Fabrizi and Lippert (2005a), pure market power considerations are instead considered in model where a project has to be adopted that would lead to an production cost reducing innovation. In that context, firms that originally compete on the market have to decide whether to join and the role of a competition authority is explicitly taken into account to characterize the types of errors that may be made when having to accept or refuse a proposed merger.

In our model the efforts that agents provide have not been bounded ex-ante. This is because the optimal contracts always implement effort levels such that the probabilities of success are well defined. However, the model could be used as well in order to assess the impact of part time versus full time job on the privately offered wage contracts, and on the social welfare. This would be possible by reinterpreting our level of effort as the number of hours worked. Our joint-two agents case would then represent an equivalent to part-time jobs, while the joint-one agent case would play the role of a full time job. This could give an explanation, other than demand side arguments such as fears of job instability or the rigidities introduced by legal constraints into the labor market, on why part-time jobs are rarely observed as compared to full-time jobs. Even when these fears or rigidities were not present, this result might be observed as a consequence of an optimal internal organization decision.

One possible extension of this paper would be to analyze patent litigation issues. This would allow for an additional rationale for the occurrence of joint projects. Firms may desire to join to insure themselves against the risk of facing a litigation, and this effect may contrast with the one we have characterized in our model: the tendency under moral hazard to observe too few joint projects where both agents were kept.

Another interesting extension could be to allow the number of entrepreneurs and agents to vary. Examples of such cases are partnerships such as law firms, where a number of seniors and juniors cooperate within the same organization in a proportion which may be variable. Our model could help understand which would be the optimal organization of such a partnership in terms of the relative number of senior partners versus junior associates.

Appendix

B.1 Proof of $t_1 = t_2$ for (JB)

In this appendix, we show that paying equal transfers in the (JB) case is cost minimizing. To show this, we minimize the transfer implementing a certain probability level, first under the assumptions that efforts are observable and then unobservable.

B.1.1 Observable efforts

Entrepreneurs employ two agents to whom a contract, that specifies an effort level and transfer(s), is proposed. Each agent then has the choice to accept or reject this contract. Thus, entrepreneurs minimize their transfers paid subject only to their respective (IR) constraints. In this case, the cost of implementing a certain probability level is exactly equal to the disutility of the efforts exerted to achieve this probability level.

The probability of success depending on two agents' efforts, is $p(JB) = \left(e_1^{1-\varepsilon} + e_2^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}$. Owner-managers solve the following minimization problem:

$$\min_{t_1,t_2} C^o(JB) = \min_{t_1,t_2} [t_1 + t_2]$$

$$s.t. \quad t_i - \frac{1}{2}e_i^2 \geq 0 \qquad \forall i \qquad (IR_i)$$

$$p(JB) = \left(e_1^{1-\varepsilon} + e_2^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}$$

The first order conditions to this minimization problem,

$$\begin{aligned}\frac{\partial C^{o}(JB)}{\partial e_1} &= e_1-\lambda\frac{1}{1-\varepsilon}\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{\varepsilon}{1-\varepsilon}}(1-\varepsilon)\,e_1^{-\varepsilon}=0\\ \frac{\partial C^{o}(JB)}{\partial e_2} &= e_2-\lambda\frac{1}{1-\varepsilon}\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{\varepsilon}{1-\varepsilon}}(1-\varepsilon)\,e_2^{-\varepsilon}=0,\end{aligned}$$

give us:

$$e_1=e_2=e.$$

This implies that symmetric transfers are optimal.

B.1.2 Unobservable efforts

Replicating the same analysis for the world with moral hazard, requires to consider that now entrepreneurs have to offer contracts specifying the transfer to be paid to their agent(s) depending on each state of nature: a positive bonus in case of success and zero in case of failure, thus, satisfying the (LL) constraints. Since efforts are not observable here, entrepreneurs have to give incentives, take (IC) constraints into account, through transfers, in addition to the (IR) constraints.

The joint entity solves now the following minimization problem:

$$\begin{aligned}&\min_{b_1,b_2} C(JB)=\min_{b_1,b_2}\left[p(JB)(b_1+b_2)\right]\\ &s.t.\quad p(JB)=\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}\\ &e_i^{-\varepsilon}\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{\varepsilon}{1-\varepsilon}}b_i=e_i\qquad\forall i\qquad (IC_i)\\ &p(JB)b_i-\frac{1}{2}e_i\geq 0\qquad (IR_i)\end{aligned}$$

Given the (LL), the (IR) are never binding. Thus, we can rewrite the program expressed in e_i

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

we derive the first order conditions

$$\begin{aligned}\frac{\partial C^{u}(JB)}{\partial e_1} = &\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{\varepsilon}{1-\varepsilon}}e_1^{-\varepsilon}\left(e_1^{1+\varepsilon}\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{-\varepsilon}{1-\varepsilon}}+e_2^{1+\varepsilon}\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{-\varepsilon}{1-\varepsilon}}\right)+\\ &\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}\left((1+\varepsilon)\,e_1^{\varepsilon}\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{-\varepsilon}{1-\varepsilon}}-\varepsilon e_1\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{-1-\varepsilon}{1-\varepsilon}}\right)+\\ &\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}\left(-\varepsilon e_2^{1+\varepsilon}\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{-1-\varepsilon}{1-\varepsilon}}e_1^{-\varepsilon}\right)=0\end{aligned}$$

$$\frac{\partial C^{u}\left(JB\right)}{\partial e_{1}}=\left(e_{1}^{1-\varepsilon}+e_{2}^{1-\varepsilon}\right)^{\frac{\varepsilon}{1-\varepsilon}}e_{2}^{-\varepsilon}\left(e_{1}^{1+\varepsilon}\left(e_{1}^{1-\varepsilon}+e_{2}^{1-\varepsilon}\right)^{\frac{-\varepsilon}{1-\varepsilon}}+e_{2}^{1+\varepsilon}\left(e_{1}^{1-\varepsilon}+e_{2}^{1-\varepsilon}\right)^{\frac{-\varepsilon}{1-\varepsilon}}\right)+$$
$$\left(e_{1}^{1-\varepsilon}+e_{2}^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}\left(\left(1+\varepsilon\right)e_{2}^{\varepsilon}\left(e_{1}^{1-\varepsilon}+e_{2}^{1-\varepsilon}\right)^{\frac{-\varepsilon}{1-\varepsilon}}-\varepsilon e_{2}\left(e_{1}^{1-\varepsilon}+e_{2}^{1-\varepsilon}\right)^{\frac{-1-\varepsilon}{1-\varepsilon}}\right)+$$
$$\left(e_{1}^{1-\varepsilon}+e_{2}^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}\left(-\varepsilon e_{1}^{1+\varepsilon}\left(e_{1}^{1-\varepsilon}+e_{2}^{1-\varepsilon}\right)^{\frac{-1-\varepsilon}{1-\varepsilon}}e_{2}^{-\varepsilon}\right)=0$$

Solving for this problem, leads again to the following result:

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

An intuition for this result is that, even though the technology is not convex for $\varepsilon < 0$, the non-linear iso-cost lines give rise to an interior solution for ε not too negative.

Chapter 3

On the design of an efficiency defense

3.1 Introduction

In recent years[1], a wave of horizontal mergers has occurred giving rise to more concentrated market structures in many industries. Historically, such a higher concentration has been viewed as detrimental to welfare as it often leads to a reduction of competitiveness in the respective market. However, mergers usually do not only have an impact on the output market side but also on the production processes, the organizational structures, the relations to suppliers of intermediate inputs or even on the financial resources of the firms through a relaxation of credit constraints. The effects of mergers can be better understood when one looks at what drives the decisions of firms about whether to merge or not. On the one side, we may think that potential synergies, efficiency gains, reduction of internal organizational costs or the increase of market power are considered positively by merging parties. On the other side, concerns about the future division of control rights, the loss in control over the actions of the management, conflicts about the sharing of potential profits may be responsible for potential merger not to come to existence.

In our paper, with their merger decision, the merging parties trade off between on the one hand potential synergies, the coordination of implemented efforts through the incentives within the merged firm, as well as the increase of market power and, on the other hand, the loss in control over the actions of the management. *Potential synergies* and the *coordination of the implemented efforts* within the firm(s) are responsible for lower expected unit production costs and, thus, are also beneficial for social welfare.

Thus, as for both, profits and social welfare, there may be positive and negative effects from a merger, it is far from clear whether a merger is beneficial, not only from a private, but also from a social point of view. There may exist, thus, a need for competition authorities to discriminate between mergers that are harmful to the *society's objective functions* either the *consumers' surplus* or *the social welfare*, from the ones that instead may enhance either of them.

In their decisions on horizontal merger cases, competition authorities may accept a so called *efficiency defense*, according to which they can allow mergers on the basis of "merger specific,

[1] This chapter is based on the paper "How much efficiency gains and price reductions to put as ingredients into an efficiency defense? 'Quanto Basta'", written jointly with Simona Fabrizi and circulated as UPV FAEII Working Paper 2004-04, quoted in this thesis as Fabrizi and Lippert (2005a).

substantial efficiency gains that are likely to be passed on to consumers via price reductions[2]" (Farrell and Shapiro, 1990 and 2001, provide an excellent assessment of this efficiency defense analyzing efficiency gains in horizontal mergers). The US Antitrust Law allows explicitly for this defense, and, even though the European Competition Law does not explicitly account for it, it is not incompatible with the use of it. The rationale behind allowing for an efficiency defense is that mergers usually do not only have an impact on the competitiveness of the market for the products sold by the parties but also on their production processes and their organizational structures. This paper takes this rationale literally and models the effects of an efficiency defense if the *efficiency gains are endogenously determined through incentives to innovate* with and without the merger.

Merging parties have the burden of proving whether efficiencies can be reached according to the US Antitrust law, while in Europe the competition authorities are responsible for collecting and processing the relevant information to justify their decision upon a merger. This is a difficult task for both, the merging parties and the competition authorities. The merging parties very often are not able to produce the hard evidence for potential efficiency gains, and, on the other side, the competition authority cannot judge perfectly upon other possible configurations as the information that it possesses comes often from the merging parties themselves. There exist attempts to measure the efficiency gains that a merger would lead to. However, the efficiency gains considered in these studies are especially the ones associated with decreases in the production costs, transaction costs, or with the internalization of costs that cancel out within the merged entity eventually.

To our best knowledge, no attempt exists to qualify the costs parties may have to incur for compensating managerial effort for reducing production costs before and after a merger and thereby to endogenize the efficiency gains from a merger through implemented optimal contracts.

This paper is an attempt to do so. We allow for *efficiency gains* that come from the implementation of optimal effort levels of the management, which, in a merger, can exploit synergies on the managers' efforts. This is done by considering firms willing to pursue a production cost reducing project to be conducted by managers, either in a stand-alone situation or in a merger. Agents are able to affect the success of the project, therefore, to affect the realized costs in the industry and their efforts are either observable or unobservable.

We determine the private decision to merge as a function of the interaction between these agents' efforts when they work together in a merger, as compared to the stand-alone situation, as well as the parameters of the industry, such as the initial costs firms face, and the potential for cost reduction. We show that mergers are privately chosen either when the potential for cost reduction is low, i.e. due to pure market power considerations, or when managerial efforts are close substitutes, or slight duplicates, i.e. when synergies induced by implemented contracts are present.

Once the private decision has been obtained, we match it with its impact on both standards, the consumers' surplus and the social welfare. Even though it is often argued that using either

[2] See e.g. the FTC 1992 Horizontal Merger Guidelines, section 4.

measure does not make a difference in practice[3], we study both, as competition authorities often seem to care about consumers' surplus, whereas economists often consider the overall social welfare impact instead. We will discuss more in detail the motivation behind this choice as well as the impact of privately taken decisions over either standards in the section devoted to the policy analysis.

Results will show that an efficiency defense based on potential efficiency gains due to a merger is generally too lax a requirement − some bad mergers would be accepted − for the observable efforts case, and, for both informational assumptions, when the initial costs are not too high. Requiring substantial efficiency gains may reduce this distortion for these mentioned cases. However, requiring substantial efficiency gains for either the unobservable case when initial costs are high, or for a larger range of costs when the standard used is the social welfare, may be too strict: some good mergers would be refused. As a general result, efficiency gains and decreased expected prices guarantee an enhancement in both consumers' surplus and social welfare more often when efforts are not observable. The reason is that under moral hazard, the firms choose to merge more often for market power reasons and less often in order to exploit synergies than if they do not face moral hazard. As a result, it will be necessary to use the two requirements 'quanto basta'. One of the contributions of this paper is to define what is 'quanto basta'.

Our work is mainly related to three different strands of literature. First, it is connected to the literature on research joint ventures and R&D cooperation in the spirit of Kamien, Muller, and Zang (1992) and d'Aspremont and Jacquemin (1988). As in Kamien et al., we also characterize a project as a reduction in the associated production costs of a good, even though in our model this project does not necessarily come in the form of joint R&D: when firms decide to stay alone, they can conduct this project separately as well. Second, our work is in line with a recent literature on the endogenous formation of partnerships for specific projects, as e.g. the work of Espinosa and Macho-Stadler (2003). However, our function for the probability of success of the project includes a parameter that captures how the managers/agents work together, i.e. the degree of substitutability of their efforts in the "production" of the success of the project. With this approach we depart from the standard literature on joint projects allowing for efforts to be substitutes, duplicates or complements. This allows us to consider more than one specific degree of complementarity between agents' efforts as it has been extensively studied for example in the team production literature; and also does it not limit us to functional forms where agents' efforts have to duplicate necessarily in a very specific way as it is the case in the literature that looks at the incentives for external monitoring of projects to be financed which could be given either to one or more banks[4].

We furthermore differ from the existing literature on endogenous partnership formation in our way of using a principal-agent-framework as opposed to a double-sided moral hazard one. A

[3] Motta (2004) argues that "[...] Article 2.1 of the Merger Regulation accepts in principle an efficiency defense "provided that it is to consumers' advantage". These provisions might indicate that consumer welfare is among the ultimate objectives of competition law. However, I am not aware of any statement of the ECJ on this point, nor of any (Commission or Court's) decision where reliance on either standard has made a difference in practice."

[4] See Holmström and Tirole (1997)

third related strand of literature is the principal-agent literature. We use Rogerson's (1985) first order approach to the "standard" agency models with hidden action. Given a configuration, agents take a non-observable action from a continuous interval which influences the expected payoff of the project. Principals write contracts on the realization of the payoff and reward agents accordingly. In the case of joint projects with multiple agents, we use the multi-agent single principal framework common to the moral hazard in teams literature. Important work on incentives and team production includes Alchian and Demsetz (1972) and Holmström (1982). A closely related work from that literature is Itoh's (1991) paper on endogenous team production. He shows that giving incentives to help, i.e. inducing team production, is optimal if own effort and helping effort are complementary. Contrary to his approach, we do not model complementarity/substitutability coming from the form of the agents' disutility of providing effort. In our model instead, efforts are substitutes to a varying degree in the probability of success they induce.

In the way we allow for different degrees of substitutability between agents' efforts we adopt the modelling used in Fabrizi and Lippert (2005b). In that paper we compare the organizational choice of entrepreneurs pursuing a *product innovation* project, either alone or jointly, in the absence of moral hazard behavior on their agents' side with that in the presence of moral hazard. Contrary to the product innovation approach considered there, in the present paper, we instead allow for a *process innovation* and market power considerations are made possible as a consequence so that, in addition, we are able to provide insights on the policy implications of mergers.

In this paper, even though we allow for the management to be responsible of the possible synergies that may arise though a merger, the management is not able to decide directly whether a merger is going to take place or not. When the management is allowed to enter actively this type of decisions, additional constraints to the ones we will explore in this analysis will have to be considered. This is done by Lippert (2005) where the management proposes the mergers at the first place and possesses superior information on the synergies and, therefore, the profitability that a merger can bring about.

The rest of the paper is organized as follows. In section 2, we introduce the model, section 3 is devoted to the private decision of firms about the merger, without and with moral hazard, section 4 considers the policy analysis, and section 5 concludes.

3.2 The model

We consider a situation where a good with demand $Q = 1 - P$ is exchanged in an economy. This good is initially produced by two firms $i = 1, 2$ at a unit production cost equal to $c \leq 1$[5]. Each firm employs one agent. We assume that there exists a project that in the case of success leads to a lower unit production cost βc, with $\beta \in [0, 1[$. The probability of success of the project thus

[5] We normalize the level of the initial cost such that it varies between zero and one. It is positive, but it cannot exceed the willingness to pay for the good to be exchanged in the economy in order to allow for non-negative gross profits.

measures the capacity of a given firm to reduce its unit production costs.

The project can be conducted by each firm alone – we will refer to this case as a stand-alone situation, (S) – or together with the other firm by merging. If each firm conducts the project alone, then each project will be conducted by one agent. However, if firms decide to merge, the agents previously employed by each firm will work jointly in the project – we will refer to this case as a merger, (M).

In our model, the agent(s) affect the probability of success or failure of the project they conduct through their chosen effort. Depending on the assumptions on the observability of efforts, this may result in a moral hazard problem. We assume both: The agents exert either an observable or a non observable, therefore not-contractible, effort e_i which is a continuous choice from the interval $[0,1]$. Exerting this effort e_i implies a disutility for the agent that is equal to $c_i(e_i) = \frac{1}{2}e_i^2$. Agents receive a transfer t_i from their respective firm (stand-alone case) or from the merged entity (joint project). They are risk neutral and their utility is additively separable between effort and money, $U_i = u_i(t_i) - c_i(e_i) = t_i - \frac{1}{2}e_i^2$. However, we assume that agents have limited liability so that for any state of nature they have to receive a non-negative transfer.

In the next subsections we will describe the possible configurations that these decisions may lead to.

3.2.1 Pre-merger or stand-alone

In this case, two separate firms $i = 1, 2$, competing à la Bertrand, decide to undertake each the production cost reducing project on their own. Each firm employs one agent. The success probability of each project undertaken is defined as $p_i(S) = e_i$, i.e. is equal to the effort exerted by agent i. We assume the probabilities of success in the two firms to be independent.

Given the Bertrand competition assumption, a firm receives a non-zero gross profit only if its own project succeeds while the one of the other firm does not. Given this assumption, the efficiency on the production side of the economy will be given by:

$$E(S) = p_1(S) + p_2(S) - p_1(S)\,p_2(S)$$

The success of one firm may lead to either a drastic or a non-drastic innovation.

It is drastic when the monopoly price associated to it is lower than the initial unit production costs, i.e.:

$$\frac{1+\beta c}{2} \leq c \qquad \Leftrightarrow \qquad \beta \leq \frac{2c-1}{c}$$

If it is, the succeeding firm can charge the monopoly price while the other one exits because at that price it cannot recover its costs.

If it is non-drastic, the succeeding firm can charge a price at most equal to the cost of the rival firm. In this case, we assume the unsuccessful firm not to make any sales[6].

[6] This assumption is the limit case for the successful firm pricing slightly below the rival's high cost which would induce it to exit the market.

Firms may face a drastic or non-drastic innovation, depending on the combinations of the parameters β and c. As these parameters can take values between zero and one, it is straightforward to show that any innovation is non-drastic for $c \in \left[0, \frac{1}{3}\right[$, it might be either drastic or not depending on the combination of β and c for $c \in \left[\frac{1}{3}, \frac{1}{2}\right[$, it is certainly drastic for $c \in \left[\frac{1}{2}, 1\right]$.

If both firms have either a high production cost, i.e. both projects fail, or a low production cost, i.e. both projects succeed, they both charge a price equal to their marginal costs and make zero gross profits.

