The Financing and Organisation of Innovative Firms

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Preface

This thesis has benefitted from the attention and advice of many people to all of whom I am much indebted.

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1

Introduction

Innovative activity is a key driver of economic growth and development as well as competitiveness at a national, industry and firm level. Despite many popular examples, innovations rarely occur as by-products of other economic activities or as chance outcomes, but are most frequently the result of purposeful, directed undertakings. Furthermore, much of the innovative process takes place not in large organisations or companies but rather in smaller, more flexible and less risk-averse units such as, for example, the archetypal 'entrepreneurial firm'. In general, these prime actors in the R&D process are cash-starved and have access to the required investment funds to cover their frequently sizeable research costs only in exceptional circumstances. Thus, the transfer and allocation of funds from investors to research units plays a central role in the fostering of innovative activity and warrants the extensive attention that has been paid to it by economic theorists, empirical researchers and practitioners alike.

This thesis aims to contribute to our understanding of how innovative firms are best financed and organised. It focuses on a number of distinct, yet closely related, issues that are faced by many innovative firms. First, we examine the impact of weak property rights -

ubiquitous in many industries at the forefront of modern technology - on financing arrangements and research incentives, we then analyse the optimal design of venture capital funds and finally examine the optimal use of communication within a research unit in order to maximise research incentives. Before drawing together the common elements of our analyses of these issues, we will present a short summary of each chapter. Summaries of the related literature are contained in the introduction of each chapter and are not repeated here.

The paradigmatic R&D process results in an innovation that is protected by enforceable intellectual property rights such as a patent or a copyright. Yet frequently, and increasingly, these property rights are challenged in court, circumvented or are so difficult to obtain that property rights become 'weak'. Chapter 2 assesses the impact of weak property rights on optimal financing arrangements and research incentives.

In particular, chapter 2 considers an investor who finances a portfolio of entrepreneurs and who can transfer weakly protected knowledge across portfolio projects in order to improve their R&D prospects. Such disclosure is not desirable to the entrepreneur holding a knowledge advantage but cannot always be prevented when property rights are absent or not always legally enforceable. As a result, the investor's threat to disclose knowledge to product market rivals carries potency and may allow him to expropriate additional surplus from the entrepreneurs. In this setting, our analysis focuses on the entrepreneur's incentives to prevent disclosure by renegotiating her financing contract so as to remove the investor's incentives to disclose. Our results indicate that such renegotiation will always lead to the first-best disclosure rule, regardless of the strength of property rights.

The strength of property rights does, however, play an important role in determining the incentives to obtain transferable knowledge in the first place. Stronger intellectual property rights tend to increase effort incentives for a given financing contract as they reduce the probability that an entrepreneur's knowledge advantage is dissipated. When the optimal financing contract is taken into account, however, stronger property rights may have a non-monotonous impact on the surplus of the R&D project. Thus, when (*i*) projects are very risky and require large up-front investments and (*ii*) property rights are not too strong, strengthening property rights will reduce a researcher's return from R&D. In all other cases, stronger property rights will increase the research project's expected surplus. Furthermore, weakening perfect property rights by a small amount may impose a discontinuously large penalty on the entrepreneur in terms of expected surplus.

This analysis rejects simplistic accounts of the interaction between intellectual property rights and financing regimes and, if anything, argues that intermediate degrees of property rights protection are likely to be optimal in our setting.

In two extensions we consider the impact of the investor's disclosure threat, accorded to him by weak property rights, on organisational choices. First, we examine the entrepreneur's choice between a close or a distant financing relationship. The latter does not allow the investor sufficient access to research results to enable him to disclose it but also reduces his ability to provide productive advice during final research. Our intuitive conclusion is that weaker property rights and better advice capability on behalf of the distant investor induce the entrepreneur is to choose close investors less often.

Second, we analyse the investor's optimal choice of portfolio size when a larger portfolio increases the potency of the disclosure threat while also rendering the incentivisation of entrepreneurs more difficult. We find that stronger property rights and lower ability to extract surplus at the initial financing stage will favour larger investment portfolios.

Chapter 3 steps away from the issue of property rights and knowledge transfer and concentrates on the optimal design of a venture capital fund. In particular, it argues that a commitment to 'shallow pockets' may improve an investor's ability to deal with entrepreneurial agency problems.

When investment is committed in stages, renegotiations over extension finance create a hold-up problem which adversely affects entrepreneurial agency problems - whether they be of a moral-hazard or adverse-selection nature. While much of the existing literature has been concerned with contractual solutions to these dilemmas, chapter 3 proposes a non-contractual solution. In particular, our analysis suggests that it may be beneficial for a venture capital fund to restrict the amount of investment funds that it initially raises. Such a restriction, i.e. a commitment to 'shallow pockets', creates competition between her portfolio entrepreneurs for cheap 'informed' (or 'inside') money at the refinancing stage. Although competition among entrepreneurs increases the investor's bargaining power during renegotiations, we find that competition may nevertheless enhance entrepreneurial effort incentives and allow the sorting of entrepreneurs according to their type. This arises from the fact that competition created by limited funds increases the responsiveness of the entrepreneur's payoff to the profits generated by his project.