As discussed before, the probabilities of success of each firm are independent of each other, so that for each of the four different states of nature (failure of one firm while the other does not, and, vice versa, failure of both, success of both of them) we can associate the following probabilities: $\Pr(\beta c, c) = e_1(1-e_2)$, $\Pr(c, \beta c) = (1-e_1)e_2$, $\Pr(c,c) = (1-e_1)(1-e_2)$, and $\Pr(\beta c, \beta c) = e_1 e_2$.

Given these assumptions, w.l.o.g. we can write the profit of firm 1, gross of the transfer to be paid to its agent, as follows:

$$\pi_1(\cdot,\cdot) = \begin{cases} \pi_1(\beta c, c) = \begin{cases} \frac{(1-\beta c)^2}{4} & \text{if } \beta \leq \frac{2c-1}{c} \\ c(1-c)(1-\beta) & \text{otherwise} \end{cases} \\ \pi_1(\beta c, \beta c) = 0 \\ \pi_1(c,c) = 0 \\ \pi_1(c, \beta c) = 0. \end{cases}$$

In the same way, we can summarize the prices for the different realizations of the unit production costs as:

$$P(\cdot,\cdot) = \begin{cases} P(\beta c, c) = P(c, \beta c) = \begin{cases} \frac{1+\beta c}{2} & \text{if } \beta \leq \frac{2c-1}{c} \\ c & \text{otherwise} \end{cases} \\ P(\beta c, \beta c) = \beta c \\ P(c,c) = c. \end{cases}$$

Let us characterize now also the corresponding levels of consumers' surplus, $CS(.,.)$, associated with each possible state of nature:

$$CS(\cdot,\cdot) = \begin{cases} CS(\beta c, c) = CS(c, \beta c) = \begin{cases} \frac{(1-\beta c)^2}{8} & \text{if } \beta \leq \frac{2c-1}{c} \\ \frac{(1-c)^2}{2} & \text{otherwise} \end{cases} \\ CS(\beta c, \beta c) = \frac{(1-\beta c)^2}{2} \\ CS(c,c) = \frac{(1-c)^2}{2}. \end{cases}$$

Note that in the stand-alone situation, a process innovation never makes consumers worse off: it always leads to a (at least weak) consumers' surplus increase as compared to the situation without the innovation.

As already introduced, the consumers' surplus will be used in our analysis as one possible objective function the competition authority cares about. The alternative objective function that we will consider will be the social welfare. The social welfare will be defined as the sum of consumers' surplus, profits, and the agents' utility. We will describe both objective functions in detail later on when introducing the policy analysis.

We will consider two cases regarding the ability to write contracts contingent on agents' actions. In one case, contracts can be written contingent on the agents' exerted efforts and the firms just pay transfers which compensate the agents for their disutility of exerting the effort:

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

In the other case, contracts cannot be made contingent on the agents' efforts but only on the realized costs, either c or βc. From standard principal-agent theory, we know that it is optimal for the bonus paid to an agent not to be a function of the cost realizations of the other firm. Therefore, contracts will only be such that agent i will receive a positive bonus, b_i, in case firm i succeeds in reducing its costs, or a transfer equal to zero, in case firm i fails in reducing them instead, no matter whether the other firm succeeded or not. The limited liability of the agents we have assumed, means that firms cannot offer any contract that might pay a negative wage to their agent for a given realization. Thus, the transfers to be paid to the agent in the stand-alone situation are:

$$t_1 = \begin{cases} b_1 & \text{if } (\beta c, c) \text{ or } (\beta c, \beta c) \\ 0 & \text{otherwise.} \end{cases}$$

3.2.2 Merger

When firms merge we consider that the previously employed agents undertake the project jointly, so that its success probability becomes a function of both agents' efforts[7], i.e.:

$$p(M) = \left(e_1^{1-\varepsilon} + e_2^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}} \qquad \text{with} \qquad \varepsilon \in [\underline{\varepsilon}, \overline{\varepsilon}] \,.$$

The parameter ε captures the degree of substitutability between agents' efforts. As discussed in the introduction, different degrees of substitutability will be considered: agents' efforts can be either perfect substitutes, or slight complements, or duplicates. This is done, in order to account for possible synergies between agents' efforts, as agents work together in the merged entity. We characterize the probability of success using values of the parameter ε that are bounded below and above. The upper bound is necessary to rule out cases where agents' efforts would be too complementary, because otherwise the assumption that the project could have been undertaken separately by each firm would not be consistent anymore. The lower bound is imposed to guarantee that the second order conditions of the maximization problems we will consider are satisfied. In addition, we will always check for the conditions such that this measure of probability is well defined, i.e. never exceeds the value of one.

[7] We use the same definition of the probability of success here as in Fabrizi and Lippert (2005b), where agents work together in a joint research project.

Pure synergies, which are merger specific, are the ones that are able to generate, for the same level of inputs, a higher output. In our case, we will have merger specific synergies whenever the induced efficiency by a merger, $E(M)$, is higher as compared to the expected one induced by a stand-alone situation, $E(S)$, i.e. if:

$$E(M) \simeq p(M) = \left(e_1^{1-\varepsilon} + e_2^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}} \geq e_1 + e_2 - e_1 e_2 = E(S).$$

A sufficient condition for having synergies through a merger is that the parameter ε takes values between zero and one. This is a sufficient but not necessary condition as lower values than zero might produce some merger specific synergies for special combinations of high levels of both agents' efforts. In addition, it can be shown that higher values than one never produce any synergy.

However, given that in our model we will solve for the optimal contracts that induce a certain level of agents' efforts, ex-post the inputs (optimal efforts) in a stand-alone situation may take different values from the ones in a merger situation. Because of this, we will need to distinguish between ex-ante synergies and ex-post ones: the first ones refer to the definition just given and the second ones refer to the same condition where the optimal levels of efforts have been replaced instead.

Once we have defined the probability of success induced by a merger, we can concentrate as before on the profits, prices, consumers' surplus, social welfare and the transfers agents receive which are associated with it.

When merging, firms enjoy monopoly profits on the product market, no matter whether the merged entity succeeds in reducing its production costs or not. Only the magnitude of the profits will be affected by the success or failure of this project. Thus the profit enjoyed by the merged entity, before making the transfers to their agent(s) is:

$$\pi\left(.\right) = \begin{cases} \pi\left(\beta c\right) = \frac{(1-\beta c)^2}{4} \\ \pi\left(c\right) = \frac{(1-c)^2}{4}, \end{cases}$$

i.e. either high or low, depending on whether the merger respectively succeeds or not in reducing its unit production costs. Here we differ from the assumption made in Fabrizi and Lippert (2005b) and Lippert (2005). In those papers, a product innovation project is considered, the failure of which brings a zero profit in any configuration.

As we consider mergers among equals, we assume that, once merged, merging parties share equally the overall monopolistic profit. Thus, assuming an equal sharing of the realized profits of a merger, we implicitly disregard the way merging parties come to such a sharing.

The prices prevailing in the economy once the merger is formed (in the cases of success and failure) are:

$$P\left(\cdot\right) = \begin{cases} P\left(\beta c\right) = \frac{1+\beta c}{2} \\ P\left(c\right) = \frac{1+c}{2}. \end{cases}$$

The realizations of the consumers' surplus, $CS(.,.)$, associated with these states of nature are then the following:

$$CS(\cdot) = \begin{cases} CS(\beta c) = \frac{(1-\beta c)^2}{8} \\ CS(c) = \frac{(1-c)^2}{8}. \end{cases}$$

As before, the consumers' surplus, as well as the social welfare that we will discuss in detail when looking at the policy analysis, will be alternatively used in our analysis as the objective functions the competition authority cares about.

Let us finally characterize the transfers the agents get within a merger. As before, we will need to distinguish whether the efforts are observable or unobservable in order to let the transfer to the agents be contingent or not on their respective exerted effort. If contracts can be written contingent on the agents' exerted efforts, agents receive transfers equal to:

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

Otherwise, contracts will give the same bonus to each agent such that[8]:

$$t_i = \begin{cases} b & \text{if success,} \\ 0 & \text{otherwise.} \end{cases}$$

As before, limited liability on the agents' side is assumed so that the minimum transfer agents can get even when there is no success is non-negative.

3.3 Private decision

3.3.1 No Moral Hazard

The goal of this section is to isolate the market power effects from the ones that would be driven by pure moral hazard behavior merging parties have to face when deciding about merging or not and which type of contract to propose to the agent(s). In this section we characterize the maximization problems firms face in a world without moral hazard.

Stand-alone, (S)

This is the case where two firms decide each to let their respective agent conduct the project alone. The success probability of this project is therefore $p_i(S) = e_i$, with $i = 1, 2$.

For notational simplicity, we will refer to the gross profits $\pi(\cdot,\cdot)$ as defined above when describing the pre-merger case: they are a function of each state of nature and also depend on the combination of the parameters that lead to a drastic or a non-drastic success, β and c. The advantage of using this notation is that it encompasses both the drastic and non-drastic situation we need to account for.

[8]Giving the same bonus to both agents can be shown to result from cost minimization. We assume it for expositional purposes.

Given this, we can, w.l.o.g., write the maximization problem firm 1 faces:

$$\max_{t_1} \Pi_1 (S) \equiv \max_{t_1} \left[e_1 (1 - e_2) \pi (\beta c, c) - t_1 \right]$$
$$s.t. \qquad t_1 - \frac{1}{2} e_1^2 \geq 0, \tag{IR}$$

where $\Pi_1 (S)$ is the expected net profit of firm 1.

Given the observability of the effort, each firm can extract any potential rent from the agent, so that the individual rationality constraint, (IR), is binding. Therefore, the maximization problem becomes simply:

$$\max_{e_1} \Pi_1 (S) \equiv \max_{e_1} \left[e_1 (1 - e_2) \pi (\beta c, c) - \frac{1}{2} e_1^2 \right].$$

The Nash equilibrium of this problem each firm faces is:

$$e_1^o (S) = e_2^o (S) = e^o (S) = p^o(S) = \frac{\pi (\beta c, c)}{\pi (\beta c, c) + 1} = \begin{cases} \frac{(1-\beta c)^2}{(1-\beta c)^2+4} & \text{if } \beta \leq \frac{2c-1}{c} \\ \frac{c(1-c)(1-\beta)}{c(1-c)(1-\beta)+1} & \text{otherwise} \end{cases}$$

where the superscript o stands for "observability of effort". The level of the optimal effort coincides here with the measure of the probability of success.

The optimal expected profit for each firm is therefore:

$$\Pi_i^o (S) = \Pi^o (S) = \frac{1}{2} \left(\frac{\pi (\beta c, c)}{\pi (\beta c, c) + 1} \right)^2.$$

Merger, (M)

In this case, the merged entity solves for the following problem:

$$\max_{t_1, t_2} \Pi (M) \equiv \max_{t_1, t_2} \left[p (M) \pi (\beta c) + (1 - p (M)) \pi (c) - t_1 - t_2 \right]$$
$$s.t. \qquad t_i - \frac{1}{2} e_i^2 \geq 0 \qquad \forall i \tag{IR}$$
$$e_i \leq 1$$
$$p (M) = \left(e_1^{1-\varepsilon} + e_2^{1-\varepsilon} \right)^{\frac{1}{1-\varepsilon}} \leq 1,$$

At this stage we solve for the unconstrained problem, i.e. taking the constraint on the probability of success as not binding. This way we get the potential unconstrained solution of the maximization problem. If this solution does not exceed the value of one, given the combination of the parameters of the model, then it will be used for the following analyses; otherwise, the maximum value of one will be considered instead[9].

[9] This is possible as we have restricted the values of the parameter ε such that the problem to be solved is a well behaved one.

For this reason, we can rewrite the previous problem as follows:

$$\max_{e_1,e_2} \Pi\left(M\right) \equiv \max_{e_1,e_2} \left[\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}} \pi\left(\beta c\right) + \left(1-\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}\right) \pi\left(c\right) - \frac{1}{2}\left(e_1^2+e_2^2\right) \right].$$

The first order conditions associated with this problem are:

$$\frac{\partial \Pi\left(M\right)}{\partial e_1} = e_1^{-\varepsilon}\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{\varepsilon}{1-\varepsilon}} \left(\pi\left(\beta c\right)-\pi\left(c\right)\right) - e_1 = 0,$$
$$\frac{\partial \Pi\left(M\right)}{\partial e_2} = e_2^{-\varepsilon}\left(e_1^{1-\varepsilon}+e_2^{1-\varepsilon}\right)^{\frac{\varepsilon}{1-\varepsilon}} \left(\pi\left(\beta c\right)-\pi\left(c\right)\right) - e_2 = 0.$$

They tell us that the solution to the problem should be such that:

$$e_1^o = e_2^o = e^o\left(M\right).$$

We should remember that the constraint over the probability of success not to exceed the value of one is necessary and sufficient to guarantee that each agent's effort will not exceed the value of one as long as $e^o\left(M\right) \leq 2^{-\frac{1}{1-\varepsilon}}$. Implementing a higher $e^o\left(M\right)$ would not lead to a higher probability of success (and, therefore, to higher expected revenues), but to increased costs as the agents would eventually have to be compensated for these extra efforts. Using this property, and the one just found above, we can solve for the system and derive the following result:

$$e^o\left(M\right) = \min\left\{2^{\frac{\varepsilon}{1-\varepsilon}}\left(\pi\left(\beta c\right)-\pi\left(c\right)\right), 2^{-\frac{1}{1-\varepsilon}}\right\}.$$

We now proceed in characterizing the measure of the probability of success associated with this case. Remember that, when two agents are kept in the merger, the success probability is a function of both agents' efforts so that:

$$p^o(M) = \min\left\{2^{\frac{1+\varepsilon}{1-\varepsilon}}\left(\pi\left(\beta c\right)-\pi\left(c\right)\right), 1\right\}.$$

The expected profit each merging party can enjoy in a merger is then:

$$\frac{\Pi^o\left(M\right)}{2} = \frac{1}{2}\left(p^o(M)\pi\left(\beta c\right) + \left(1-p^o(M)\right)\pi\left(c\right) - \left(e^o\left(M\right)\right)^2\right).$$

Merger decision under no MH

Firms are willing to merge any time the share of the expected merged entity's profit they may enjoy is higher than the one they expect in a stand-alone situation. Therefore, to characterize under which conditions firms would propose a merger, we need to solve for the following inequality:

$$\frac{\Pi^o\left(M\right)}{2} > \Pi^o\left(S\right)$$
$$\Updownarrow$$
$$\frac{1}{2}\left(p^o(M)\pi\left(\beta c\right) + \left(1-p^o(M)\right)\pi\left(c\right) - \left(e^o\left(M\right)\right)^2\right) > \frac{1}{2}\left(\frac{\pi\left(\beta c, c\right)}{\pi\left(\beta c, c\right)+1}\right)^2$$

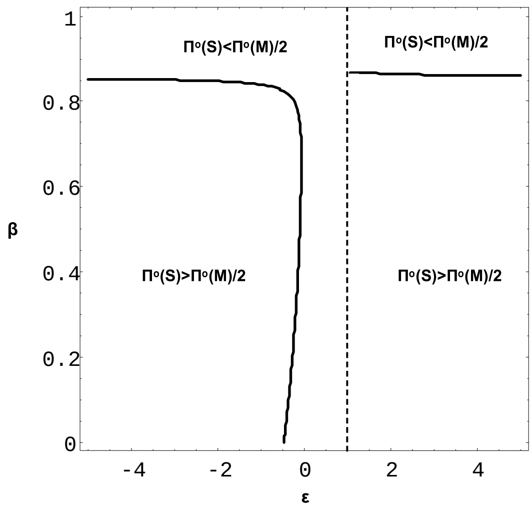


Figure 3.1: Private merger decision for $c = 0.99$ under no moral hazard.

The expression of the merged entity's profit is a function of three different parameters, β, c, and ε. Given the complexity of the expression it is difficult to solve analytically for the values of these parameters for which the inequality might hold. We therefore use graphical representations in order to show for which combination of the relevant parameters firms are willing to merge.

To this purpose, we will fix different values of the initial cost economy faces and we let the other parameters vary freely. This will allow us to characterize qualitatively the decision to merge which will be shown to be taken more often, the lower the initial level of costs. This result can be seen in figures 1 and 2.

In the vertical axis different values of $\beta \in [0,1]$ are considered: low values of β imply high relative cost savings, while high levels of it imply the opposite. In the horizontal axis the parameter ε is represented only for a restricted range such that $\varepsilon \in [-5,5]$. We restrict the attention to this interval for pure descriptive reasons. Extending the range would not add any information on the firms' merger decision as the lines of indifference will continue asymptotically. In addition, in the analysis that will follow the interesting results will come in the interval where $\varepsilon \in [-1,1[$, so that we will even concentrate on this range to show under which circumstances a competition authority's decision may induce a type I or type II error when relying on an efficiency defense.

Firms are always willing to merge, no matter which is the value of β, as long as $\varepsilon \in [0,1[$. This result was partially expected as we know that pure synergies occur in that range. However a decision to merge may also arise in ranges where pure synergies are not present. This is the case, for values of ε above one where mergers are still privately preferred as long as potential cost savings are not too high. On the other hand, when ε is negative we might still expect firms to merge for high β. The intuition behind this result is that for high β, due to the low implemented efforts, the probability that no firm succeeds in inventing the product both, in stand-alone and in the merger situation, is high. Contrary to the stand-alone situation, in a merger, the firms

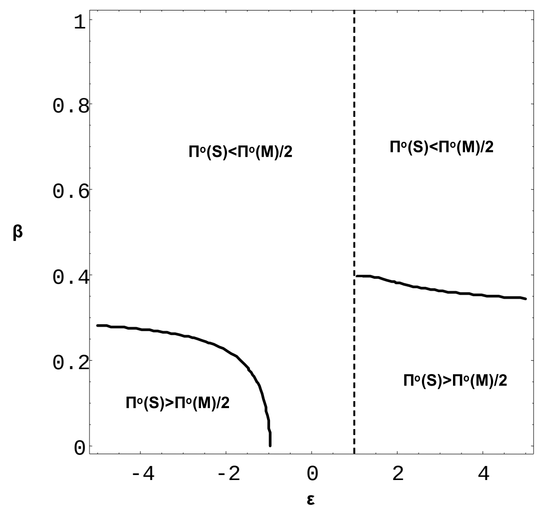


Figure 3.2: Private merger decision for $c = 0.79$ under no moral hazard.

make a positive profit also in the case of a failure of the project. The decision to merge for a low cost reduction potential is driven by market power considerations. This result contrasts with the product innovation case considered in Fabrizi and Lippert (2005b), where both, in stand-alone and joint development, a failure means zero profits.

3.3.2 Moral Hazard

In this section, we will repeat the analysis made for the observable efforts case considering the efforts as unobservable instead. This is done in order to be able to compare results obtained in the absence of moral hazard with the ones obtained introducing it into the model and to discuss them.

Stand-alone, (S)

As before, we can write the maximization problem each firm solves when choosing to conduct the project alone. In this case, however, we need to remember that, given the moral hazard assumption, the contract firms propose to their respective agent has to be incentive compatible. Agents will receive a transfer higher than the one they would have enjoyed if their efforts were observable.