Chapter 3 lays out the conditions under which such an increase in responsiveness can be achieved through the non-contractual means of limited funds. When this is the case, the benefit of improved incentives may outweigh the costs of inefficient refinancing by the initial investor, e.g. the increased cost of refinancing through uninformed outside investors or the failure to receive funding for the second stage at all. We find that raising limited funds is an optimal strategy when the following two conditions hold: first, the probability that a given project fails at the interim stage is relatively high; second, the *incremental* returns from improving the project are relatively small compared to the absolute value of financial rewards if the project is a success. We show that this reasoning applies in both a moral hazard as well as in an adverse selection setting.

As a result, this chapter provides an endogenisation of a widespread phenomenon in venture capital finance, namely, provisions that limit a venture capital fund's size and make it more difficult to attract further investors after the fund has been raised

Chapter 4 abstracts from the optimal financing of an innovative firm and turns to the issue of how to best organise R&D. In particular, it focuses on the communication policy between two competing researchers. In contrast to the existing literature, our analysis in chapter 3 argues that it may be optimal to commit to communication in order to maximise research incentives, even though communication does not create spillovers. As such, it presents a strong argument for increasing transparency and knowledge flows within organisations.

The model set up in chapter 4 considers two researchers who form a partnership to research an innovation and renegotiate their sharing rule once intermediate research results have been realised. In such a setting, communication of an agent's intermediate know-how to her partner has two effects: first, it may improve the partnership's ability to innovate, e.g. through spillovers, and thus increase the surplus to be distributed; second, it will strengthen her partner's ability to conduct research outside the partnership and thus improve her partner's bargaining power during renegotiations. Traditionally, the literature has emphasised the first effect. Chapter 4 departs from this approach and focuses exclusively on the implications of the latter effect.

One immediate result is that, for given knowledge levels, communication by an agent will only ever weaken her bargaining position and reduce the surplus she can extract from renegotiations. As a result, an agent's commitment to communicate at the intermediate stage is equivalent to a commitment to reduce her bargaining power. On the other hand, chapter 4 argues, such a commitment may also serve to increase her partner's incentives to conduct research and acquire intermediate knowledge if the two partners' research paths are sufficiently complementary. As a result, a commitment to communicate may increase *ex ante* surplus although it weakens the communicating agent's bargaining position at the intermediate stage. As a result, our analysis provides a novel justification for open organisational structures and for communication within firms that does not rely on exogenously postulated spillovers.

Finally, a few comments on themes and approaches shared by these chapters. On the most general level, all three chapters are concerned with interactions between researchers that compete in some sense, whether as a part of the investor's portfolio or within an organisation in which surplus needs to be bargained over. Chapters 2 and 3, in particular, depart from the existing literature, which mainly concentrates on the bilateral relationship between an entrepreneur and her investor. Knowledge, its transfer through communication, and the resulting effect on research incentives are a themes common to both chapters 2 and 4. In chapter 2, such communication is always involuntary from the entrepreneur's perspective, while chapter 3 considers a setting with strong property rights and voluntary communication only. Finally, on a more technical level, a common theme of chapters 3 and 4 is that they argue that actions that reduce an agent's *ex post* bargaining power may nevertheless prove optimal from an *ex ante* perspective whenever they ameliorate agency problems.

2

Financing Innovative Firms in the Presence of Weak Property Rights

2.1 Introduction

When investors finance a portfolio of entrepreneurs, their aim is to maximise the return of their entire portfolio rather than that of a particular individual portfolio project. A conflict of interests exists between an investor and her portfolio entrepreneur if an action by the investor achieves the former but not the latter objective. We trace out the implications of this conflict of interests in a setting in which the entrepreneur generates interim knowledge in an R&D contest that the investor is able to transfer across her different portfolio projects. While such a transfer is never in the interest of the entrepreneur whose interim knowledge is disclosed, she cannot always prevent such a disclosure legally if intellectual property rights (IPR)[1] are weak.

This chapter focuses on her ability to *prevent disclosure of interim knowledge through contractual means.* In particular, we analyse the investor's incentives to disclose interim knowledge once it has been created by the entrepreneur, as well as the entrepreneur's in-

[1]Throughout this chapter, the terms 'intellectual property rights', 'property rights' and 'IPR' are used synonymously.

centives to renegotiate her original financing contract in order to prevent such disclosure. We characterise the resulting optimal contract between investor and entrepreneur as well its implications for entrepreneurial effort incentives (and thus the expected value of her project). Our main conclusions are that, firstly, the optimal contract induces the investor to disclose if, and only if, disclosure is socially efficient. Secondly, under the optimal contract the strength of property rights is an important determinant of entrepreneurial effort incentives and project value, regardless of whether knowledge is transferred at the interim stage or not. We also find that the impact of the strength of property rights on the value of the entrepreneur's project may be non-monotonously related to riskiness of the project and that weakening perfect property rights by a small amount may lead to a discontinuous penalty in terms of project value. In two extensions, we examine the impact of the investor's threat to disclose on the entrepreneur's choice between a close or distant financing relationship, as well as on the investor's optimal size of portfolio.

More precisely, our model consists of a two-stage R&D contest between entrepreneurs that are financed by the same investor. Entrepreneurial effort determines the probability of obtaining research knowledge at the interim stage which, in turn, determines the likelihood of research success at the final stage. Payoffs depend on the two entrepreneurs' relative research performance at the final stage. The investor learns any interim knowledge produced by the entrepreneurs so that he can transfer interim knowledge at the interim stage. The strength of IPR determines the entrepreneur's ability to legally prevent such interim knowledge disclosure.

We find that, in general, the investor prefers to disclose inefficiently often at the interim stage while the entrepreneur prefers to prevent disclosure inefficiently often. However, interim renegotiations always induce socially efficient disclosure behaviour by the investor in equilibrium. When interim knowledge is very important in R&D, disclosure is not socially efficient and the entrepreneur will always find it optimal to renegotiate the initial financing contract in order to prevent disclosure. The investor will not disclose and may extract additional surplus from the entrepreneur if the threat of disclosure is credible. When interim knowledge is not important in R&D, by contrast, disclosure is socially efficient and it is too expensive for the entrepreneur to prevent disclosure by ceding additional surplus to the investor. As a result, the investor will disclose whenever the entrepreneur cannot legally insist on her property rights.

This analysis has several implications for the role of the strength of property rights. First, the incidence of disclosure depends on the strength of IPR only if disclosure is socially efficient. Moreover, our analysis suggests that, *everything else being equal*, stronger property rights reduce efficiency as they merely allow the entrepreneur to legally prevent efficient disclosure while not affecting the incidence of inefficient disclosure. By contrast, the second implication of our analysis holds that stronger property rights reduce the potency of the investor's threat to disclose and thus the severity of the interim hold-up problem, so that effort incentives tend to be strengthened.

As a result, IPR strength affects expected surplus in two opposite directions. When disclosure is inefficient, i.e. when the research project is not very risky, this trade-off is resolved in favour of stronger property rights. In particular, expected surplus is strictly increasing in IPR strength when this is sufficiently low, but independent when IPR strength is sufficiently strong. Importantly, we find that weakening perfect property rights by a very small amount leads to a discontinuous loss in surplus.

When projects are risky so that disclosure is efficient, the above trade-off is not unambiguous. We provide conditions under which stronger property rights in fact reduce expected surplus. The main implication is that the impact of IPR strength on project value may be non-monotonously related to the importance of interim knowledge: when interim knowledge is not important IPR may reduce project value, otherwise they may increase project value.

We examine the impact of the investor's threat to disclose on two organisational choices in our extensions. First, we extend the basic model to allow the entrepreneur to choose between a distant investor, who can commit not to disclose but is not a capable advisor, and a close investor, who cannot commit to not disclose but provides more productive advice. Our intuitive conclusion is that the distant investor will be chosen if (*i*) he induces higher effort than the close investor and (*ii*) his advice capability is not too low. This will be the case when effort is very important and when the threat of disclosure allows the close investor to extract a large part of the surplus, e.g. because property rights are weak.

Our second extension of the basic model considers the investor's optimal choice of portfolio size. A larger portfolio endows the investor's threat to disclose with more potency and allows him to extract more surplus. By the same token, a larger portfolio will render it more expensive to incentivise the entrepreneur. As a result, the investor will prefer a larger portfolio if (*i*) entrepreneurial effort is important relative to interim knowledge and (*ii*) the investor cannot extract too much surplus by threatening disclosure, e.g. because property rights are strong.

There is strong evidence that property rights are far from perfect because, for example, patents are difficult to obtain or undesirable or because they are difficult to enforce and easy to circumvent.[2]. This issue is particularly relevant for innovative firms. Lanjouw and Schankerman (2001), for example, find that the incidence of patent litigation is particularly

[2] Among many, Anton and Yao (1994, 2004), Anand and Galetovic (2000b) and Lanjouw and Schankerman (2004) provide evidence on these points.

pronounced for IT, bio-technology and non-drug health patents as well as small firms. Similarly, entrepreneurs face difficulties when trying to protect their proprietary knowledge via alternative means such as non-disclosure agreements[3] or trade secret laws and no-compete agreements (Besen and Raskind (1991)).

When property rights are weak, the relationship between the entrepreneur and her investor suffers from the threat of expropriation. Chesbrough (2000), for example, argues that *"For some entrepreneurs... the loss of control is no longer the biggest downside. ... Rather, it's the fear that VC firms may compromise the ideas on which their companies are founded."* In the context of corporate venture capital, Block and MacMillan (1993) find that *"Entrepreneurs harbor a fundamental distrust of large corporations. ... [They fear] that the corporation will steal their ideas."* Finally, Bhattacharya and Chiesa (1995) and Quindlen (2000) provide evidence that venture capitalists engage in 'portfolio thinking' by co-ordinating the strategies of their portfolio companies and transferring knowledge among them.[4]

The model presented in this chapter shares traits with a number of other contributions. Most obviously, the analysis conducted in this paper is related to that of Bhattacharya and Chiesa (1995) whose setting our model is based on. However, our model differs in several important respects. Firstly, access to interim knowledge bestows additional bargaining power on the investor at the interim stage. This implies that the strength of property rights matters whether or not disclosure actually occurs. Secondly, we explicitly allow for varying degrees of IPR strength and argue that the impact of property rights on project value may

[3]See Anton and Yao (1994) and Severinov (2001) for empirical evidence on this point.