Thus, w.l.o.g. we can now write the profit maximization of firm 1 as follows:

$$\max_{b_1} \Pi_1(S) \equiv \max_{b_1} \left[e_1 (1 - e_2) \pi(\beta c, c) - e_1 b_1 \right]$$

$$s.t. \qquad e_1 b_1 - \frac{1}{2} e_1^2 \geq 0 \qquad (IR)$$

$$e_1 = \arg\max_{e_1} \left[e_1 b_1 - \frac{1}{2} e_1^2 \right]. \qquad (IC)$$

Solving for the Nash equilibrium, we get:

$$b_1 = b_2 = b(S) = e^u(S) = p^u(S) = \frac{\pi(\beta c, c)}{\pi(\beta c, c) + 2} = \begin{cases} \frac{(1-\beta c)^2}{(1-\beta c)^2+8} & \text{if } \beta \leq \frac{2c-1}{c} \\ \frac{c(1-c)(1-\beta)}{c(1-c)(1-\beta)+2} & \text{otherwise} \end{cases},$$

where the superscript u stands for "unobservability of effort". As a consequence, the expected profit of each firm corresponds to:

$$\Pi_1(S) = \Pi_2(S) = \Pi^u(S) = \frac{1}{2}\left(\frac{\pi(\beta c, c)}{\pi(\beta c, c) + 2}\right)^2.$$

Merger, (M)

In this case, remember that the probability of success in reducing production costs is given by:

$$p(M) \equiv \left(e_1^{1-\varepsilon} + e_2^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}.$$

The merged entity pays the same bonus b in case of success to both agents[10]. The non-observability of agents' efforts, makes it impossible to separate the contribution one agent has given to the project from the contribution of the other agent. The merged entity faces again the (IC) constraint due to the non-observability of agents' efforts. The (IC) constraint here will result from the Nash equilibrium of each agent's utility maximization problem. The (IC) - that will be a function of the bonus - can be obtained this way as each agent maximizes his utility considering that his chosen level of effort will not lead to a probability exceeding one. The merged entity will have already internalized the feasibility constraint over the probability of success when it chooses the level of the bonuses. This means that the merged entity will never propose a level of the bonus that may induce each agent to choose an effort that may lead to a probability exceeding the level of one[11].

Therefore, the merged entity solves for the following problem:

$$\max_b \Pi(M) = \max_b \left[p(M)\pi(\beta c) + (1 - p(M))\pi(c) - 2p(M)b\right]$$

$$s.t. \qquad p(M)b - \frac{1}{2}e_i^2 \geq 0 \qquad \forall i \qquad (IR)$$

$$e_i = \arg\max_{e_i}\left[p(M)b - \frac{1}{2}e_i^2\right] \qquad \forall i \qquad (IC)$$

$$p(M) = \left(e_1^{1-\varepsilon} + e_2^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}} \leq 1.$$

The solution to this maximization problem gives:

$$b(M) = \min\left\{\frac{1}{4}(\pi(\beta c) - \pi(c)), 2^{-\frac{1+\varepsilon}{1-\varepsilon}}\right\}$$

$$e^u(M) = 2^{\frac{\varepsilon}{1-\varepsilon}} b(M)$$

$$p^u(M) = \min\left\{2^{\frac{1+\varepsilon}{1-\varepsilon}}\frac{1}{4}(\pi(\beta c) - \pi(c)), 1\right\}.$$

[10] Remember that equal bonuses for both agents would result from cost minimization in equilibrium.

[11] This would not be feasible anyway, but costly.

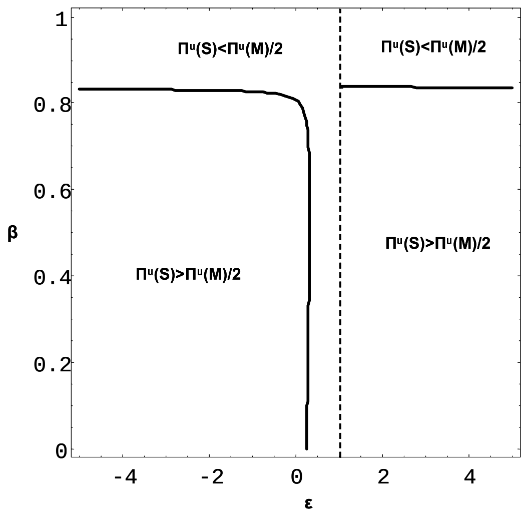


Figure 3.3: Private decision for $c = 0.99$ under moral hazard.

The merged entity's expected profit associated to this optimal bonus and probability of success is:

$$\frac{\Pi^u(M)}{2} = \frac{1}{2}\left[p^u(M)\left(\pi(\beta c) - 2b\right) + \left(1 - p^u(M)\right)\pi(c)\right].$$

Merger decision under MH

As before, we know that a merger will be proposed as long as:

$$\frac{\Pi^u(M)}{2} > \Pi^u(S)$$

$$\Updownarrow$$

$$\frac{1}{2}\left(p^u(M)\pi(\beta c) + \left(1 - p^u(M)\right)\pi(c) - \left(e^u(M)\right)^2\right) > \frac{1}{2}\left(\frac{\pi(\beta c, c)}{\pi(\beta c, c) + 2}\right)^2.$$

We have again the same type of complexity as before, so to solve for this inequality we will proceed with graphical representations in order to describe the combination of the parameters of the model that will drive the merger decisions of firms. Different values of the initial cost will be fixed here as well, while the other parameters will be let free to vary.

Figures 3 and 4 show results of the merger decision under moral hazard, for a comparable range of the parameter ε as in the case of observable efforts.

As before, in the vertical axis different values of $\beta \in [0, 1]$ are considered. Again, low values of β imply high relative cost savings, and high levels of it imply the opposite. The horizontal axis accounts again for different values of the parameter ε in the range $[-5, 5]$.

The first fact to be noticed is that for a high costs savings potential, firms are less often willing to merge. Specifically, for high initial costs, they do not anymore always merge in the range where $\varepsilon \in [0, 1[$. However, as soon as the initial cost is lower a similar behavior can be expected by firms: the lower the initial cost the more often they are willing to merge. It can be

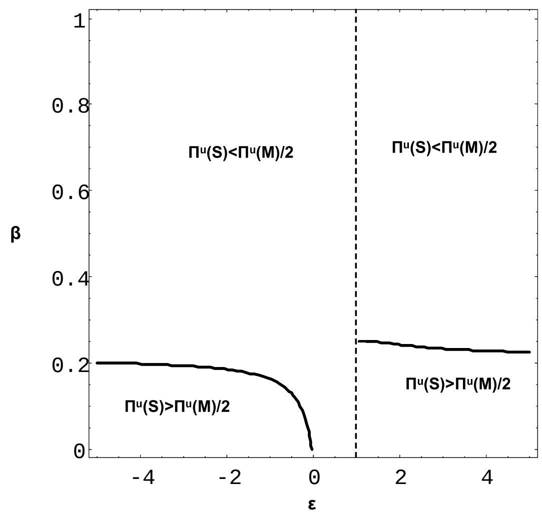


Figure 3.4: Private decision for $c = 0.79$ under moral hazard.

shown that for $c < 0.69$, firms are always willing to merge no matter which values β and ε may take. The rest of the comments from the observable efforts case apply here as well.

3.3.3 Comparing private decisions on mergers

Now that we have characterized the private decision on mergers under the assumption of observable and unobservable agents' efforts, we can compare these decisions with each other. To do so, we combine the graphs referred respectively to $c = 0.99$ and $c = 0.79$ for both the observable and unobservable case, obtaining figures 5 and 6. In these figures some profits appear with the superscript $j = o$, u. This is done as, when combining figures 3 and 4, there exist regions in which the decisions about merging stay the same for both assumptions on observability of efforts. Instead, we highlight the differences in the behavior of the merging parties as results of this comparison show that there exist areas where the decision taken under observable efforts does not coincide with the one taken in the presence of moral hazard. We have two different types of these areas. Areas (a) are the ones where under observable efforts firms are not willing to merge, but they are instead under moral hazard. In area (b), arising for values of $\varepsilon \in [-1, 1[$, the opposite occurs: firms are willing to merge for observable efforts, but not for unobservable ones.

The intuitions for the existence of areas (a) and (b) are as follows. In a merger, it is not anymore possible to observe the success of each manager separately. This makes it - absent any synergies - more expensive to implement the same probability of success, and - again absent synergies - a lower probability of success will be implemented. For the same cost savings potential, therefore, a lower probability of success is implemented, and it is more often preferred to use the increase in market power through a merger. This explains (a). At the same time, a higher degree of synergies is required to compensate for the loss in control over the management, which explains (b). The effect of (b) was also present in the product innovation case of Fabrizi and

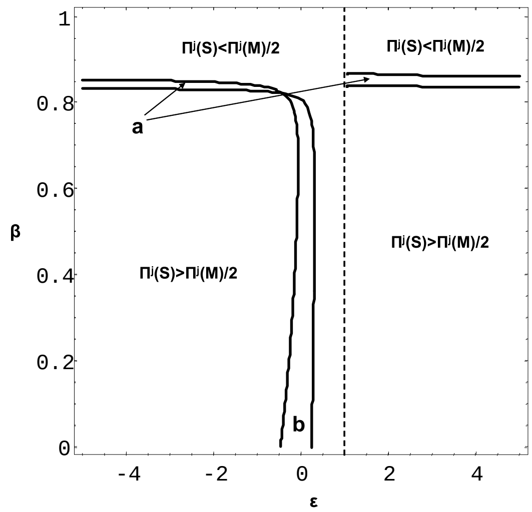


Figure 3.5: Comparison between private decisions for $c = 0.99$.

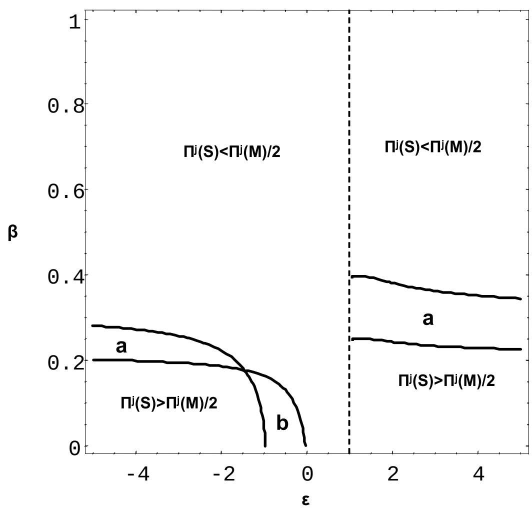


Figure 3.6: Comparison between private decisions for $c = 0.79$.

Lippert (2005b), whereas the effect of (a) was not.

Proposition 3.1 *If low synergies are present (ε small or bigger than one, i.e. efforts are not close substitutes), the firms choose more often to merge under moral hazard than with observable efforts. For higher synergies (ε around zero, i.e. efforts are close substitutes), the firms choose less often to merge under moral hazard than with observable efforts.*

3.4 Policy analysis

Now that we have determined under which conditions firms are willing to merge, we need to verify the impact of their decisions on both the consumers' surplus and the social welfare depending on which of them is taken as the objective function by a competition authority. We study the impacts on both, because competition authorities often seem to care about consumers' surplus, even though economists often consider the overall social welfare impact to judge a merger instead.

Several justifications why a merger authority should care about consumers' surplus and not about overall social welfare have been given.

One reason is that, in the decisions a national competition authority has to make on mergers, only consumers' surplus should matter given that the profits accruing from a merger might be enjoyed elsewhere than in the domestic market. This is certainly the case for mergers occurring between firms, the respective ownership of which is based abroad. However, this is not a general case as many mergers may occur between firms selling their products in a given domestic market while one of them at least can be held domestically. In these alternative cases, it is not obvious anymore why the profits of the merging firms should be disregarded.

Another reason that has been put forward to privilege the consumers' surplus as an objective by the competition authorities is that consumers are less likely to coordinate in order to voice their concerns. The argument implies that they are in a weaker position than merging parties might be. However, it is not clear why, even if this was the case, this should represent a justification for considering only consumers' surplus. What we mean with this, is that if consumers cannot protect themselves from the potentially adverse effects of a merger it does not have to be that the competition authority has to take a biased point of view favoring them.

One last argument in favor of adopting consumers' surplus that is often advocated is that it does not matter whether a competition authority adopts a consumers' surplus standard instead of a social welfare one, as the first represents anyhow a good approximation for the second. However, as results will show, it is not clear whether this is always true. Apart from overstating the role of consumers as opposed to firms, consumers' surplus also neglects another component which might be crucial in a merger situation: namely the cost of efforts associated with the undertaken project. The integration efforts that enable the firms to create synergies come at a cost. It is therefore important as well to compare it with the cost separate firms will have to encounter when developing projects alone. In our model, the cost of effort can be interpreted as the cost of development of a given technology that comes to existence. Such a development cost is not a fixed one though, as it is often modeled in R&D literature, as we have made it become endogenous through the optimal contracts implemented before and after the merger.

On the other hand, a tendency of considering a broader objective than the consumers' surplus has been observed as well. As Motta (2004) points out:

> In the EU, Article 81(3) allows any agreement, decision or concerted practice "which contributes to improving the production or distribution of goods or to promoting technical or economic progress, while allowing consumers a fair share of the resulting benefit". Furthermore, Article 2.1 of the Merger Regulation accepts in principle an efficiency defense "provided that it is to consumers' advantage". These provisions might indicate that consumer welfare is among the ultimate objectives of competition law. However, I am not aware of any statement of the ECJ on this point, nor of any (Commission or Court's) decision where reliance on either standard has made a difference in practice.
>
> In other jurisdictions, such as Canada, Australia, New Zealand, competition authorities seem instead to lean towards a total welfare standard (Lyons, 2003:3).

In the following subsections, we will define two measures as proxies of either the enhanced consumers' surplus or the social welfare, namely the expected efficiency gains, and the reduction in expected prices.

The way proxies are determined is always disputable. For example, any time prices are weighted using a different weight than the exchanged quantities associated to each of them, the measure of the expected price reductions is not indicative for an enhanced consumers' surplus. Therefore, using such a measure as a 'correct' approximation for the consumers' surplus would lead to some errors.

However, as it will become clearer, it is possible to characterize the type of errors that can be committed when relying on a proxy.

3.4.1 Objective functions: expected welfare and consumers' surplus

Before we turn to evaluating the mentioned proxies, let us describe which would be the ideal decisions if the objective functions expected social welfare and expected consumers' surplus were to be followed directly.

Irrespective of the observability of efforts, in the stand-alone case, there are four states of nature implying three different realizations of the consumers' surplus: both firms succeed in reducing their costs, leading to $CS^j(\beta c, \beta c)$, no firm succeeds leading to $CS^j(c, c)$ or either one firm succeeds while the other one fails, in which case we will have either $CS^j(\beta c, c)$ or $CS^j(c, \beta c)$, respectively, where $CS^j(\beta c, c) = CS^j(c, \beta c)$. Weighted with the corresponding probability, we obtain the expected consumers' surplus:

$$CS^j(S) = \left(p^j(S)\right)^2 CS^j(\beta c, \beta c) + \left(1 - p^j(S)\right)^2 CS^j(c, c) + 2p^j(S)\left(1 - p^j(S)\right) CS^j(\beta c, c),$$

where the superscript j stands for o or u, the observability or unobservability of the agents' efforts.

In addition to the expected consumers' surplus, the expected social welfare also includes the expected gross profits, as well as the agents' disutility of exerting an effort. Taking this into account, we can write for the expected social welfare in the pre-merger situation:

$$\begin{aligned} W^j(S) &= 2p^j(S)\left(1-p^j(S)\right)\left(\pi(\beta c,c)+CS(\beta c,c)\right)+\left(p^j(S)\right)^2 CS(\beta c,\beta c)+ \\ & \quad \left(1-p^j(S)\right)^2 CS(c,c)-2\left(\frac{1}{2}\left(p^j(S)\right)^2\right). \end{aligned}$$

If firms merge, there are only two states of nature, either the merged firm succeeds or it does not, leading to the respective realizations of the consumers' surplus, $CS^j(\beta c)$ and $CS^j(c)$, respectively. Again, weighted with their probability, we obtain the expression of the expected consumers' surplus:

$$CS^j(M) = p^j(M)\, CS^j(\beta c) + \left(1-p^j(M)\right) CS^j(c),$$

where we use the superscript j as above.

As for the pre-merger case, additionally to the expected consumers' surplus, the expected social welfare includes the merged entity's expected gross profit, and the agents' disutility of exerting an effort, leading to:

$$W^j(M) = p^j(M)\left(\pi(\beta c)+CS^j(\beta c)\right)+\left(1-p^j(M)\right)\left(\pi(c)+CS^j(c)\right)-2\left(\frac{1}{2}\left(e^j(M)\right)^2\right).$$

Figure 7 represents the impact of a merger on social welfare and consumer's surplus if efforts are observable and unobservable, respectively, and for high initial unit production costs, $c = 0.99$. The $CS-CS$ and $W-W$ lines represent the combinations of β and ε for which a competition authority, pursuing alternatively the consumers' surplus or the welfare standard, would be indifferent between the stand-alone situation and the merger. In addition to these two lines, we again depict the lines of indifference between merging and staying alone for the firms, labelled $\Pi-\Pi$.

In both worlds, the firms decide to stand-alone to the lower left of the $\Pi-\Pi$ line and the welfare (consumers' surplus), if firms merge, is higher than otherwise to the lower right of the $W-W$ line (the $CS-CS$ line). We see that a consumers' surplus standard is stricter than a welfare standard in both worlds, that is also when the agents that are responsible for reducing unit production costs are able to capture an information rent.

However, the $CS-CS$ and $W-W$ lines are closer to each other when efforts are unobservable. That means that adopting either standard would make less of a difference in a world where agents are subject to moral hazard. On top of this, the $\Pi-\Pi$ line also approaches the two lines mentioned so that the area of a potential conflict, i.e. the area where privately preferred mergers are undesired from either a welfare or a consumers' surplus point of view, is reduced. This is particularly striking for high initial unit production costs and not too low potential for their reduction, i.e. for $\beta < 0.8$.

Furthermore, in the unobservable efforts case with high initial costs, the $W-W$ line crosses the $\Pi-\Pi$ line. This means that there exist welfare increasing potential mergers which would

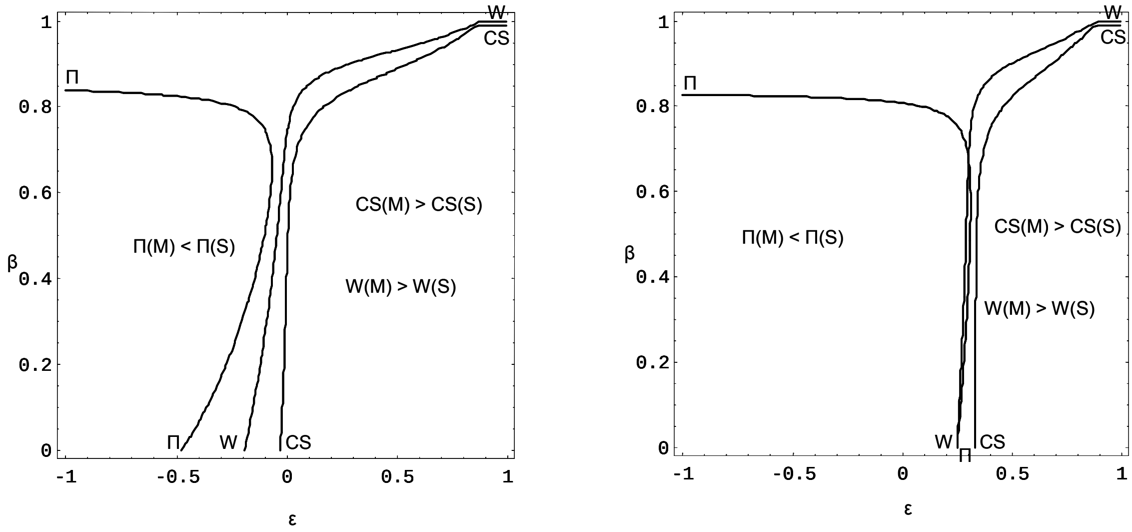


Figure 3.7: The firms' merger decision and its social welfare and consumers' surplus impact under no moral hazard (left) and under moral hazard (right) for $c = 0.99$

not be proposed by the merging parties. In this area, the expected welfare is increasing, and both, expected net profits and expected consumers' surplus, are falling. This means that there has to be another component of the expected welfare that compensates: the social cost of the effort exerted is reduced sensibly.