[4]Arping (2002) also provides evidence on the coordination of portfolio companies' product market strategies by venture capitalists.

be non-monotonic. Finally, we consider the impact of weak property rights on the optimal size of the investor's portfolio.

The analysis provided in Cestone and White (2003) also closely related as they consider a setting in which an entrepreneur can design a contract that induces an investor with (exogenously given) market power to not finance potential product market rivals. Our analysis differs in that it concentrates on a potentially non-exclusive and non-rival input, knowledge, as well as the role of the strength of property rights. Moreover, the investor's threat of disclosure is not predicated on his exogenously given market power but arises endogenously in our setting. Finally, we consider the entrepreneur's *ex ante* incentives to expose herself to this expropriation threat.

The literature on research joint ventures has focussed on the role of knowledge spillovers with a recent emphasis on the endogenous determination of knowledge transfers.[5] Most closely related is Severinov (2001) who analyses a firm's ability and incentives to regulate her employees' knowledge exchange with employees of other firms in a setting in which employees are risk-averse, have no bargaining power and in which property rights do not exist.

Finally, a large literature on weak property rights has focussed on related issues.[6] Most closely related is Ueda (2004) who analyses the impact of an investor's ability to steal an idea prior to the signature of contracts on the choice of investors. The focus of our analysis, by contrast, is on the impact of weak property rights after the initial contract has been signed.

[5] See, for example, Gallini and Wright (1990), Gandal and Scotchmer (1993), Perez-Castrillo and Sandonis (1996), Rosenkranz and Schmitz (1999) and Pastor and Sandonis (2002).

[6] These issues include selling an imperfectly protected idea (Anton and Yao (1994, 2001)), the structure of optimal licensing contracts (Bhattacharya and Ritter (1983), Bhattacharya, Glazer, and Sappington (1992) and D'Aspremont, Bhattacharya, and Gerard-Varet (2000)) and the optimal organisation of R&D (Anton and Yao (1995), Anand and Galetovic (2000b) and Baccara and Razin (2004)).

Section 4.2 introduces the model while section 2.3 analyses the tension between *ex ante* and *ex post* efficient disclosure rules. Section 2.4 analyses the renegotiations over knowledge disclosure and characterises the *ex post* efficient contracts as well as the impact of the strength of property rights on contracts and effort incentives. Section 2.5 presents two extensions to this model and section 2.6 concludes.

2.2 The Model

There are two types of agents, entrepreneurs and investors,[7] and three periods, which we denote by $t = 0, 1, 2$. For simplicity we assume that all parties are risk neutral and do not discount future cash flows. Furthermore, there are more potential investors than entrepreneurs so that, *ex ante,* there is competition for entrepreneurs.[8] All entrepreneurs compete in the same industry and we assume that this industry consists of two entrepreneurs.[9]

2.2.1 Project Technologies

Entrepreneurs have zero wealth and are engaged in an R&D contest for cost-reducing inventions in the product market. Each entrepreneur has an idea that is embedded in a project which requires an investment $I_0 > 0$ at $t = 0$, and which can be extended at cost $I_1 > 0$ at $t = 1$ in a sense to be made more precise below. The entrepreneur is essential to the

[7] Throughout this chapter, we will follow the convention of using female pronouns for entrepreneurs and male pronouns for the investor.

[8] This assumption is standard and not essential for our main results. Section 2.5.1 presents an extension in which it is relaxed.

[9] This assumption merely reduces the complexity of the analysis. An extension of our main mechanism to an industry with $n > 2$ entrepreneurs is conceptually straightforward as long as entrepreneurs with lower costs earn higher profits than other entrepreneurs.

project in that it cannot be continued without her presence.[10] Further, we assume that the entrepreneurs' projects are symmetric.[11]

A project produces 'interim' ($t = 1$) and a 'final' ($t = 2$) research. Both research outcomes are observed by all market participants and we follow Bhattacharya and Chiesa (1995) in assuming that neither research output is verifiable and contractible. *Final research* takes the form of 'success' or 'failure' and the entrepreneur's relative performance at final research determines the project's payoffs at $t = 2$. An entrepreneur who is the only final research success earns a product market return of $V > I_1 + I_0$. If both entrepreneurs succeed at final research, Bertrand competition ensures that they earn zero profits. If final research fails, the entrepreneur does not earn any positive product market returns.