When the level of the initial cost is lower, the gap between the $\Pi - \Pi$, $W - W$ and CS lines is in general bigger than for higher initial costs. This is due to a large extent to the increased profitability of a merger as compared to the stand-alone situation when costs are not initially high. Opposite to the high initial costs case, i.e. when firms are more willing to go for a stand-alone project – as this guarantees them to be the sole beneficiary of a high monopoly profit should they succeed as the only one – lower initial costs make the perspective to merge be more attractive. Figure 3.8 shows this.

3.4.2 Proxies for the society's objective functions

Once the distinction between the consumers' surplus and the social welfare has been made, we can describe the consequences in the characterization of the type of errors a competition authority may commit when relying on an efficiency defense on the basis of proxies.

As for the consumers' surplus and for the social welfare, we can use the common superscript $j = o, u$ for each of the components of both the expected efficiency and prices in order to account for the observable and the unobservable efforts cases. This is possible as the nature of each component stays the same through these two environments: the only thing changing is their respective level as each of them has been obtained solving for different optimization problems.

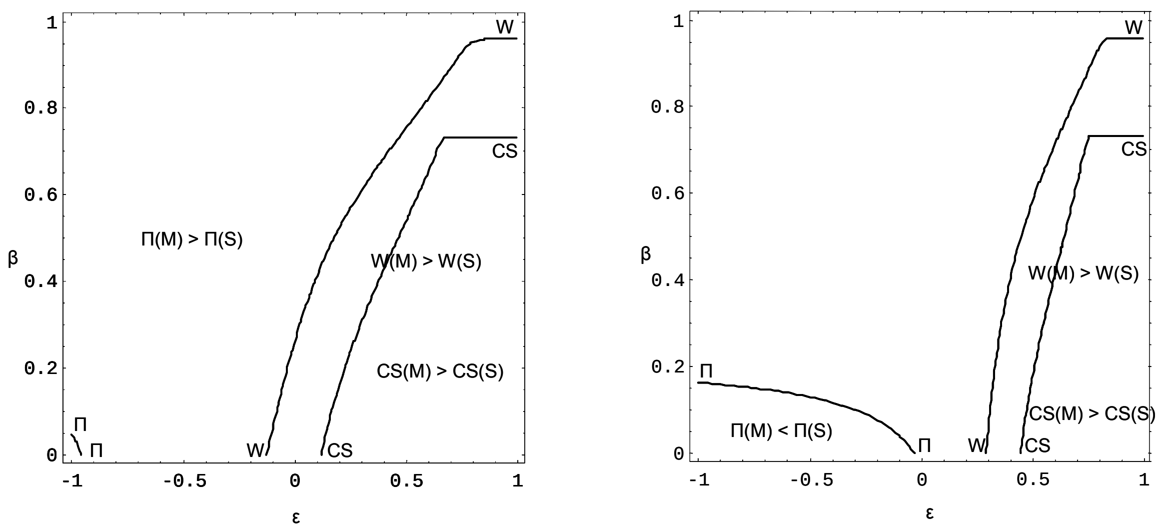


Figure 3.8: The firms' merger decision and its social welfare and consumers' surplus impact under no moral hazard (left) and under moral hazard (right) for $c = 0.79$

Expected efficiency gains

Let us concentrate first on the composition of the elements that enter the expected efficiency measure. In the stand-alone case, the expected efficiency takes the following form:

$$E^j(S) = \left(p^j(S)\right)^2 + 2p^j(S)\left(1 - p^j(S)\right),$$

whereas in the merger case:

$$E^j(M) = p^j(M).$$

These expressions play the equivalent role of the measure of the overall efficiency on the production side of the economy, respectively when two firms face a Bertrand competition on the market, and when the two firms merge*:* they give the probability of producing the good with the low production costs βc in the economy*.* In both these cases we will talk about ex-post efficiency, as we are considering – when writing the expressions the way we are doing – that the privately optimal induced probabilities of success have been replaced into the expressions of the ex-ante measures of efficiency.

The differences between the post-merger efficiencies and the pre-merger ones, both, under the no-moral hazard and the moral hazard assumptions, will determine, when positive, whether a merger leads to expected efficiency gains. If the following inequality holds, we will talk about efficiency gains due to a merger, either when moral hazard is not an issue, or when it is instead:

$$E^j(M) - E^j(S) > 0$$

The interest of the analysis is to combine the results of these inequalities, one for each of the two regimes considered, alternatively with the consumers' surplus and the social welfare. As argued in the previous section, in our analysis these two objective functions will be alternatively taken as a standard by a competition authority when it has to judge upon a proposed merger.

In order to perform the necessary comparisons, we repeat the same type of analyses as the ones we made when considering the merger decision of firms, or when we explained the relationships between the consumers' surplus and the social welfare as possible objective functions chosen by a competition authority. Thus, once more, in order to make the relevant graphical comparisons, we will fix different values of the initial costs, and we will let the parameters β and ε free to vary[12].

Let us take the consumers' surplus as the reference objective function first. Efficiency comparisons for this objective function can be described using figures 9 and 10, where the $E-E$ line depicts, in both, the curve where the difference between the pre and the post merger expected efficiency is zero. Again, comparisons are made for the observable and the unobservable efforts cases, and for two levels of the initial costs, a high and a moderate one. Given that when taking lower levels of the initial costs, the $\Pi-\Pi$ curve moves gradually to the left lower corner, and the $CS-CS$ as well as the $E-E$ lines move to the right lower corner, restricting our attention to only two levels of the initial costs is enough to describe the main results that can be obtained when performing this type of comparisons. Note that for any value of the initial cost c, the $E-E$ line always stays above the $CS-CS$ one.

Expected efficiency gains due to a merger only occur to the right of the $E-E$ line, i.e. both, in regions II and IV. However, while region II is not a problematic one as consumers' surplus increases too, in region IV consumers' surplus would decrease due to a permitted merger. Therefore, if an efficiency defense of all the proposed mergers leading to an expected efficiency gain was accepted then type I errors would be made for mergers falling in region IV: bad mergers would be accepted. Notice that the occurrence of the type I error is reduced, when facing a moral hazard behavior from the agents' side: area IV shrinks and the $E-E$ line gets closer to the $CS-CS$ line. The intuition for this result is that, under moral hazard, firms go together more often "*for the wrong*" reason, i.e. for pure market power reasons (compare area (a) in figures 5 and 6), and less often "*for the right*" reason, i.e. for the exploitation of synergies between the agents' efforts (compare area (b) in figures 5 and 6). This is reflected both, in the expected efficiency and in the consumers' surplus.

Notice also that requiring a significant efficiency gain due to a merger, may help reducing the occurrence of type I error when the society does not face a moral hazard behavior from the agents' side. The relevant indifference curve would be to the right of the $E-E$ line so that area IV would shrink as a result. However, the same recommendation is not a valid one anymore when facing a moral hazard behavior instead. The relevant indifference curve for the application of this recommendation would lie to the lower right of the $E-E$ line. Thus, using this new indifference curve another type of error would arise: a type II error, i.e. some good mergers would be refused instead. This is true at least when the level of the initial costs that the economy faces is high (see figure 9).

We can now repeat the same type of analysis made for the consumers' surplus, taking the

[12] Remember that the relevant comparisons will be made only in the range where $\varepsilon\,[-1,1[$.

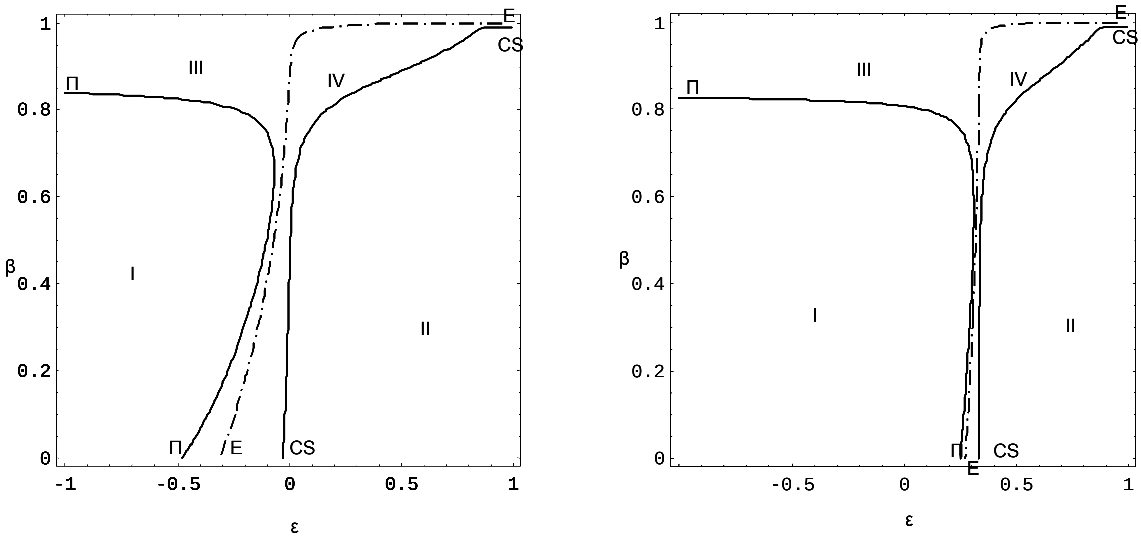


Figure 3.9: Efficiency gains: under consumers' surplus objective function, for both, observable (left) and unobservable (right) efforts, for $c = 0.99$.

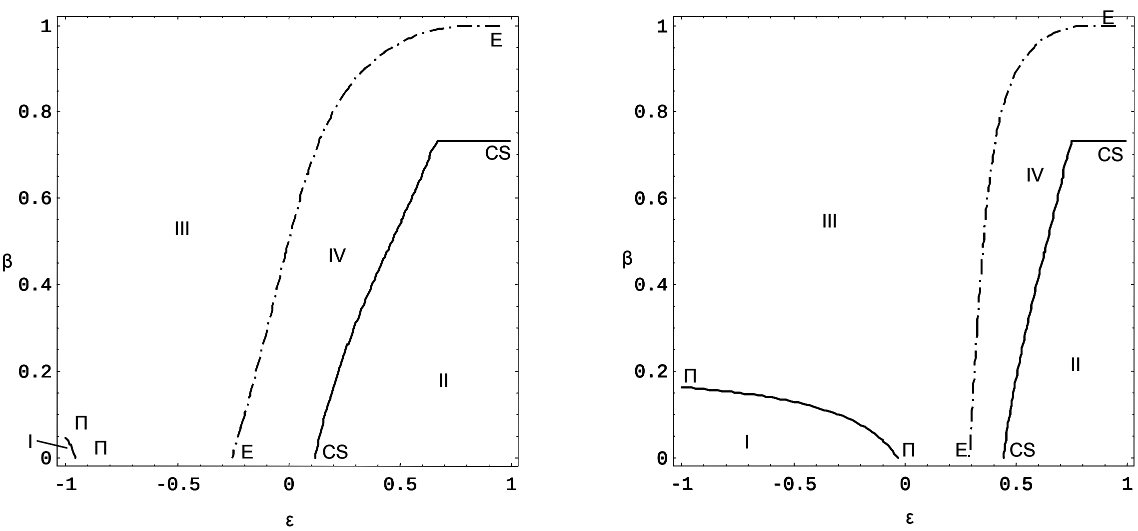


Figure 3.10: Efficiency gains: under consumers' surplus objective function, observable (left) and unobservable (right) efforts, for $c = 0.79$.

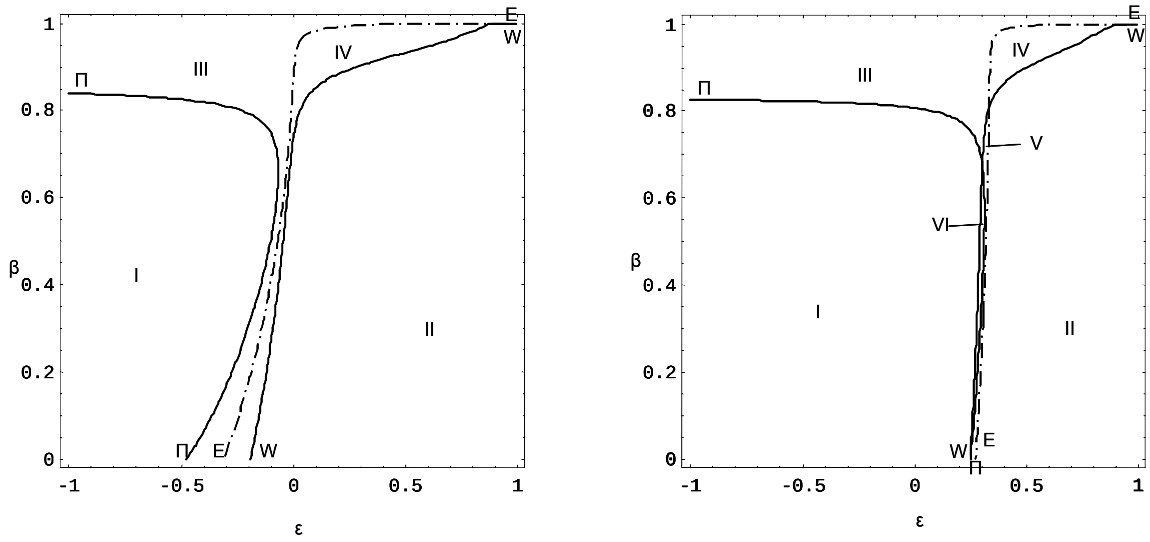


Figure 3.11: Efficiency gains: under social welfare objective function, both, observable (left) and unobservable (right) efforts, for $c = 0.99$.

social welfare as the reference objective function a competition authority may care about. Doing so, we obtain figures 11 and 12. As for the case where the consumers' surplus is the objective function chosen by the competition authority, we can characterize an area where type I errors are made when accepting an efficiency defense based on an enhanced efficiency induced by a merger. This area is labelled again as area IV, given that it has the same characteristics as before.

It is easy to check that, if social welfare is taken as a standard, the recommendation of having significant efficiency gains due to a merger may lead to type II errors both, in a world with and without moral hazard. Figure 11 shows that, in particular, these errors would be made systematically when the industry faces high initial costs: good mergers would be more often rejected than if only enhanced efficiency due to a merger were required instead.

Furthermore, under the moral hazard assumption, for values of β below 0.8 the $\Pi-\Pi$, $E-E$ and $W-W$ lines get closer to each other, up to the point that the $E-E$ crosses the $W-W$ line and the latter one crosses the $\Pi-\Pi$ line instead. This tells us two different things. First, that whenever the potential for cost reduction is not very low, even asking for an enhanced efficiency induced by a merger in order to approve it may be too demanding, in the sense that some mergers that would have been desirable under the social welfare standard would be rejected. These mergers are the ones falling in area V. Second, due to the crossing between the $W-W$ and the $\Pi-\Pi$ lines, an area VI appears where there exist mergers that would be socially desirable which are not even privately proposed. These two areas, V and VI, disappear for lower levels of the initial costs as shown in figure 12, thus making the requirement of enhanced, or even substantially enhanced, efficiency due to a merger be justified for lower levels of the initial costs.

To summarize:

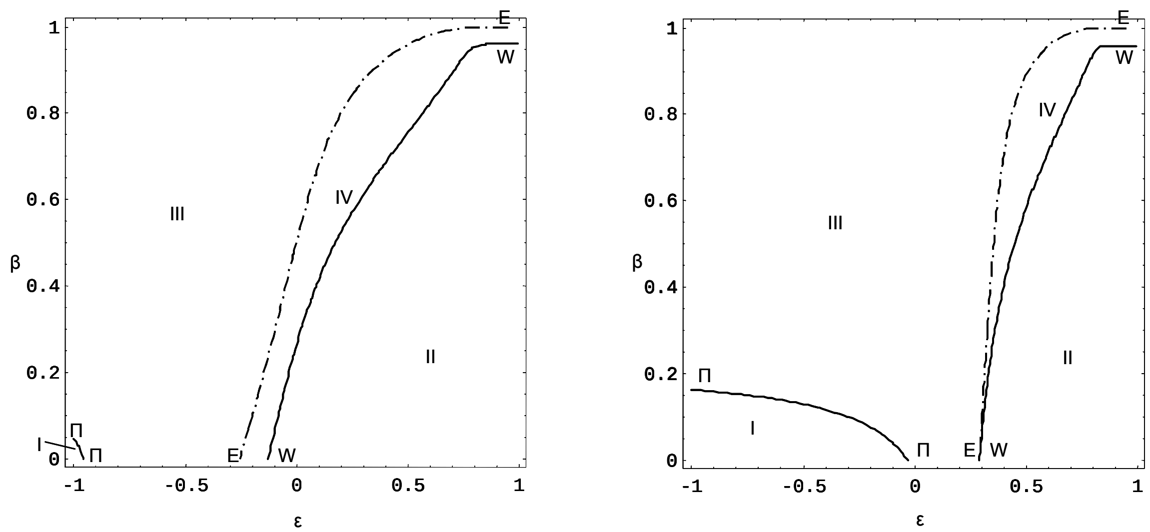


Figure 3.12: Efficiency gains: under social welfare objective function, both, observable (left) and unobservable (right) efforts, for $c = 0.79$.

Proposition 3.2 *If a competition authority adheres to a* (CS) *standard and relies on expected efficiency gains for judging proposed mergers:*

(i) Under no MH, type I errors are systematically committed, i.e. bad mergers are accepted, unless significant expected efficiency gains are required;

(ii) Under MH, type I errors are committed as well, but they occur less often than under the no MH assumption; for high initial costs the requirement of significant expected efficiency gains would lead to type II errors in addition, i.e. some good mergers would be rejected.

Proposition 3.3 *If a competition authority adheres to a* (W) *standard and relies on an expected efficiency gains for judging proposed mergers:*

(i) Under no MH, type I errors are systematically committed, i.e. bad mergers are accepted, but they occur less often than when using a (CS) *standard. For high initial costs, the significant expected efficiency gains requirement would lead to type II errors in addition, i.e. some good mergers would be rejected;*

(ii) Under MH, type I errors are committed for smaller regions than under the (CS) *standard, but type II errors can be committed in addition unless the potential for cost savings is low, i.e.* $\beta > 0.8$*. For high and moderate initial cost asking for substantial efficiency gains would lead to refuse some good mergers, i.e. type II errors are committed in addition.*

Corollary 3.1 *Under MH, the expected efficiency proxy is better calibrated to the objective functions than under no MH.*

Again, the intuition for the corollary is that, under moral hazard, firms go together more often "*for the wrong*" reason, i.e. for pure market power reasons, and less often "*for the right*" reason, i.e. for the exploitation of synergies between the agents' efforts. This is reflected in the expected efficiency as well as in the consumers' surplus and social welfare.

Expected price reductions

We now move to the comparisons concerning possible price reductions due to a merger. In order to do so, we characterize the expected price under the stand-alone and the merger cases respectively, replacing the relevant optimal levels of the probabilities of success obtained under each regime. Thus, the induced expected prices of a stand-alone situation are:

$$E^j\left[P(.,.)\right] = 2p^j(S)(1-p^j(S))P(\beta c, c) + \left(p^j(S)\right)^2 P(\beta c, \beta c) + (1-p^j(S))^2$$

where $j = o, u$ accounts, as before, for both the observable and the unobservable efforts cases.

The induced expected prices by a merger are:

$$E^j\left[P(.)\right] = p^j(M)P(\beta c) + (1-p^j(M))P(c).$$

When the following is true, a merger induces expected price reductions, either under observable or unobservable efforts:

$$E^j\left[P(.,.)\right] - E^j\left[P(.)\right] > 0$$

As before, we want to determine the impact over alternatively the consumers' surplus and the social welfare of relying on reductions in expected prices when deciding upon proposed mergers. We use here graphical representations in the same way as before to comment results of these comparisons.

Figures 13 and 14 show the comparisons when consumers' surplus is taken as a standard. In both figures, the $P-P$ line depicts the frontier between the mergers that do not lead to expected price reductions $-$ the ones to the left of this line $-$ and the mergers that would lead to reductions of the expected prices instead $-$ the ones to the right of it.

For high levels of the initial costs, the $P-P$ line intersects the $CS-CS$ one both in a world with and without moral hazard. The crossing results in the occurrence of two different areas, areas IV and V. The requirement of a reduction in the expected prices induced by a merger would provoke a type I error for mergers falling in area IV: bad mergers would be accepted, or a type II error for mergers falling in area V: good mergers would be rejected instead. The reduction of the expected price is too lax a requirement in certain cases, and a too strict one in others. However, under the moral hazard assumption the occurrence of type I errors in particular is sensibly reduced when compared to the one under the no moral hazard assumption. For lower values of the initial costs, the $P-P$ line always lies below the $CS-CS$ line, implying that only type II errors would eventually be made in these cases by requiring a reduction in the expected price induced by a merger in order to approve it: all the bad mergers are refused, together with some good ones.

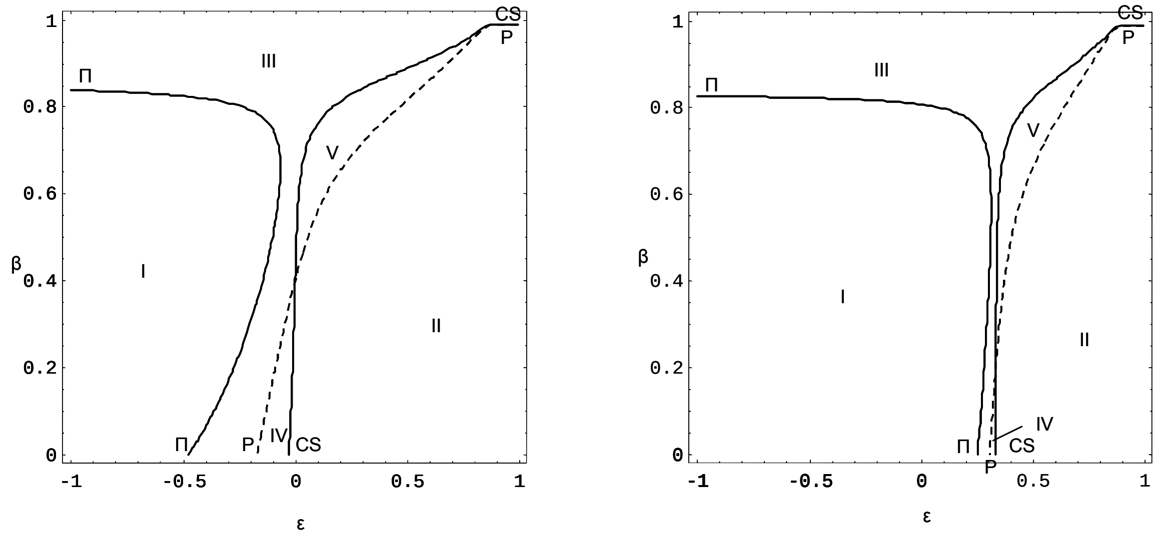


Figure 3.13: Expected Price: under consumers' surplus objective function, both, observable (left) and unobservable (right) efforts, for $c = 0.99$.

When we perform the parallel analysis using the social welfare as a standard we get figures 15 and 16. We can conclude that requiring a reduction in the expected price induced by a merger always leads only to type I errors, as the $P - P$ line always lies below the $W - W$ line no matter which is the initial level of costs considered, or whether or not we are facing a moral hazard problem in the industry. The type I error occurs again in the area labelled V.

As has been pointed out in section 3.4.1, under moral hazard and high initial costs, we have an area VI, given by the crossing between the $W - W$ and the $\Pi - \Pi$ lines, where welfare enhancing mergers are not proposed by the parties.

To summarize:

Proposition 3.4 *If a competition authority adheres to a* (CS) *standard and relies on reductions in the expected prices for judging proposed mergers:*

(i) Under no MH, type I and II errors are systematically made for high initial costs: for low β *some bad mergers are accepted and for higher* β *some good ones rejected. For lower initial costs, only type II errors are made. The requirement is either too lax or too strict.*

(ii) Under MH, type I errors are committed as well, but to a lower extent than under the no MH assumption and only for high initial costs. In addition, type II errors are made regardless of the level of the initial costs, i.e. the requirement is overall too strict.

Proposition 3.5 *If a competition authority adheres to a* (W) *standard and relies on reductions in the expected prices for judging proposed mergers: under no MH and MH assumptions, type II errors are systematically committed, i.e. some good mergers are rejected regardless of the level of the initial costs.*

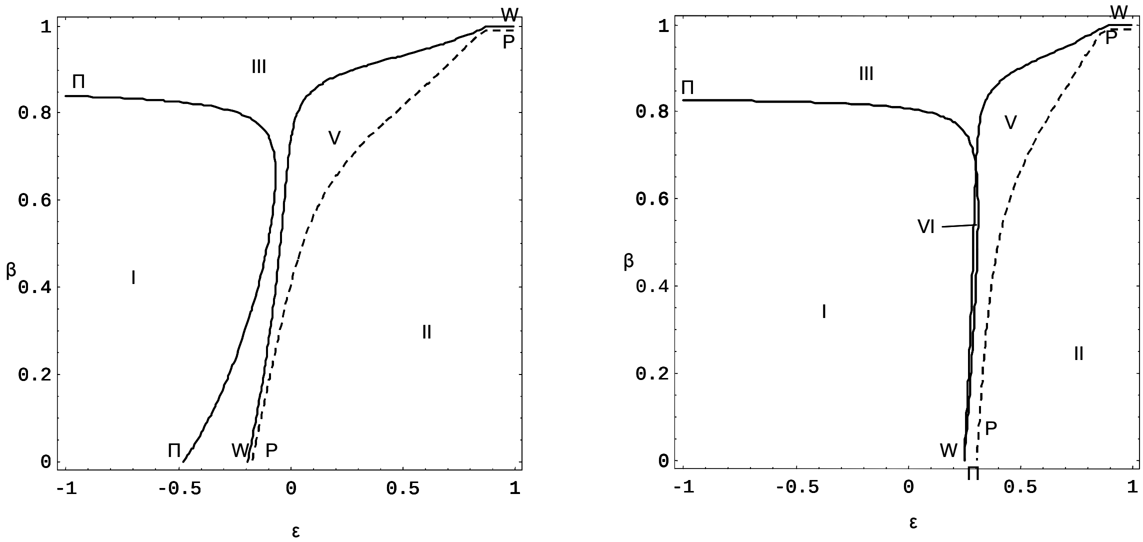


Figure 3.14: Expected Price: under social welfare objective function, both, observable (left) and unobservable (right) efforts, for $c = 0.99$.

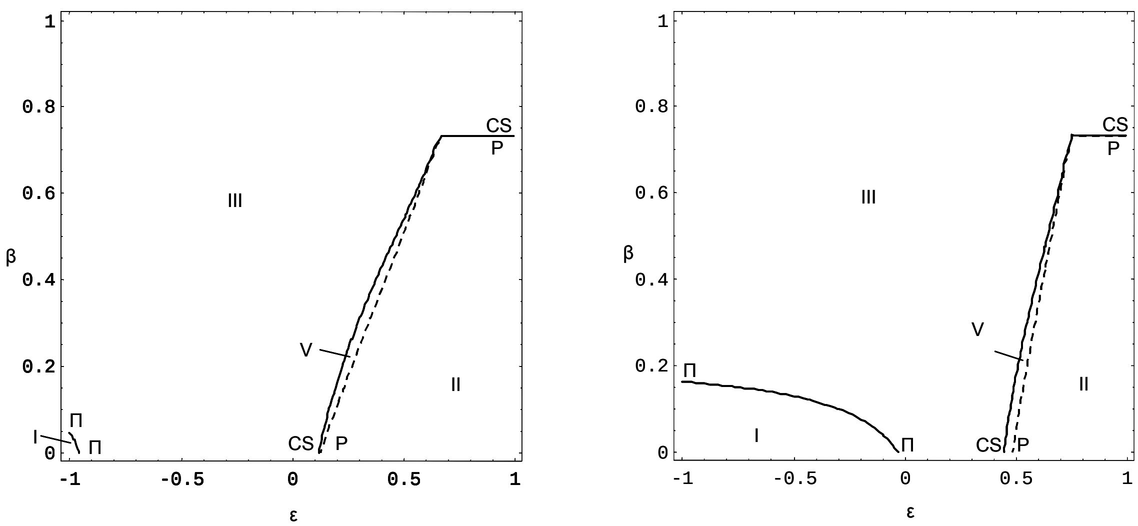


Figure 3.15: Expected Price: under consumers' surplus objective function, both, observable (left) and unobservable (right) efforts, for $c = 0.79$.

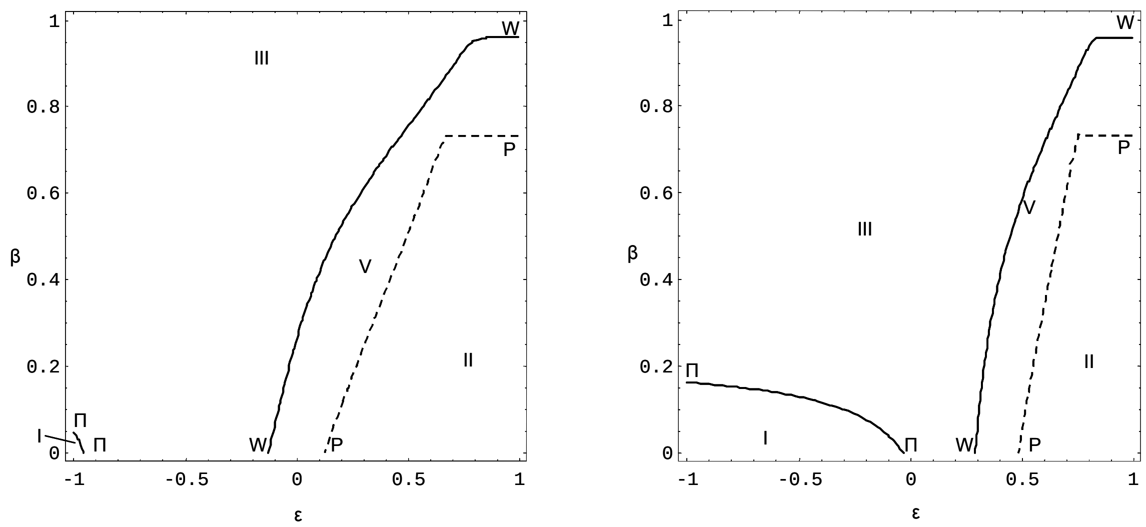


Figure 3.16: Expected Price: under social welfare objective function, both, observable (left) and unobservable (right) efforts, for $c = 0.79$.

Corollary 3.2 *Under MH, the expected price proxy is better calibrated to the objective functions than under no MH.*

The same intuition applies as the one for the expected efficiencies: under moral hazard, firms go together more often "*for the wrong*" reason, i.e. for pure market power reasons, and less often "*for the right*" reason, i.e. for the exploitation of synergies between the agents' efforts. This is reflected in the expected prices as well as in the consumers' surplus and social welfare.

3.4.3 Policy implications

Up to now, our analysis has focussed on the positive side of evaluating mergers using simple proxies such as expected efficiency gains or reductions in the expected prices.

We have argued that a proxy leads to errors as it cannot perfectly substitute for the real objective function. In this paper we have provided a characterization of the type of errors that might be committed when using these proxies, under two different regimes, i.e. with and without moral hazard. This characterization has been made in terms of parameters such as the potential for innovation, β, the type of the joint project, ε, and the level of the initial costs of the industry, c. Implicitly, we thereby also provided suggestions about which combination of these parameters do not lead to commit systematically errors of either type I or II.

At this point, we would like to go back to the criticism related to the use of proxies, such as expected efficiency gains and price reductions, as substitutes for either the consumers' surplus or the social welfare. If the use of these proxies helps giving some precise recommendation about which mergers to accept and which ones to refuse, then they may be used whenever they may allow to save on information to be collected and processed.

If a measure for these proxies could be constructed using the partial information that a competition authority may have access to, on the basis of the results obtained, we could conclude which is the potential danger in adopting one proxy instead of another as a function of the characteristics of the industry the merger is concerned with.

As an example, whenever the industry faces a moral hazard behavior from the agents' side, the potential for innovation is not too low, and the initial costs are high, then the expected efficiency gains would be a good statistic for the 'real' objective function pursued by a competition authority when deciding whether a proposed merger should be rejected or not. In this particular case, the collection of data to construct a precise measure for that proxy may result to be not as essential to judge upon the likelihood for the merger to lead to an improvement from both the social welfare and the consumers' surplus point of views. We know that in this case both consumers' surplus and social welfare induced by a proposed merger would be enhanced.

Whenever the initial costs are lower, no matter whether we face moral hazard or not, expected efficiency gains should be proved instead. In this case, the collection of data to construct an as precise measure of the proxy as possible may be crucial in deciding upon the merger. This is particularly true as long as the standard is the (CS). Furthermore, the lower the initial costs the more substantial the expected efficiency gains should be.

These are only some general implications that are directly coming from the results we have obtained in our analysis. Depending on the real objective of the competition authority and the parameters characterizing the industry, one or another proxy, or different combinations of them, could be alternatively preferred and constructed to adapt them and use them '*quanto basta*' in order to fit real merger cases decisions.

3.5 Conclusions

The wave of horizontal mergers that has occurred in this last decade, has opened a debate about the effects of mergers in their respective markets. On the one hand, worries have been voiced about the potential increase in market power, concentration, therefore decreased degree of competitiveness in these markets due to mergers. On the other hand, arguments in favor of mergers have been put forward, stressing their potential virtues, as their ability to create efficiency gains, coming from reduced production costs, transaction costs, or internal organization costs.

We have built a model where merger decisions and their potential efficiency gains are endogenized. The channel we propose and analyze has been formed by interactions of agents' efforts when they are devoted to a joint project within a merger as compared to when each agent has to conduct the same project alone. We have shown this way that mergers happen either when the potential for cost reduction is low, i.e. out of pure market power considerations, or when managerial efforts are close substitutes, or alternatively slight duplicates, when ex-post synergies, i.e. induced by implemented contracts, are present. Synergies are the results of both the interaction between these agents' efforts and the implemented contracts that drive the profitability of mergers, and determine the impact on consumers' surplus and social welfare.

Results tell us that an efficiency defense based on potential efficiency gains due to a merger is generally too lax a requirement − some bad mergers would be accepted − for the observable efforts case, and, for both informational assumptions, when the initial costs are not too high. In these cases, requiring substantial efficiency gains may reduce this distortion. Results also show that requiring the same for either the unobservable case when initial costs are high, or for a larger range of costs when the standard used is the social welfare, may be too strict: some good mergers would be refused. In any case when efforts are unobservable, this requirement is more aligned to either type of standards.

We have also shown that the alternative requirement of comparing prices before and after the merger, which would require to have additional information processed from the demand side, turns out not to be necessary. The measure of the expected efficiency gains can be precise enough when adjusted in the right way: using it 'quanto basta'.

Chapter 4

Control over joint development and the incentives to innovate

4.1 Introduction

There are various ways in which a firm's competitive environment affects the optimal managerial incentives to exert an effort in the invention of new products, the reduction of production costs, or the selling of a product. Several studies highlight that competition affects managerial incentives positively. It offers a yardstick to the shareholders, as the firm's performance can be measured against close competitors. It enables relative performance evaluation which "may be seen as a consequence of Holmström's (1979, 1982) informativeness principle that stipulates that in a principal-agent relationship all informative signals should be included in contracting" (Celentani and Loveira, 2004). It offers insurance to risk averse managers by reducing the impact of exogenous (demand or cost) shocks and thus increases incentives (Rey and Tirole, 1986). It may improve incentives to the management in firms with poor governance structures to adopt new technologies through the threat of bankruptcy (Aghion, Dewatripont, and Rey, 1997).

This paper takes an alternative approach to show the impact of the competitive environment – or more specifically, of a pro-competitive policy – on managerial incentives to develop new products[1], one coming directly from the separation of ownership and control inside the firms. In our paper, we analyze a situation in which – without any policy intervention – the competitive structure in which the invention of a new product is carried out, is not given exogenously but emerges endogenously as a choice of both, the shareholders and their managers. Shareholders give their managers optimal incentives to develop the new product – either in stand-alone or in joint development with the other firm – and trade off the possibility to internalize a negative externality and to enjoy synergies by means of joint development against the disadvantage of being unable to attribute a success to a specific manager under joint development.

In stand-alone development, firms exercise a negative externality on their competitor: an increase in the development effort of one firm, ceteris paribus, reduces the probability that the

[1] Although our example is that of a product development, our analysis is not limited to it. One may easily think of alternative interpretations of the project, such as production cost reductions, process innovations or the supply of retail services.

other firm is successful alone and therefore the other firms expected profits. As the optimally implemented development effort is increasing in the value of the potential innovation, this externality increases in this value, too. This may induce joint development, within which the externality is internalized: In joint development, the implemented effort levels (given through the bonuses given to the management) are "coordinated". This, however, means a reduction of the optimal bonuses, which may go against the interest of the management itself. If then the management has superior information on how valuable a joint development of the product might be, i.e. about the extent of the synergies that may be achieved, it may be costly to let them reveal that information in those situations, in which the management would oppose a profit increasing joint development. On the other hand, if the value of the potential innovation is low, the effect of the externality is outweighed by the disadvantage of being unable to attribute a success to a specific manager under joint development. However, the inability to attribute a success to a specific manager is a source of rents to the managers. Again, if the management has superior information on how valuable a joint development of the product might be, i.e. about the extent of the synergies that may be achieved, it may be costly to let them reveal that information in those situations, in which the management would prefer a profit decreasing joint development.

Our results show that, under this type of asymmetric information, for a high value of the innovation, the owners optimally reduce the incentives they give to their managers in stand-alone development. As a consequence, we show that, for high value innovations, a *pro-competitive policy will also increase* the *incentives* given to the management to exert an effort in the stand-alone development as compared to laissez faire.