Final research success depends on *interim knowledge* and *project extension.* We denote interim knowledge produced by entrepreneur i at $t = 1$ by θ_i and restrict it to be 'high' $\left(\theta_i = \theta^H\right)$ or low $\left(\theta_i = \theta^L\right)$ with $0 < \theta^L < \theta^H < 1$. If the project is extended at cost I_1 at $t = 1$, final research success will be obtained with probability θ_i, where $1 > \theta^H > \theta^L > 0$. If extension does not take place, final research will succeed with probability θ^0 regardless of the degree of interim knowledge, where $\theta^L > \theta^0 > 0$.

An entrepreneur's level of interim knowledge is, in turn, determined by the *non-contractible effort* exerted by her at $t = 0$. For simplicity, the entrepreneur acquires $\theta_i = \theta^H$ with probability p_i where $p_i = p > 0$ if the entrepreneur exerts effort, and $p_i = 0$ otherwise.[12] The cost of effort is given by $c > 0$. To streamline the exposition, let θ_i^e denote the expected probability of success at $t = 0 : \theta_i^e := \theta^L + p_i \left(\theta^H - \theta^L\right)$.

[10] Firing the entepreneur and installing a new manager is assumed to incur prohibitive costs.

[11] Our main results do not rely on the assumption of asymmetry (see also footnote 30).

[12] The assumption of a binary effort choice is not crucial in our context but severely simplifies the analysis. Similarly, the assumption that low effort is equal to zero merely represents a standardisation. It is relaxed in the extension presented in Section 2.5.1.

To summarise, the entrepreneur must exert non-contractible effort in order to produce interim knowledge which, in turn, will allow him to engage in final research. Relative performance in final research determines final payoffs.

2.2.2 Financing

Each investor finances two entrepreneurs in the same industry.[13] Investors compete to provide finance I_0 to entrepreneurs at $t = 0$. At $t = 1$, the investor can decide whether to extend project i at cost I_1 or not. If he refuses, entrepreneurs can approach alternative sources for extension finance. Since the realisation of interim research is observable by all, the entrepreneur has full bargaining power in the renegotiation game at $t = 1$ absent any further considerations[14] and extension financing will be fairly priced.

During our main analysis, we assume that the investor automatically gains access to any interim knowledge produced by her portfolio entrepreneurs at $t = 1$ so that he can transfer it when desirable in the manner described in the next subsection. This assumption is relaxed in the extension presented in Section 2.5.1, where we allow the entrepreneur to choose whether to give the investor access to interim knowledge.

2.2.3 Property Rights and the Transfer of Knowledge

A central feature of our analysis is that interim knowledge can be transferred across agents. This feature rests on two assumptions.

[13] The extension presented in Section 2.5.2 relaxes this assumption.
This setting can also be interpreted as one in which a corporation with a research unit invests in an entrepreneurial firm that threatens to enter a related product market. Such corporate venture capital financing is frequently observed and often justified on grounds of knowledge acquisition (see Block and MacMillan (1993) and Gompers and Lerner (2000)).

[14] Note that this assumption also renders moot any consideration of committing to a restriction on the funds available to the investor. For an analysis of the potential benefits of such a restriction in a different setting, see Chapter 3.

First, we draw a distinction between *observing* and *possessing* knowledge, in the sense that the observation of an entrepreneur's knowledge does not endow the observer with its possession.[15] As a result, a transfer of high interim knowledge from, say, entrepreneur i to j will improve $j's$ productive ability if he does not possess high interim knowledge, although j has already observed that i has produced high interim knowledge. Furthermore, interim knowledge can be transferred only by someone who possesses it and only a deliberate transmission can confer possession of knowledge to someone else. Possession, in the sense used in our analysis, should not be confused with any claims to property rights. It merely implies that the agent has a thorough understanding of a particular invention and can pass it on in a way that it can be used by a rival.

Second, we assume that interim knowledge, but not final research output, exhibits a degree of *non-exclusivity.* To put it differently, *intellectual property rights* over interim knowledge *are weak* or not well-defined.[16] We denote the *strength of property rights* as $\beta \in [0, 1]$ and interpret it as the probability with which an entrepreneur can verify that the investor has disclosed interim knowledge to her rival and thus legally prevent her from disclosure.[17] We refer to knowledge disclosure by an investor as 'successful' if it was not prevented by the entrepreneur, and as 'failed' if it was prevented. In case of disclosure failure, entrepreneurs continue to research with their original 'pre-disclosure' knowledge levels.[18]

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[15] To clarify this distinction, suppose that Ω is the set (of measure 1) of all possible states of the world which are equally likely. The true state of the world $\tilde{\omega}$ is unknown at $t = 0$ but revealed at $t = 1$. During interim research, the entrepreneur investigates the optimal final research path for a subset of measure p_i of all possible states of the world. Her final research will work well (i.e. interim knowledge is high) if $\tilde{\omega}$ is in the subset p_i. In this setting, *observing* entrepreneur $i's$ interim knowledge at $t = 1$ is equivalent to observing the subset p_i that i explores as well as the realisation of $\tilde{\omega}$ (i.e. whether it is in p_i or not). *Possessing* $i's$ interim knowledge implies acquiring the optimal final research paths for subset p_i.

[16] See Bhattacharya and Chiesa (1995) for a similar assumption.

[17] For example, the strength of property rights β can be interpreted as the ease with which original inventorship can be proven so that rivals can be prevented from using a particular innovation.

[18] What matters here is that, when disclosure fails, the entrepreneur with the original knowledge advantage will earn higher expected returns as compared to when disclosure succeeds. This may be, for example, because the receiver of a failed disclosure can be prevented from actually using this knowledge or because the investor as well as the entrepreneur can be sued for the expected loss in earnings. See Lerner (1994), Schankermann and Scotchmer (2001)

Knowledge disclosure is observable and can be undertaken either by the entrepreneur, who produced the knowledge, or by her investor. We assume that licensing of interim or final knowledge is not possible[19] and that neither the investor nor the entrepreneur can commit themselves to not disclose interim knowledge.[20]

Since knowledge is *non-rival,* a successful transfer of knowledge can only increase the knowledge level of the receiver but will never reduce the knowledge level of the sender. We assume that if both entrepreneurs have the same knowledge level, knowledge disclosure is ineffective and will not occur. Interim disclosure will be desirable only if on entrepreneur, say i, has high interim knowledge $\theta_i = \theta^H$ while j has low interim knowledge, $\theta_j = \theta^L$. If disclosure is successful, it raises θ_j to θ^H so that $\theta_j = \theta_i = \theta^H$. If disclosure fails, we assume that $\theta_i = \theta^H$ and $\theta_j = \theta^L$.

2.2.4 Payoff Assumptions

First, not that extension finance creates an incremental return of $\left(\theta_i - \theta^0\right)\left(1 - \theta_j\right) V - I_1$ for entrepreneur i.

Assumption 1: *Extension finance is ex post efficient for all* $\theta_i \in \left\{\theta^L, \theta^H\right\}$:

$$\left(\theta^L - \theta^0\right)\left(1 - \theta^H\right) V > I_1.$$

This assumption allows us to abstract from issues relating to efficient project extension.

and Lanjouw and Schankerman (2001, 2004) for an empirical analysis of the incidence and determinants of patent litigation.

[19] This restriction allows us to focus on involuntary disclosure from the entrepreneur's perspective. See Bhattacharya, Glazer, and Sappington (1992) for an analysis of knowledge-licensing contracts.

[20] An alternative interpretation would be that entrepreneur and investor can contract on a disclosure rule but that such a contract can be enforced with probability β only.

Next, let V^D and V^{ND} denote the expected return at $t = 0$ of a project when disclosure does and does not occur, respectively:

$$V^{ND} = \left(\theta^L + p\left(\theta^H - \theta^L\right)\right)\left(1 - \left(\theta^L + p\left(\theta^H - \theta^L\right)\right)\right)V$$
$$V^D = \left(\theta^H - (1-p)^2\theta^L\right)\left(1 - \left(\theta^H - (1-p)^2\theta^L\right)\right)V.$$

Assumption 2: *It is ex ante efficient to exert effort:*

$$\begin{aligned} p\left(\theta^H - \theta^L\right)\left(1 - \left(\theta^L + p\left(\theta^H - \theta^L\right)\right)\right)V &\geq c \text{ and} \\ p(1-p)\,\theta^L\left(1 - 2\left(\theta^L + p\left(\theta^H - \theta^L\right)\right)\right)V &\geq c; \end{aligned}$$

and it is ex ante efficient to invest if and only if effort has been exerted:

$$\min\left[V^{ND}, V^D\right] > I_1 + I_0 \geq \theta^L\left(1 - \theta^L\right)V.$$

This assumption ensures that the severity of the entrepreneur's moral hazard problem is a measure of the loss of efficiency generated by a particular financing contract and disclosure rule.

2.2.5 Contracts and Renegotiations

In our setting, the initial contract signed at $t = 0$ specifies a repayment R in payoff state V in return for initial investment I_0. The entrepreneur retains the residual cash flow. This contract is renegotiated to repayment r, defined analogously, at $t = 1$ whenever extension finance takes place[21] and whenever the investor can threaten to disclose interim knowledge. Repayments must fulfill the standard conditions of limited liability: $R, r \in [0, V]$.

This contract arises naturally out of the assumption that interim knowledge disclosure cannot be contracted on the original contract. We assume that agents cannot commit not to renegotiate at $t = 1$ so that renegotiations take place whenever extension finance needs to be committed.[22]

At $t = 1$, the entrepreneur and the investor bargain over extension finance and knowledge disclosure. Bargaining takes place sequentially, that is, first over extension finance and then over knowledge transfer.[23]

The entrepreneur can obtain extension finance from the original investor or from alternative sources. Since the realisation of interim research is observed by all, alternative investors can provide extension financing at the same rate as the original investor so that the original investor will not be able to extract any of the incremental surplus created by extension finance. We specify that bargaining over extension financing occurs according to Nash bargaining with equal bargaining powers.