In this paper, we propose a simple model characterized by the following features. There is a project for the development of a new product and there are two firms, which have the potential to develop the product. These two firms face the decision of whether to conduct the project each on a stand-alone basis, targeting a common market, or jointly, sharing the market later on. The project(s) is (are) conducted by managers employed by the firms and protected by limited liability[2]. In the stand-alone configuration, each of the firms employs one manager, whereas in the joint situation, both managers are employed by the joint entity, which, that way, exploits potential synergies coming from the collaboration of the managers. The managers' efforts put into the development of the product, which are assumed (throughout most of the paper) to be not contractible, affect the probability of success of their respective project. Joint projects are characterized by a degree of synergies coming from a reduction of duplication of the managers efforts to develop the product. Before starting the project, the managers may receive a perfectly informative signal on the extent of potential synergies in a joint project. We assume that this signal is not observable by the owners. These can, however, by distorting the contract they would offer under symmetric information, provide incentives to the managers to reveal their information.

Our work is closely related to Fabrizi and Lippert (2005a) and (2005b). Fabrizi and Lippert

[2] The alternative interpretation is that the managers are infinitely risk averse and would not accept a contract that pays a negative wage in any state of nature (see Tirole and Rey, 1986, for a similar interpretation).

(2005b) shows the impact of moral hazard on the organizational choice for conducting a research project leading to an innovation of a fixed value. In Fabrizi and Lippert (2005b) joint research is chosen for high values of the innovation and/or for high synergies. Furthermore, under moral hazard, even thought the cost of implementing the same level of effort is higher, the joint research, which shares these costs, is chosen less often than in the absence of moral hazard. In Fabrizi and Lippert (2005a), a merger decision in the presence of a process innovation is considered and implications of the presence of moral hazard for an adoption of an efficiency defense are drawn. Contrary to both Fabrizi and Lippert (2005a) and (2005b) we abandon here the assumption maintained in these papers of full information on the amount of achievable synergies. In addition, in this paper, we differ in our approach on how to model synergies, introducing a parameter taking values from no synergies to full elimination of overlap, which allows us to disentangle the effects of each of our assumptions more easily.

In order to derive our results and the intuitions for them, we are proceeding in a step-wise fashion, isolating the effect of each assumption. In section 3, we will assume that there is symmetric information on the extent of the potential synergies between the owners of the firm and the managers and that owners have full control over the decision whether to pursue the development of the product in a stand-alone or in a joint organization. We will first derive the optimal contracts for the stand-alone organization. Second, we will do the same for the joint project organization under two different assumptions: (1) owners observe a separate statistic for each manager employed and coordinate the incentives to give to them and (2) owners observe only one joint statistic for the managers' efforts. In the first of the joint situations, owners observe whether each of the managers succeeded in their part of the project, whereas in the second, only the success of the overall project is observed. For each of the joint organizations, we allow the synergies to vary between the extremes of no synergies and full elimination of the duplication of the managers' efforts. In the case of no synergies, the change between the stand-alone and the joint organizations comes under (1) and (2) from the coordination in giving incentives to the managers and under (2) from the modified assumptions on the availability of statistics for the managers' efforts. For all these assumptions, we will show the configurations chosen by the owners and their implication for the managers' utility.

In section 4, we will lift the assumption that the owners have full control over the decision whether to pursue the project in a stand-alone or in a joint organization. We assume that the management retains real control over the organizational form by being better informed about the synergies attainable in a joint project.

The paper ends with a summary of our findings and an outlook to further research.

4.2 Model setup

In this section, we describe the setup of the basic model. We describe the project, the payoffs for the shareholders of the firms, as well as the payoffs of the managers carrying out the project.

Project There is a project to develop a new product that targets a given market of value π. Let there be two firms, indexed $i = 1, 2$, pursuing each this project. The shareholders of the firms face the decision of whether to conduct the project each in a stand-alone fashion or jointly. If, in a stand-alone project, only one of the firms succeeds, she will appropriate the whole value of π attainable in the market. If on the other hand both firms succeed in developing the product, we assume them to share the market[3], appropriating each the value of $\frac{\pi}{2}$. In case the firms decide to conduct the project jointly, we assume them to form a new entity to do so. In case of success, this joint entity appropriates the value π. We assume an exogenously determined sharing rule, according to which the payoffs (and the costs) of a joint project are shared equally among the two firms. Thus, in case of success of the joint project, each firm gets $\frac{\pi}{2}$. In case of failure, both, a stand-alone and a joint project, pay off zero.

Probability of success The development of the new product is assumed to be carried out (or supervised) by the management of the firms. In a stand-alone project, each firm i employs one manager, also indexed i. With their effort e_i, the managers affect the probability of success of their respective project. This probability is assumed to be $p_i^S = e_i$. Thus, the success of one stand-alone project is assumed to be statistically independent of the success of the other one. In a joint project, both managers of the two firms are working together. The probability of success of the joint project is assumed to be a function of both managers' efforts, e_1 and e_2, and of a parameter s capturing the extent of synergies in a joint project. It is defined as $p^J = e_1 + e_2 - (1 - s)\, e_1 e_2$. This probability function captures two aspects. First, if the two managers conducting the joint project do that in a parallel fashion, it is enough if one of them succeeds. Second, if $s = 0$, the success of the parts of each of the managers is independent of the success of the other one. There is, therefore, the same "overlap" or duplication of their efforts as in the stand-alone situation. An $s \in (0, 1]$ signifies that, in a joint project, there is some (exogenous) coordination between the two managers, alleviating (some of) the duplication of their efforts. We call this the *synergies* coming from a joint project. The extent of the synergies is assumed to be given exogenously. It cannot be affected by the managers or the owners of the firms.

Managers Managers affect the probability of success of the project through their effort. Throughout most of the paper, we will assume that these efforts are not observable and that it is therefore not possible to write contracts contingent on them. Exerting the effort e_i implies a disutility for the manager that is equal to $c_i(e_i) = \frac{1}{2} e_i^2$. For carrying out the project, the managers receive a transfer t_i from the entrepreneurs employing them. The managers' utility is additively separable between effort and money,

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

Managers are assumed to be protected by limited liability, i.e. the transfers t_i made by the

[3] It can be shown that our results do not change qualitatively if we assume that a success of both firms destroys value appropriable by the firms, i.e. if each of them receives only less than $\frac{\pi}{2}$.

firms have to be non-negative[4]. As it is impossible to write contracts contingent on efforts, under stand-alone development, these will be written on the observable and verifiable success of the respective project. For joint development, we take two different assumptions: first, we will assume that it is possible to observe and verify the success of each manager separately, i.e. there is an independent statistic for the effort of each manager. Under this assumption, contracts will be written on the success of the manager in his respective part of the joint project. Second, we will assume that it is only possible to observe and verify the success of the project as a whole, i.e. there is only one common statistic for both managers' efforts. Under this alternative assumption, contracts will be written on the success of the whole project. In a joint project, we always impose equal contracts to both agents[5].

In any configuration, we assume that the managers do not observe each other's effort choice. This implies that they cannot collude.

Shareholders Shareholders are assumed to be risk neutral and maximize their expected profits.

4.3 The joining decision if shareholders have full control over it

In this section, we assume that both, the shareholders of the firm and the managers, have full information on the synergies achievable if they develop the product jointly.

Assumption 4.1 *s is observable and verifiable.*

The shareholders decide to develop the product in a joint venture if the expected profit from doing so exceeds the one they can get in a stand-alone development. In the following, we will first derive the optimal contracts, both for observable and unobservable efforts, for the stand-alone development and for the two assumptions on the statistics for the agents' efforts under joint development. We will then characterize the shareholders' decision and their impact on the utility of their managers. This will become the basis for the comparisons in the next section.

4.3.1 Stand-alone development

Observable efforts

If efforts are contractible, the owner of firm i $(i, j = 1, 2,\ i \neq j)$ maximizes

$$\max_{e_i} \left[e_i \left(1 - e_j\right) \pi + e_i e_j \frac{\pi}{2} - \frac{1}{2} e_i^2 \right].$$

[4] An alternative interpretation of this assumption is that the managers are infinitely risk averse, and that they require that their transfer in the worst possible outcome (the only one they care about ex ante) be non-negative (see Rey and Tirole, 1986, for a similar assumption).

[5] It can be shown that giving equal contracts to both managers would emerge in equilibrium as the result of the minimization of the cost of implementing a given probability of success.

Resulting from these maximization problems, in the *stand-alone* equilibrium with *observable* efforts, labelled with S, o, each owner i implements an effort level of

$$e_i^{S,o} = \frac{2\pi}{\pi + 2},$$

leading to an expected profit of

$$E\Pi_i^{S,o} = \frac{2\pi^2}{(\pi + 2)^2}.$$

Unobservable efforts

In this subsection, the agents' efforts are assumed to be not contractible. Contracts will, thus, be written contingent on the observable and verifiable outcome of the project. In case of failure of the project in firm i, manager i receives a base wage $w_i^{S,u}$, whereas in case of success, he receives, in addition to the base wage $w_i^{S,u}$, the bonus $b_i^{S,u}$, where the superscript S, u stands for *stand-alone* development with *unobservable* efforts. Manager i then chooses the level of effort to exert such as to maximize his utility. His maximization program is

$$\max_{e_i} \left[w_i^{S,u} + e_i b_i^{S,u} - \frac{1}{2} e_i^2 \right],$$

which results in the incentive compatibility constraint

$$e_i = b_i^{S,u}.$$

Manager i accepts the contract if his expected utility from doing so exceeds the one of his outside option, which we normalize to zero. Furthermore, as the managers are protected by limited liability so $w_i^{S,u}$ has to be non-negative.

Firm i's maximization problem under stand-alone development is

$$\begin{aligned}
&\max_{w_i^{S,u}, b_i^{S,u}} \left[e_i (1 - e_j) \pi + e_i e_j \frac{\pi}{2} - e_i b_i^{S,u} - w_i^{S,u} \right] \\
&s.t. \qquad e_i = b_i^{S,u} \qquad\qquad (IC) \\
&\qquad\qquad w_i^{S,u} \geq 0 \qquad\qquad (LL) \\
&\qquad\qquad w_i^{S,u} + e_i b_i^{S,u} - \tfrac{1}{2} e_i^2 \geq 0. \qquad\qquad (IR)
\end{aligned}$$

The solution to this problem gives

$$\begin{aligned}
w_i^{S,u} &= 0, \\
b_i^{S,u} &= e_i^{S,u} = \frac{2\pi}{\pi + 4},
\end{aligned}$$

as well as the expected per entrepreneur profits, $E\Pi_i^{S,u}$, and expected utility of the managers, $EU_i^{S,u}$,

$$E\Pi_i^{S,u} = \left(\frac{2\pi}{\pi+4}\right)^2,$$
$$EU_i^{S,u} = \frac{1}{2}\left(\frac{2\pi}{\pi+4}\right)^2.$$

4.3.2 Joint development

Next, we derive the optimal contracts if shareholders opt for joint development. We do so first for the assumption of observable efforts, then under the premise that the shareholders observe the success of each agent separately and finally supposing that the shareholders observe only the success of the whole project.

Observable efforts

Under the observable efforts assumption, the joint maximizes

$$\max_{e_1,e_2} \left(e_1 + e_2 - (1-s)\, e_1 e_2\right) \pi - \frac{1}{2}e_1^2 - \frac{1}{2}e_2^2.$$

Resulting from this maximization problem, the *joint* entity with *observable* efforts, labelled with J, o, implements effort levels of

$$e_i^{J,o} = \frac{\pi}{1+(1-s)\,\pi}.$$

The resulting expected profit of the joint entity is

$$E\Pi^{J,o} = \frac{\pi^2}{1+(1-s)\,\pi}.$$

Proposition 4.1 *If efforts and the extent of synergies are observable,* $\forall\pi$, $\forall s \in [0,1]$, $\frac{1}{2}E\Pi^{J,o} \geq E\Pi_i^{S,o}$; *and* $e_i^{J,o} \geq e_i^{S,o}$ *iff* $s \in \left[\frac{1}{2}, 1\right]$.

Proof. $\frac{1}{2}E\Pi^{J,o} \geq E\Pi_i^{S,o} \Leftrightarrow \frac{1}{2}\frac{\pi^2}{1+(1-s)\pi} \geq \frac{2\pi^2}{(\pi+2)^2} \Leftrightarrow \pi^2 \geq -4s\pi$, which is true $\forall\pi$, $\forall s \in [0,1]$. $e_i^{J,o} \geq e_i^{S,o} \Leftrightarrow \frac{\pi}{1+(1-s)\pi} \geq \frac{2\pi}{\pi+2} \Leftrightarrow s \geq \frac{1}{2}$. QED. ■

If efforts and the extent of synergies are observable, the firms choose joint over stand-alone development for any profit and synergy level. Doing so, they implement higher effort levels than the stand-alone firms if and only if $s \geq \frac{1}{2}$[6].

In stand-alone development, each firm does not take into account the decrease in the expected profit of the other firm due to its own increase in the implemented effort. This effect does not appear if these two firms form a joint entity. Therefore, even if s was close to 0, i.e. that

[6] The results use the optimal contracts calculated in this section without explicitly taking the constraints $p^{J,os} \in [0,1]$ and $p^{S,o} \in [0,1]$ into account. However, we do not need to restrict our comparison to $\pi - s-$combinations for which $e_i^{J,os} = \frac{\pi}{(1-s)\pi+1} \leq 1$, i.e. to $\pi \leq \frac{1}{s}$, and $e_i^{S,u} = \frac{2\pi}{\pi+2} \leq 1$, i.e. $\pi \leq 2$, as it is possible to show that there are contracts that take into account the restrictions, for which the *qualitative* statements made hold.

there were (almost) no synergies, the firms would prefer joint development. They do so as going for joint development allows them to "coordinate" on the levels of efforts to implement. For low synergies, this "coordination" in the levels of efforts leads to lower implemented efforts. Increasing the level of synergies makes an increase of the effort level more profitable, and as a result, from a certain synergy level on, i.e. for $s \geq \frac{1}{2}$, the implemented effort levels under joint development is higher than under stand-alone development.

Unobservable efforts, owners observe the success of each agent separately

In this subsection, we assume that each of the agents is fulfilling a separable task and that, for the success of the whole project, it is only necessary that one of them succeeds in his task. The task, thus, corresponds simply to the development of the product. We assume – as in the stand-alone development – that agent i succeeds in his task with probability $p_i = e_i$. This success is observable and verifiable and contracts will, thus, be written contingent on it.

Manager i maximizes

$$\max_{e_i} \left[w^{J,us} + e_i b^{J,us} - \frac{1}{2} e_i^2 \right],$$

which results in the incentive compatibility constraint

$$e_i = b^{J,us}.$$

The superscript J, us stands for *joint* development with *unobservable* efforts and *separately* observable success of the managers. He accepts the contract again if it gives him an expected utility of at least zero.

Given that we assumed that there is some duplication of the agents' efforts, which is potentially smaller than under independent, stand-alone development – this accounts for synergies – the joint entity is successful with probability $p = e_1 + e_2 - (1-s) e_1 e_2$. It pays a bonus to agent i with probability e_i. Therefore, it maximizes

$$\begin{aligned}
&\max_{w^{J,us}, b^{J,us}} \left[(e_1 + e_2 - (1-s) e_1 e_2) \pi - e_1 b^{J,us} - e_2 b^{J,us} - 2w^{J,us} \right] \\
&s.t. \qquad e_i = b^{J,us} \qquad (IC) \\
&\qquad\qquad w^{J,us} \geq 0 \qquad (LL) \\
&\qquad\qquad w^{J,us} + e_i b^{J,us} - \tfrac{1}{2} e_i^2 \geq 0. \qquad (IR)
\end{aligned}$$

The solution to this gives

$$\begin{aligned}
w^{J,us} &= 0, \\
b^{J,us} &= e_i^{J,us} = \frac{\pi}{(1-s)\pi + 2},
\end{aligned}$$

as well as the expected profit of the joint entity, $E\Pi^{J,us}$, and the expected utility of each manager, $EU_i^{J,us}$,

$$E\Pi^{J,us} = \frac{\pi^2}{(1-s)\pi+2},$$
$$EU_i^{J,us} = \frac{1}{2}\left(\frac{\pi}{(1-s)\pi+2}\right)^2.$$

Proposition 4.2 *Under assumption 4.1, if the results of the managers' tasks are independently observable,* $\forall\pi$, $\forall s\in[0,1]$, $\frac{1}{2}E\Pi^{J,us}\geq E\Pi^{S,u}$; $e_i^{J,us}\geq e_i^{S,u}$ *iff* $s\in\left[\frac{1}{2},1\right]$; *and* $EU_i^{J,us}\geq EU_i^{S,u}$ *iff* $s\in\left[\frac{1}{2},1\right]$.

Proof. $\frac{1}{2}E\Pi^{J,us}\geq E\Pi^{S,u}\Leftrightarrow\frac{1}{2}\frac{\pi^2}{(1-s)\pi+2}\geq\left(\frac{2\pi}{\pi+4}\right)^2\Leftrightarrow\pi^2\geq-8s\pi$, which is true $\forall\pi$, $\forall s\in[0,1]$. $e_i^{J,us}\geq e_i^{S,u}\Leftrightarrow\frac{\pi}{(1-s)\pi+2}\geq\frac{2\pi}{\pi+4}\Leftrightarrow s\geq\frac{1}{2}$. $EU_i^{J,us}\geq EU_i^{S,u}\Leftrightarrow\frac{1}{2}\left(\frac{\pi}{(1-s)\pi+2}\right)^2\geq\frac{1}{2}\left(\frac{2\pi}{\pi+4}\right)^2\Leftrightarrow s\geq\frac{1}{2}$. QED. ■

The comparison of the expected profits reveals that shareholders prefer the joint development for any π, even if there are no synergies, i.e. even if $s=0$. This result is due to the possibility of coordinating the managers' implemented efforts. However, as long as the synergies are not high enough, i.e. if $s<\frac{1}{2}$, the management's utility decreases as this coordination in the managers' implemented efforts means a reduction in their bonuses. The result parallels that for observable efforts[7].

Note that the extent of the externality on firm exercises on the other one – for a given effort level of that other firm – does not depend on the introduction of the moral hazard. Furthermore, the synergies are *not* cost side synergies, thus, there is no coordination of the *incentive contracts*, but only on the implemented *efforts*. This explains the congruence of the results in this section with the one before.

Unobservable efforts, owners only observe the success of the overall project

In this section, we again assume that each of the agents is fulfilling a task and that, for the success of the whole project, it is only necessary that one of them succeeds in his task. Again, agent i succeeds in his task with probability $p_i=e_i$. However, we assume now that this *individual success* is *not observable* and verifiable and contracts can, thus, not be written contingent on it. Instead, only the fact whether the product has been developed at all can be observed and verified and contracts will be written contingent on this observation.

Manager i maximizes

$$\max_{e_i}\left[w^{J,uc}+(e_1+e_2-(1-s)e_1e_2)\,b^{J,uc}-\frac{1}{2}e_i^2\right],$$

[7] The results use the optimal contracts calculated in this section without explicitly taking the constraints $p^{J,us}\in[0,1]$ and $p^{S,u}\in[0,1]$ into account. However, as with observable efforts, we do not need to restrict our comparison to $\pi-s-$ combinations for which $e_i^{J,us}=\frac{\pi}{(1-s)\pi+2}\leq 1$, i.e. to $\pi\leq\frac{2}{s}$, and $e_i^{S,u}=\frac{2\pi}{\pi+4}\leq 1$, i.e. $\pi\leq 4$, as it is again possible to show that there are contracts that take into account the restrictions, for which the *qualitative* statements made hold.

where J, uc stands for *joint* development, *unobservable* efforts, and the fact that shareholders observe only a *common* statistic for the success of both managers. This results in the incentive compatibility constraint

$$e_i = \frac{b^{J,uc}}{(1-s)\, b^{J,uc} + 1}.$$

The firm maximizes

$$\max_{w^{J,uc}, b^{J,uc}} \left[(e_1 + e_2 - (1-s)\, e_1 e_2) \left(\pi - 2b^{J,uc} \right) - 2w^{J,uc} \right]$$

$$s.t. \qquad e_i = \frac{b^{J,uc}}{(1-s) b^{J,uc} + 1} \qquad (IC)$$

$$w^{J,uc} \geq 0 \qquad (LL)$$

$$w^{J,uc} + (e_1 + e_2 - (1-s)\, e_1 e_2)\, b^{J,uc} - \tfrac{1}{2} e_i^2 \geq 0. \qquad (IR)$$

The first order condition to this maximization program with respect to $b^{J,uc}$ is

$$\frac{\partial \Pi^{J,uc}}{\partial b} = \left(\pi - 2b^{J,uc} \right) \left(\frac{2}{1 + (1-s)\, b^{J,uc}} - \frac{4b^{J,uc}(1-s)}{\left(1 + (1-s)\, b^{J,uc}\right)^2} + \frac{2\left(b^{J,uc}\right)^2 (1-s)^2}{\left(1 + (1-s)\, b^{J,uc}\right)^3} \right) - 2\left(\frac{2b^{J,uc}}{1 + (1-s)\, b^{J,uc}} - (1-s) \frac{\left(b^{J,uc}\right)^2}{\left(1 + (1-s)\, b^{J,uc}\right)^2} \right) = 0,$$

and the optimal base wage and bonus resulting from the problem are $w^{J,uc} = 0$ and

$$b^{J,uc} = -\frac{1}{(1-s)} + \frac{\phi}{(1-s)^2 \sqrt[3]{18}} - \frac{\sqrt[3]{\frac{2}{3}}}{\phi},$$

where

$$\phi = \sqrt[3]{18\,(1-s)^3 + 9\pi\,(1-s)^4 + \sqrt{3}\,(1-s)^3 \sqrt{112 + 108\pi\,(1-s) + 27\pi^2\,(1-s)^2}}.$$

We renounce to report the algebraic expressions for the expected profits and the managers' expected utility. Instead, we offer a graphical comparison with the stand-alone development.

In figure 4.1, the $\Pi - \Pi-$ line corresponds to the $\pi - s-$ combinations, for which the expected profit of each firm from a stand-alone development equals the one it can have in a joint development. Below the line, the expected profits from stand-alone development are higher than those from joint development and vice versa. The $U - U-$ line is the managers' indifference curve between these two organizational forms. For $\pi - s-$ combinations below the line, they prefer stand-alone development. The $Pr - Pr-$ line corresponds to the $\pi - s-$ combinations, for which the probability of success under joint development equals the probability that the product is successfully developed by at least one firm under stand-alone development. Above this line, the probability of success of joint development is higher than the corresponding probability under

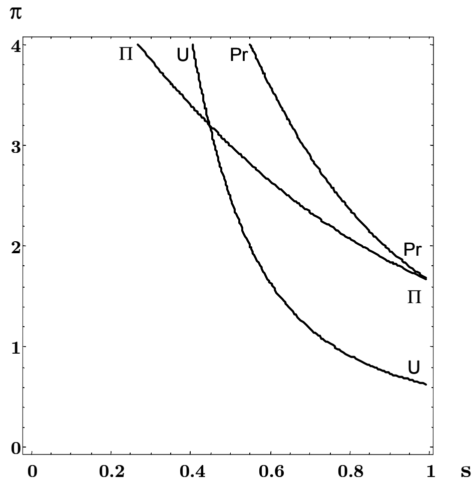


Figure 4.1: Comparison stand-alone vs. joint development if only one statistic for both managers is available

stand-alone development. Note also that the implemented efforts under (S, u) are always higher than those under (J, uc)[8].

From figure 4.1, we notice two areas of disagreement between the shareholders and the managers. For relatively high values of π and intermediate synergies s, there are profit increasing joint projects that are decreasing the utility of the managers and for intermediate to low π and intermediate to high synergies, there are joint projects that increase the managers' utility while decreasing the profits of the shareholders.

Furthermore, it is possible to show that the effort levels implemented under stand-alone development are always higher than under the joint configuration when only the overall success is observable.

Proposition 4.3 *Under assumption 4.1, if there is only one statistic for the efforts of both agents in the joint venture,*

1. *there exist high $\pi-$ high s combinations for which under joint development both, the owners' profit and the managers' utility, are higher than under stand-alone development,*

2. *there exist low/intermediate $\pi-$ low/intermediate s combinations for which under joint development both, the owners' profit and the managers' utility, are lower than under stand-alone development,*

[8] As we assumed the synergies to be the reduction of overlap between the efforts of the agents, $s = 0$ corresponds to no reduction and $s = 1$ to full reduction, we limit our comparison to $s \in [0, 1]$. Furthermore, this figure uses the optimal contracts calculated in this section without taking feasibility constraints into account, i.e. there exists a line, above which the probability of success $p^{J,uc} = \left(2\frac{b^{J,uc}}{(1-s)b^{J,uc}+1} - (1-s)\left(\frac{b^{J,uc}}{(1-s)b^{J,uc}+1}\right)^2\right)$ would exceed one. Similarly, for $\pi \geq 4$, the probability of success $p^{S,u} = e^{S,u} = \frac{2\pi}{\pi+4}$ would exceed one. However, we do not need to restrict our comparison to the area below these values as it is possible to show that there are contracts that take into account the restrictions, for which the qualitative statements made in the graph hold.

3. *there exist $\pi - s-$ combinations for intermediate synergies, for which profit enhancing joint development would reduce the managers' utility,*

4. *there exist $\pi - s-$ combinations for high synergies, for which profit reducing joint development would increase the managers' utility,*

5. *the implemented effort levels under stand-alone development always exceed the ones under joint development,*

6. *an increase in the implemented probability of success is sufficient for a profit and utility increasing joint development.*

Proof. Proposition 4.3 follows from comparing the values obtained in the sections 4.3.1 and 4.3.2, as well as from figure 4.1. ■

For high values of the innovation π, the efforts implemented in a stand-alone situation are very high, such that the probability that both firms succeed in developing the product and then have to compete/share the market is very high. Therefore, shareholders can gain from coordinating the implemented efforts under joint development. This reduces the bonus to be paid to the managers and, thus, makes them loose utility in a joint project, which enhances profits over a stand-alone project. For low values of π, this component does not carry so much weight and the reduced ability to attribute a success or a failure to one of the managers becomes relatively more important. The informational rents in a joint project would be very high which, therefore, makes managers better and shareholders worse off.

4.4 The joining decision if shareholders do not have full control over it

Let us now assume that shareholders do not have full control over the decision whether to develop the product alone or jointly. There are several reasons why this could be the case. One is that shareholders are simply too dispersed to put such a decision on the agenda of the firm's general assembly. Another reason might be that there is asymmetric information on the synergies. If managers know the amount of synergies and shareholders cannot observe these unless managers reveal them, then there is scope for the management to extract rents from the shareholders. As we will see, in this case, the shareholders will optimally "distort" the incentive contracts to be given to the managers in a way that the managers will announce the synergies.

Therefore, the innovative activity in the firms with and without a joint venture will be affected by the possibility to conduct the development of the product in an RJV. If there was a policy, "ruling out" joint development, the contracts will not be "distorted" that way and we, thus, might observe a more or a less innovative industry as compared to before the introduction of the policy.

Assuming that managers have superior information on the extent of the synergies is a reasonable assumption, as often "outside directors are [...] carefully chosen so as to be overcommitted. Most outside directors in the largest US corporations are CEOs of other firms. Besides having a full workload in their own company, they may sit on a large number of boards. In such circumstances, they may come to board meetings (other than their own corporation's) unprepared and they may rely entirely on the information disclosed by the firm's management" (Tirole, 2005). A consequence is that there is little real control of the shareholders over the activities of the management, including the choice of whether to develop products together with potential competitors or alone and whether this choice is indeed profit maximizing.

4.4.1 Assumptions

In order to capture the superior information of the management on the extent of synergies achievable, we introduce asymmetric information on s in assumption 4.2.

Assumption 4.2 *With probability $p_i^{Signal} \in]0,1[$, before the start of the development project, each manager receives independently from the other manager, a costless, perfectly informative, hideable, but not falsifiable private signal about the value of s. With probability $1 - p_i^{Signal}$, the manager does not receive a signal. The occurrence of the signal is independent of s.*

Assumption 4.3 *Neither owners nor manager j observe whether manager i received a signal.*

We assume the costlessness of the signal for simplicity, but also other scenarios can be thought of. A consequence of assumption 4.2 is that the managers have the choice of whether to reveal or hide the signal they received, if they received one. Given that the managers receive the signals independently of each other, it is not possible to devise Maskin game type mechanisms, thanks to which the owners could costlessly obtain the agent's information.

With respect to the distribution of s and the occurrence of the signal, we assume that, without further knowledge on the realization of s, each owner i prefers (S). Put differently:

Assumption 4.4 *For all π, a signal showing a high s is sufficiently rare not to justify joint development without revelation of a signal.*

We will specify what this means in the following subsection on incentive constraints. Such an assumption is justifyable as, in reality, joint projects are rarely implemented without having received an "expertise" by the management (or/and external sources).

4.4.2 Incentive constraints

We now have two types of incentive constraints: *effort incentive constraints* and *revelation incentive constraints*. The former are the usual incentive compatibility constraints, specifying the utility maximizing *effort* level for each bonus. The latter ones are to ensure that the managers *reveal* the signal if they received one and, thus, *propose* all joint developments that are profit increasing over stand-alone development.

Effort incentive constraints

There is effectively no change in the effort incentive constraint as compared to section 4.3. In the stand-alone situation, agent i maximizes

$$\max_{e_i}\left[w_i^{S,up}+e_i b_i^{S,up}-\frac{1}{2}e_i^2\right],$$

implying the incentive compatibility constraint

$$e_i=b_i^{S,up}. \qquad (IC_i^{e,S})$$

The p in the superscript (additional to the already introduced S,u) denotes the "*private information*" of the managers on the extent of the synergies s.

If owners observe the success of each agent separately, under joint development, agent $i\in\{1,2\}$ maximizes

$$\max_{e_i}\left[w^{J,usp}+e_i b^{J,usp}-\frac{1}{2}e_i^2\right],$$

implying

$$e_i=b^{J,usp}. \qquad (IC_i^{e,J,s})$$

Again, the p in the superscript (additional to the already introduced J,us) denotes the "*private information*" of the managers on the extent of the synergies s.

If owners only observe the success of the overall project, under joint development, agent $i\in\{1,2\}$ maximizes

$$\max_{e_i}\left[w^{J,ucp}+\left(e_1+e_2-(1-s)\,e_1e_2\right)b^{J,ucp}-\frac{1}{2}e_i^2\right],$$

implying

$$e_i=\frac{b^{J,ucp}}{(1-s)\,b^{J,ucp}+1}. \qquad (IC_i^{e,J,c})$$

Again, the p in the superscript (additional to the already introduced J,uc) denotes the "*private information*" of the managers on the extent of the synergies s. With a bonus $b^{J,ucp}$, the shareholders implement therefore a probability of success of

$$p^{J,ucp}=2\frac{b^{J,ucp}}{(1-s)\,b^{J,ucp}+1}-(1-s)\left(\frac{b^{J,ucp}}{(1-s)\,b^{J,ucp}+1}\right)^2.$$

Revelation incentives

Owners observe the success of each agent separately Let us first assume that under joint development, owners observe the success of each agent separately. Remember that, as the shareholders face only forces favoring joint development, with symmetric information, joint development was profit enhancing *for all* $\pi-s-$ *combinations.* Therefore, the *private information* of the managers *does not have* a *value for* the *owners.* Given that, the owners can simply distort the incentives in the never preferred stand-alone development such that managers propose the joint project. The owners choose the under symmetric information optimal contract for the joint project and pay a zero transfer in any state of the world in the stand-alone project.

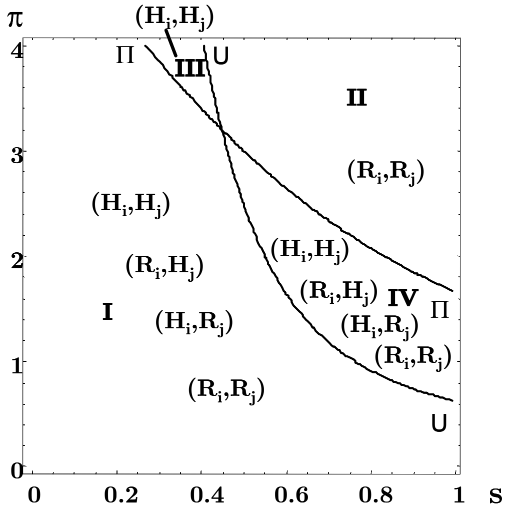


Figure 4.2: The revelation equilibria with full information on s contracts

Owners only observe the success of the overall project Let us now assume that, under joint development, owners only observe the success of the overall project. In order to derive revelation incentive constraints, it is useful to exogenously fix the contracts to the level of the full information on s case, i.e. to $w^{S,u}$, $b^{S,u}$, $w^{J,uc}$, and $b^{J,uc}$, and to see which equilibria with respect to the managers choice to reveal an eventually received signal exist. Consider the owners strategy to choose joint development if and only if at least one manager reveals a signal, for which the expected profit of joint development is higher than that for stand-alone development. Due to assumption 4.4, it is optimal for the owners to choose stand-alone development if not signal is revealed. And if s was revealed, they can always implement the profit maximizing organization.

Denote manager i's decision to reveal with R_i and his decision to hide with H_i. In figure 4.2, we characterize the $(s, \pi)-$ combinations, for which there would be (R_i, R_j), (R_i, H_j), (H_i, R_j), and (H_i, H_j) equilibria, respectively. Remember that the signal is hidable, but hard information. It is therefore enough that one manager reveals it for the owners to have this information and to choose their preferred configuration accordingly.

In areas I and IV, no matter whether any agent reveals the signal, the configuration chosen by the owners will be (S). Therefore, no matter what manager j does and no matter whether manager j received a signal, manager i is indifferent between revealing and hiding. This indifference, and therefore the multiplicity of equilibria, can be (almost) costlessly avoided by paying $w^{S,u} = \varepsilon$, ε greater than but close to zero, in case a signal has been revealed and $w^{S,u} = 0$ otherwise.

In areas II and III, if there is at least one manager revealing the signal, the owners will choose the (J).

In area III, only (H_i, H_j) is an equilibrium in the revelation subgame. The reason is that if manager j hides the signal or if he did not receive a signal, revelation by manager i would lead to a utility decreasing switch from (S) to (J). (R_i, R_j), (R_i, H_j), and (H_i, R_j) are not an equilibrium, as although in case both managers received the signal, manager i would be indifferent between hiding and revealing if manager j revealed, with probability $1 - p_j^{Signal}$, manager j did not receive a signal and in this case, revealing would be utility decreasing for manager i.

Lastly, in area II, only (R_i, R_j) is an equilibrium in the revelation subgame as, if manager j reveals the signal, manager i would be indifferent between revealing and hiding, but if j did not receive a signal, revealing would lead to a utility increasing switch from (S) to (J). (H_i, H_j), (R_i, H_j), and (H_i, R_j) are not an equilibrium as revealing if the other manager hides would lead to a utility increasing switch from (S) to (J).

It is now possible to specify more exactly how rare a signal stating a high s has to be (see assumption 4.4). A deviation to implementing (J) using expected values over s to derive the contracts has to be not profitable. In the most difficult case, this amounts to (J) being not preferred if both agents choose to reveal in area I[9]. In this case, if the owners do not get a signal revealed; this means that either no signal was obtained or at leat one signal was obtained, which falls into area III. Assumption 4.4 then reads as $\left(1 - p^{Signal}\right)^2 E_{s \in [0,1]} \left[E\Pi_i^{J,uc}\right] + \left(1 - \left(1 - p^{Signal}\right)^2\right) E_{s \in [\widetilde{s}, \widehat{s}]} \left[E\Pi_i^{J,uc}\right] < E\Pi_i^{S,u}$, where E_s is the expectation operator over s, where $\widetilde{s}$ is the synergy level for which, under full information over s, the owners are indifferent between (S) and (J) and where $\widehat{s}$ is the synergy level for which, under full information over s, the managers are indifferent between (S) and (J), and $E\Pi_i^{J,uc}$ is the share of firm i in the joint profit.

Now that we have specified the revelation equilibria under the contracts derived for full information over s, we can turn to conditions for which (H_i, H_j) equilibria disappear. Shareholders would want the managers, if these received a signal, to reveal it. As we have seen, with contracts $w^{S,u}$, $b^{S,u}$, $w^{J,uc}$, and $b^{J,uc}$, this is not always an equilibrium. For $(s, \pi) \in III$, there is no equilibrium in which at least one manager reveals the signal. With the contracts offered, the shareholders therefore also have to give the management an incentive always to reveal the signal received, i.e. to propose a joint development if this is profitable. Managers reveal the signal if their expected utility of doing so exceeds the one of hiding the signal.

In order to let agents reveal a signal if s and π are such that they fall into area III, they have to be at least as well off as if stand-alone was implemented. Therefore, they have to get a payment, additional to their bonus and base wage, of $t \geq EU_i^{S,up}(N) - EU_i^{J,ucp}$, where the N stands for non-revelation. For each s, this utility difference is a function of the bonuses and the base wages to be paid in stand-alone without revelation of the signal and in joint development. The owners will, thus, pay an information rent to the first of managers to reveal the signal for an (s, π) combination in an area similar to III as long as this is profitable. This transfer will be paid as long as it is necessary, i.e. if

$$EU_i^{S,up}(N) > EU_i^{J,ucp}$$

[9] Remember that this is (almost) costlessly achievable by paying a $w^{S,u} = \varepsilon$ if agents reveal and $w^{S,u} = 0$ otherwise.

and as long as it is profitable, i.e. if

$$E\Pi_i^{J,ucp} - \left(EU_i^{S,up}(N) - EU_i^{J,ucp}\right) > E\Pi_i^{S,up}(N).$$

The firms are maximizing their profits over $b_i^{S,up}(N)$, $w_i^{S,up}(N)$, $b_i^{S,up}(R)$, $w_i^{S,up}(R)$, $b^{J,ucp}$, $w^{J,ucp}$, and t, where R stands for revelation.

Denote $\underline{s}(\pi)$ the s for which $E\Pi_i^{J,ucp} - \left(EU_i^{S,up}(N) - EU_i^{J,ucp}\right) = E\Pi_i^{S,up}(N)$. This is the lowest s for which the owners would be willing to pay a transfer to the managers for revealing the signal in order to avoid a type III area. Denote $\overline{s}$ the s for which $EU_i^{S,up}(N) = EU_i^{J,ucp}$. This is the highest s, for which an extra transfer for the revelation would have to be paid to the agents in order to avoid a type III area.