If the entrepreneur, say E_i, has an interim knowledge advantage over the other portfolio entrepreneur E_j, the investor can threaten to disclose interim knowledge successfully with probability $(1 - \beta)$. Disclosure has the effect of terminating renegotiations with E_i. Since knowledge is a non-physical asset, the investor can also choose to disclose knowledge once

[21] Our implicit assumption, made for simplicity, is that extension financing is not contractible. Relaxing this assumption would not affect our main results as these are driven by the non-contractibility of interim knowledge disclosure. See also the discussion in the next footnote.

[22] This rules out long-term contracts under which an investor would commit funds $I_0 + I_1$ at $t = 0$ in return for repayment R_i at $t = 2$. Such a restriction can be easily justified by an appeal to fraudulent investors (e.g. see chapter 3 for the use of a similar assumption). Our main analysis, however, would not be affected if we allowed for long-term financing contracts as these would also be renegotiated whenever the investor can threaten to disclose. See Bhattacharya and Chiesa (1995) for an analysis of the relative incentive merits of short and long-term contracts.

[23] This specification is for clarity only. The same payoffs would obtain if bargaining over extension finance and disclosure occured simultaneously since the entrepreneur would be able to obtain fairly priced extension finance from outside investors if this bargaining broke down.

bargaining has been successfully concluded. In this sense, the renegotiated contract has to be *ex post* incentive compatible.

Suppose that contract $\hat{r}_i$ and $\hat{r}_j$ are those resulting from renegotiations over extensions finance. We specify that renegotiations over knowledge disclosure then proceed as follows:

t′= 1 : The investor and E_i bargain over disclosure. If negotiations with E_i are successful, repayment $\hat{r}_i$ is replaced by new repayment r_i.

t′= 2 : If negotiations at $t' = 1$ were successful, the investor decides whether to disclose to E_j given contractual payment $\hat{r}_j$. If negotiations at $t' = 1$ were unsuccessful, the investor decides whether to make a new offer to E_i so that the game returns to $t' = 1$ or whether to disclose to E_j given contractual payment $\hat{r}_j$.

t′= 3 : If the investor has decided to disclose to E_j, he bargains over the surplus from disclosure given contracts $\hat{r}_i$ and $\hat{r}_j$.

Again, bargaining outcomes are determined by Nash bargaining with equal bargaining powers.

To summarise, Figure 2.1 depicts the timeline of our model.

2.3 *Ex Ante* vs. *Ex Post* Optimal Disclosure Incentives

This section establishes the *ex ante* as well as the *ex post* optimal disclosure rule from the entrepreneur's perspective.

At $t = 0$, the total expected value of the entrepreneur's project in the absence of disclosure is $\theta_i^e \left(1 - \theta_j^e\right) (V - R_i) - I_0 - I_1$ for a given contract R_i. Disclosure from E_i to E_j increases θ_j from θ^L to θ^H whenever E_j suffers from an interim knowledge disadvantage and vice

t=0	*t=1*	*t=2*
- Investor offers initial contract R_i to entrepreneur in exchange for investment I_0 - If entrepreneur accepts R_i, entrepreneur exerts effort $p_i \in \{0, p\}$ at cost $c(p)$	- Entrepreneur i obtains observable but not verifiable interim knowledge $\theta_i \in \{0, \theta\}$ where $prob(\theta_i = \theta) = p_i$ - Investor and entrepreneur bargain over extension finance and, possibly, over interim knowledge disclosure => renegotiated contract r_i - Investor decides whether to disclose or not	-Entrepreneur i obtains final research success with probability $\theta_i \in \{0, \theta\}$ - Final payoffs realised according to relative final research success

FIGURE 2.1. The Timeline.

versa for E_i. The value of the project with disclosure is thus is given by

$$\left[\theta_i^e\left(1-\theta_j^e\right)+\left(\theta^H-\theta^L\right)\left[p_j\left(1-p_i\right)\left(1-\theta^H\right)-p_i\left(1-p_j\right)\theta^H\right]\right]\left(V-R_i\right)-I_0-I_1$$

A comparison of these two terms establishes that it is *ex ante* optimal for the entrepreneur to disclose at $t = 1$ whenever $p_j\left(1-p_i\right)\left(1-\theta^H\right) \geq p_i\left(1-p_j\right)\theta^H$ which, in equilibrium $(p_i = p_j = p)$, reduces to

$$\theta^H \leq \frac{1}{2}.$$

If the entrepreneur could commit herself to a disclosure rule at $t = 0$, she would choose the *ex ante* optimal disclosure rule. As in Bhattacharya and Chiesa (1995), this disclosure rule is also the socially efficient one.[24][25]

[24]Disclosure when $\theta^H \leq \frac{1}{2}$ is the *ex ante* optimal disclosure rule for any R_i, including $R_i = 0$. Thus it is also the socially efficient *ex ante* disclosure rule. Similarly, it is easy to show that it is also the *ex post* optimal disclosure rule.

[25]Allowing for asymmetric projects does not change the substance of this analysis. For example, suppose that the setting is amnded such that the probability of interim knowledge discovery following effort exertion, θ^H, is such that $\theta_i^H \neq \theta_j^H$. Then interim knowledge disclosure is *ex ante* efficient and socially optimal whenever $\theta_i^H + \theta_j^H \leq 1$.