The owners' maximization problem

In the following, we assume that the owners construct the contracts such that the agents reveal if they received the signal. The owners maximize their expected profits. These are, in case no signal has been received by either agent $E\Pi_i^{S,up}(N)$. This happens with probability $\left(1-p^{Signal}\right)^2$. In case at least one agent received a signal, which happens with probability $\left(1-\left(1-p^{Signal}\right)^2\right)$, the firms expected profit is $\int_0^{\underline{s}} E\Pi_i^{S,up}(R) f(s)\, ds + \int_{\underline{s}}^{\overline{s}} \left(E\Pi_i^{J,ucp} - \left(EU_i^{S,up}(N) - EU_i^{J,ucp}\right)\right) f(s)\, ds + \int_{\overline{s}}^{1} E\Pi_i^{J,ucp} f(s)\, ds$, where $f(s)$ is the marginal distribution function of the synergies, s. Therefore, the firms' expected profit is

$$\begin{aligned} E\Pi_i = {} & \left(1-p^{Signal}\right)^2 E\Pi_i^{S,up}(N) + \\ & \left(1-\left(1-p^{Signal}\right)^2\right) \int_0^{\underline{s}} E\Pi_i^{S,up}(R) f(s)\, ds + \\ & \left(1-\left(1-p^{Signal}\right)^2\right) \int_{\underline{s}}^{\overline{s}} \left(E\Pi_i^{J,ucp} - \left(EU_i^{S,up}(N) - EU_i^{J,ucp}\right)\right) f(s)\, ds + \\ & \left(1-\left(1-p^{Signal}\right)^2\right) \int_{\overline{s}}^{1} E\Pi_i^{J,ucp} f(s)\, ds. \end{aligned}$$

The restrictions to be fulfilled are the limited liability constraint, the agents' participation constraint, and the effort incentive compatibility constraints. Furthermore, it should be an equilibrium to reveal also if the signal is such that stand-alone is preferred, i.e.

$$EU_i^{S,up}(N) \leq EU_i^{S,up}(R).$$

The first order condition with respect to the bonus of agent i if he does not reveal a signal,

$b_i^{S,up}(N)$, can be written as (we show this in the appendix)

$$\left(1-b_j^{S,up}(N)\right)\pi+b_j^{S,up}(N)\frac{\pi}{2}-2b_i^{S,up}(N)$$
$$+\underbrace{\frac{\left(1-\left(1-p^{Signal}\right)^2\right)}{\left(1-p^{Signal}\right)^2}\left(\frac{\partial\underline{s}}{\partial b_i^{S,up}(N)}\left(E\Pi_i^{S,up}(R)-E\Pi_i^{S,up}(N)\right)f(s)\Big|_{s=\underline{s}}\right)}_{\leq 0}$$
$$\underbrace{-\frac{\left(1-\left(1-p^{Signal}\right)^2\right)}{\left(1-p^{Signal}\right)^2}\int_{\underline{s}}^{\overline{s}}\frac{\partial EU_i^{S,up}(N)}{\partial b_i^{S,up}(N)}f(s)\,ds}_{\leq 0}=0.$$

Under full information on s, the first order condition was

$$\frac{\partial E\Pi_i^{S,u}}{\partial b_i^{S,u}}=\left(1-b_j^{S,u}\right)\pi+b_j^{S,u}\frac{\pi}{2}-2b_i^{S,u}=0.$$

Comparing it to that with private information on synergies, for any $b_j^{S,up}\left(=b_j^{S,u}\right)$, the optimal value of $b_i^{S,up}$ is lower than under full control of the shareholders, $b_i^{S,u}$. Thus, with a private signal of the managers on s, the incentives to develop the new product in a stand-alone situation are *lower* than under full control of the management for *high values of the invention.*

Proposition 4.4 *If managers receive a private signal on achievable synergies in joint development and $\pi>\pi^*$, the owners distort the optimal bonus to their agents such that $b_i^{S,up}(N)<b_i^{S,u}$, inducing a lower probability of an innovation in stand-alone development as compared to full information over the synergies. For $\pi\leq\pi^*$, the offered bonus stays the same as under full info over the synergies.*

Proof. This follows directly from the discussion in this section. ■

A lower level of the bonus in stand-alone will be implemented, giving rise to a lower innovative activity in stand-alone if no signal has been received. This comes from the fact that, in case that a signal has been received, the principal can reduce the information rent to be paid to the agent for revealing the signal by reducing the bonus that would be paid if no signal is revealed.

4.4.3 Policy Implications

The results obtained in this paper have implications for a pro-competitive policy with regard to the development of new products, which would be preventing a joint development in order to strengthen the competitive environment the firms sell their products in. As our analysis shows, in addition to a possible ruling out of joint development, this type of policy may have an impact on the incentives to innovate in stand-alone development. In other words, if joint development is not an option, the best contracts the shareholders can offer are the ones from section 4.3.1, i.e. the ones obtained for stand-alone development if the owners have full information over the synergies.

As a consequence, the introduction of these policies may reduce the innovative activity for projects with $\pi - s-$values for which shareholders would choose voluntarily the organizational form "prescribed" by the policy. Proposition 4.5 states exactly this.

Proposition 4.5 *For $\pi > \pi^*$, a policy impeding joint development will increase incentives given to managers to innovate in stand-alone development.*

4.5 Conclusion

In this paper, we examine a channel through which a pro-competitive policy may have an impact on managerial incentives to develop new products, one using directly the separation of ownership and control inside the firms. If the managers conducting innovative projects also have private information on the best organizational form in which to conduct these projects, the owners of the firms would distort the incentives they give to their managers in each of the organizational forms, depending on the value of the projects up or down, in a way that these managers reveal their private information. If a policy prescribes stand-alone development, then there will be no reason for them anymore to distort the incentives and the effect of the policy may also be a change of the innovative activity in projects for which the "prescribed" organizational form would have been chosen voluntarily. A (positive) side effect of such a policy would then be an increase of innovative activity for projects with high value in stand-alone.

Finally, we would like to emphasize that, although our example is that of a product development, our analysis is not limited to it. One may easily think of alternative interpretations of the project, such as production cost reductions, process innovations (as considered in Fabrizi and Lippert, 2005a) or the supply of retail services.

In future research, we will study the problem in an environment, in which the managers can falsify the signal on s when they reveal it to the owners.

Appendix

D.1 Proposition 4.4

The firms' expected profit is

$$
\begin{aligned}
E\Pi_i = {} & \left(1 - p^{Signal}\right)^2 E\Pi_i^{S,up}(N) + \\
& \left(1 - \left(1 - p^{Signal}\right)^2\right) \int_0^{\underline{s}} E\Pi_i^{S,up}(R)\, f(s)\, ds + \\
& \left(1 - \left(1 - p^{Signal}\right)^2\right) \int_{\underline{s}}^{\overline{s}} \left(E\Pi_i^{J,ucp} - \left(EU_i^{S,up}(N) - EU_i^{J,ucp}\right)\right) f(s)\, ds + \\
& \left(1 - \left(1 - p^{Signal}\right)^2\right) \int_{\overline{s}}^{1} E\Pi_i^{J,ucp} f(s)\, ds.
\end{aligned}
$$

The restrictions to be fulfilled are the limited liability constraint, the agents' participation constraint, and the effort incentive compatibility constraints. Furthermore, it should be an equilibrium to reveal also if the signal is such that stand-alone is preferred, i.e. $EU_i^{S,up}(N) \leq EU_i^{S,up}(R)$.

The first order condition with respect to the bonus of agent i if he does not reveal a signal, $b_i^{S,up}(N)$, is

$$\begin{aligned}
\frac{\partial E\Pi_i}{\partial b_i^{S,up}(N)} &= \left(1-p^{Signal}\right)^2 \frac{\partial E\Pi_i^{S,up}(N)}{\partial b_i^{S,up}(N)} \\
&\quad + \left(1-\left(1-p^{Signal}\right)^2\right)\left(\frac{\partial \underline{s}}{\partial b_i^{S,up}(N)} E\Pi_i^{S,up}(R) f(s)\Big|_{s=\underline{s}}\right) \\
&\quad + \left(1-\left(1-p^{Signal}\right)^2\right)\left(\frac{\partial \overline{s}}{\partial b_i^{S,up}(N)}\left(E\Pi_i^{J,ucp} - \left(EU_i^{S,up}(N) - EU_i^{J,ucp}\right)\right) f(s)\Big|_{s=\overline{s}}\right) \\
&\quad - \left(1-\left(1-p^{Signal}\right)^2\right)\left(\frac{\partial \underline{s}}{\partial b_i^{S,up}(N)}\left(E\Pi_i^{J,ucp} - \left(EU_i^{S,up}(N) - EU_i^{J,ucp}\right)\right) f(s)\Big|_{s=\underline{s}}\right) \\
&\quad - \left(1-\left(1-p^{Signal}\right)^2\right)\int_{\underline{s}}^{\overline{s}} \frac{\partial EU_i^{S,up}(N)}{\partial b_i^{S,up}(N)} f(s)\,ds \\
&\quad - \left(1-\left(1-p^{Signal}\right)^2\right)\frac{\partial \overline{s}}{\partial b_i^{S,up}(N)} E\Pi_i^{J,ucp} f(s)\Big|_{s=\overline{s}} = 0.
\end{aligned}$$

We know that in $\underline{s}$, $E\Pi_i^{J,ucp} - \left(EU_i^{S,up}(N) - EU_i^{J,ucp}\right) = E\Pi_i^{S,up}(N)$ and in $\overline{s}$, $EU_i^{S,up}(N) = EU_i^{J,ucp}$. Substituting and dividing by $\left(1-p^{Signal}\right)^2$, this condition can be written as

$$\begin{aligned}
&\left(1-b_j^{S,up}\right)\pi + b_j^{S,up}\frac{\pi}{2} - 2b_i^{S,up} \\
&\quad + \frac{\left(1-\left(1-p^{Signal}\right)^2\right)}{\left(1-p^{Signal}\right)^2}\left(\frac{\partial \underline{s}}{\partial b_i^{S,up}(N)}\left(E\Pi_i^{S,up}(R) - E\Pi_i^{S,up}(N)\right) f(s)\Big|_{s=\underline{s}}\right) \\
&\quad - \frac{\left(1-\left(1-p^{Signal}\right)^2\right)}{\left(1-p^{Signal}\right)^2}\int_{\underline{s}}^{\overline{s}} \frac{\partial EU_i^{S,up}(N)}{\partial b_i^{S,up}(N)} f(s)\,ds = 0. \quad (A1)
\end{aligned}$$

We want to show that the implemented bonuses in stand-alone without revelation are lower with private information on s than with full information on s. For this, we will compare the first order conditions with respect to this bonus in both situations and we will see that the one under private information on s will be equal to the one under full information, augmented by a negative term. This lets us conclude that the reaction function of each owner for a given bonus level of the other owner is smaller under private information than under full information on s, which means also a lower equilibrium level of these bonuses in stand-alone.

For this, we will show that

$$\frac{\left(1-\left(1-p^{Signal}\right)^{2}\right)}{\left(1-p^{Signal}\right)^{2}}\left(\frac{\partial \underline{s}}{\partial b_{i}^{S,up}\left(N\right)}\left(E\Pi_{i}^{S,up}\left(R\right)-E\Pi_{i}^{S,up}\left(N\right)\right)f\left(s\right)\Big|_{s=\underline{s}}\right) - \frac{\left(1-\left(1-p^{Signal}\right)^{2}\right)}{\left(1-p^{Signal}\right)^{2}}\int_{\underline{s}}^{\overline{s}}\frac{\partial EU_{i}^{S,up}\left(N\right)}{\partial b_{i}^{S,up}\left(N\right)}f\left(s\right)ds<0. \quad (A2)$$

We have $\frac{\left(1-\left(1-p^{Signal}\right)^{2}\right)}{\left(1-p^{Signal}\right)^{2}}>0$, which follows from the fact that $p^{Signal}\in\left]0,1\right[$. The threshold $\underline{s}$ was defined as

$$\underline{s}=\left\{s:E\Pi_{i}^{J,ucp}-\left(EU_{i}^{S,up}\left(N\right)-EU_{i}^{J,ucp}\right)=E\Pi_{i}^{S,up}\left(N\right)\right\}.$$

Taking the total differential, and keeping in mind that only $E\Pi_{i}^{S,up}\left(N\right)$ and $EU_{i}^{S,up}\left(N\right)$ depend on $b_{i}^{S,up}$, and only $E\Pi_{i}^{J,ucp}\left(\underline{s}\right)$ and $EU_{i}^{J,ucp}\left(\underline{s}\right)$ depend on $\underline{s}$, we get

$$0=\frac{\partial\left(E\Pi_{i}^{J,ucp}\left(\underline{s}\right)+EU_{i}^{J,ucp}\left(\underline{s}\right)\right)}{\partial \underline{s}}d\underline{s}-\frac{\partial\left(E\Pi_{i}^{S,up}\left(N\right)+EU_{i}^{S,up}\left(N\right)\right)}{\partial b_{i}^{S,up}\left(N\right)}db_{i}^{S,up}\left(N\right),$$

which leads to

$$\frac{d\underline{s}}{db_{i}^{S,up}\left(N\right)}=\frac{\frac{\partial\left(E\Pi_{i}^{S,up}(N)+EU_{i}^{S,up}(N)\right)}{\partial b_{i}^{S,up}(N)}}{\frac{\partial\left(E\Pi_{i}^{J,ucp}(\underline{s})+EU_{i}^{J,ucp}(\underline{s})\right)}{\partial \underline{s}}}.$$

As $\frac{\partial\left(E\Pi_{i}^{S,up}(N)+EU_{i}^{S,up}(N)\right)}{\partial b_{i}^{S,up}(N)}>0$ (due to the unobservability of efforts) and $\frac{\partial\left(E\Pi_{i}^{J,ucp}(\underline{s})+EU_{i}^{J,ucp}(\underline{s})\right)}{\partial \underline{s}}>0$, we get

$$\frac{d\underline{s}}{db_{i}^{S,up}\left(N\right)}=\frac{\frac{\partial\left(E\Pi_{i}^{S,up}(N)+EU_{i}^{S,up}(N)\right)}{\partial b_{i}^{S,up}(N)}}{\frac{\partial\left(E\Pi_{i}^{J,ucp}(\underline{s})+EU_{i}^{J,ucp}(\underline{s})\right)}{\partial \underline{s}}}>0.$$

Revelation of $\underline{s}$ requires that $\left(EU_{i}^{S,up}\left(N\right)-EU_{i}^{S,up}\left(R\right)\right)\Big|_{s=\underline{s}}\leq 0$, which implies that $\left(E\Pi_{i}^{S,up}\left(R\right)-E\Pi_{i}^{S,up}\left(N\right)\right)f\left(s\right)\Big|_{s=\underline{s}}\leq 0$. We therefore get

$$\frac{\left(1-\left(1-p^{Signal}\right)^{2}\right)}{\left(1-p^{Signal}\right)^{2}}\left(\frac{\partial \underline{s}}{\partial b_{i}^{S,up}\left(N\right)}\left(E\Pi_{i}^{S,up}\left(R\right)-E\Pi_{i}^{S,up}\left(N\right)\right)f\left(s\right)\Big|_{s=\underline{s}}\right)<0.$$

As $\frac{\partial EU_{i}^{S,up}(N)}{\partial b_{i}^{S,up}(N)}>0$, we have that $\int_{\underline{s}}^{\overline{s}}\frac{\partial EU_{i}^{S,up}(N)}{\partial b_{i}^{S,up}(N)}f\left(s\right)ds>0$, which then implies that

$$-\frac{\left(1-\left(1-p^{Signal}\right)^{2}\right)}{\left(1-p^{Signal}\right)^{2}}\int_{\underline{s}}^{\overline{s}}\frac{\partial EU_{i}^{S,up}\left(N\right)}{\partial b_{i}^{S,up}\left(N\right)}f\left(s\right)ds<0.$$

This shows that

$$\frac{\left(1-\left(1-p^{Signal}\right)^2\right)}{\left(1-p^{Signal}\right)^2}\left(\frac{\partial \underline{s}}{\partial b_i^{S,up}(N)}\left(E\Pi_i^{S,up}(R)-E\Pi_i^{S,up}(N)\right)f(s)\bigg|_{s=\underline{s}}\right) - \frac{\left(1-\left(1-p^{Signal}\right)^2\right)}{\left(1-p^{Signal}\right)^2}\int_{\underline{s}}^{\overline{s}}\frac{\partial EU_i^{S,up}(N)}{\partial b_i^{S,up}(N)}f(s)\,ds<0.$$

We know that for full information on s, the first order condition was

$$\left(1-b_j^{S,u}\right)\pi+b_j^{S,u}\frac{\pi}{2}-2b_i^{S,u}=0. \quad (A3)$$

Keeping the bonus of firm j fixed to $b_j^{S,u}$, letting both equations $A1$ and $A3$ hold amounts to $b_i^{S,up}\left(b_j^{S,u}\right)<b_i^{S,u}\left(b_j^{S,u}\right)$. Q.E.D.

General Conclusion

Achieving cooperation among economic agents who are interacting for (partially) common goals may be desirable, both, from an individual and/or from a social point of view. There are attempts to create this cooperation, for example in R&D, using various policy measures starting from subsidies for joint R&D going to the creation of technological parks by public authorities. This dissertation deals with the phenomenon of cooperation, shedding light on it from two distinct perspectives of Industrial Organization.

Part I of this thesis studies cooperation and collusion in networks of cooperative/collusive agreements. There are several main insights. First, pooling payoff asymmetries in infinitely repeated prisoners dilemmas in a multilateral punishment mechanism may systain cooperation where without this possibility it would not be sustainable: it avoids an end-network effect. Second, unforgiving multilateral punishments inhibit the use in-network information transmission and may thereby hamper cooperation. Third, the ability to cooperate within a bilateral mechanism may inhibit the existence of a larger network of cooperative agreements. Finally, social capital is defined and a game theoretical reason for Coleman's argument that closure of social networks allows for more cooperation is given.

Part II of this thesis studies the impact of agency problems on the formation and organization of joint R&D.

In the first chapter of this part of the thesis, a product innovation project is considered. There are two main insights from this chapter. First, it is shown that entrepreneurs choose to carry out the research in a joint project if this is of high value and/or if there are high synergies between the research units from a joint conducting of the project. Second, in the presence of moral hazard the threshold value a potential innovation has to have in order to have the entrepreneurs choose a joint project, is higher than if the research is carried out by the owners themselves. Similarly, the synergies from conducting a joint project of a given value have to be higher with moral hazard than without in order to let the entrepreneurs choose to carry out the research project jointly.

In the second chapter of this part of the thesis, a process innovation project is considered, which may be executed by each of two competing firms separately or by both of them together in a merger. There are two main insights from this chapter. First, it is shown that agent managed firms merge more often out of pure market power considerations and less often in order to use synergies as compared to owner-manager (or family-run) firms. Second, it is shown that, due to the systematically different equilibrium organizations, a competition authority incurs fewer type

I and type II errors if it accepts an efficiency defense based on lower expected unit production costs from agent-managed firms than if it accepts this defense from owner-managed firms.

Finally, in the third chapter of this part of the thesis, again, a product innovation project is considered, which can be carried out by two entrepreneurs separately or by both in a research joint venture. As in the chapters before, the research project is carried out by agents exerting an unobservable effort. Contrary to the chapters before, in this chapter, these agents have superior information on the optimal organizational form in which to carry out the project. There are again two main insights from this chapter. First, it is shown that, in this case, the owners of the firms optimally distort the incentives of their agents to exert an effort in stand-alone development in order to induce them to reveal their private information on the optimal organizational form. And second, as a consequence, it is shown that a policy promoting competitive research may – as a byproduct – also affect (to be specific: increase) the probability of an invention under stand-alone development.

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Ehrenwörtliche Erklärung

Hiermit erkläre ich ehrenwörtlich, dass ich die Arbeit selbständig angefertigt und die benutzten Hilfsmittel vollständig und deutlich angegeben habe.

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