By assumption, the entrepreneur cannot commit herself at $t = 0$ to a disclosure rule at $t = 1$ so that she will prefer disclosure if and only if it is *ex post* optimal. Since

$$\theta^H \left(1 - \theta^L\right)(V - R_i) - I_1 > \theta^H \left(1 - \theta^H\right)(V - R_i) - I_1$$

this is never the case so that *ex ante* and *ex post* disclosure incentives conflict whenever $\theta^H \leq \frac{1}{2}$. This also implies that an entrepreneur would never voluntarily disclose at the interim stage so that we can restrict our attention to the investor as the only source of knowledge transfers at $t = 1$.

In Bhattacharya and Chiesa (1995), this conflict is resolved by allowing the entrepreneur to choose between multi-lateral and uni-lateral investors at $t = 0$, where the latter serves as a commitment device to non-disclosure at $t = 1$ while the former investor will undertake disclosure according to the *ex ante* optimal disclosure rule. An important ingredient in their analysis is the assumption that both entrepreneurs are financed by the same two investors. As a result, the investors compete over the returns from knowledge disclosure during renegotiations and neither investor can use her disclosure threat to extract additional surplus.

Our analysis also considers multi-lateral finance in the sense that each investor finances a portfolio of two entrepreneurs. However, we assume that each entrepreneur is financed by one investor only so that the investor's threat of disclosure increases his bargaining power.[26]

[26] What is crucial to our analysis is that the investor gains in bargaining power at the interim stage from having access to interim knowledge. An alternative setting in which this is the case is one in which an entrepreneur has more than one investor but in which not all investors have access to interim knowledge. For example, venture capital funds generally consist of general and limited partners, where the general partner is intimately involved in the portfolio entrepreneur's activity while limited partners are passive. Similarly, venture capital syndicates generally designate a lead VC who is responsible for the direct interaction with the entrepreneur. See Gompers and Lerner (2000) for more detail on the institutional aspects of venture capital finance.

As a result, the next section argues, the *ex post* disclosure incentives of both entrepreneur and investor are affected and will depart from *ex ante* optimal disclosure incentives.

2.4 *Ex Post* Optimal Contracts

At $t = 1$, the investor and her portfolio entrepreneurs will renegotiate the initial contract R in response to the need to inject extension finance and whenever asymmetric interim knowledge creates disclosure opportunities. We first analyse the renegotiations over extension finance and then focus on interim knowledge disclosure in the subsequent sections.

At $t = 1$, the investor and the entrepreneur engage in bilateral bargaining over extension finance. The original contract specifies repayment R_i. According to assumption 1, extension finance will create a surplus of $\left(\theta_i - \theta^0\right)(1-\theta_j)V - I_1 > 0$. The outside option in bargaining over extension finance are given by $\theta^0(1-\theta_j)(V-R_i)$ and $\theta^0(1-\theta_j)R_i$ for E_i and investor, respectively. Since the realisation of interim research is observable by all, the entrepreneur will appropriate the entire surplus. As a result, the entrepreneur will have a payoff of

$$\theta^0(1-\theta_j)(V-R_i) + \left(\theta_i - \theta^0\right)(1-\theta_j)V - I_1.$$

at $t = 1$, while the investor will earn expected gross returns of

$$\theta^0(1-\theta_j)R_i + I_1.$$

Denote by $\hat{r}_i$ the renegotiated contract that is the outcome of bargaining over extensions finance at $t = 1$. It will be such that

$$\theta_i (1 - \theta_j) \hat{r}_i = \theta^0 (1 - \theta_j) R_i + I_1. \tag{2.1}$$

Absent any disclosure considerations, the investor's expected returns at $t = 0$ would be

$$\theta^0 \left(1 - \theta_j^e\right) R_i$$

while the entrepreneur would earn an *ex ante* expected return of

$$\theta^0 \left(1 - \theta_j^e\right) (V - R_i) + \left(\theta_i^e - \theta^0\right) \left(1 - \theta_j^e\right) V - I_1.$$

The total expected returns from an *ex ante* perspective depends on the incidence of disclosure at $t = 1$ so that we delegate their full analysis until after the next section, which examines the disclosure decision in more detail.

2.4.1 The Ex Post Optimal Disclosure Decision

The focus of this section is the *ex post* optimal disclosure rule at $t = 1$ from the point of view of the investor as well as that of the entrepreneur with an interim knowledge advantage. Since extension finance is *ex post* efficient, we assume it to have been committed by the original investor in return for a renegotiated contract $\hat{r}$.

When both entrepreneurs possess the same level of interim knowledge, disclosure of interim knowledge is ineffective and will not occur. In the remainder of this section, we assume that entrepreneur i initially possesses interim knowledge $\theta_i = \theta^H$ while entrepreneur $j's$ interim research was not successful $\left(\theta_j = \theta^L\right)$.

Successful disclosure by the investor to E_j would raise her interim knowledge to $\theta_j = \theta^H$ and her expected return from $\theta^L\left(1-\theta^H\right)\left(V-\hat{r}_j\right)$ to $\theta^H\left(1-\theta^H\right)\left(V-\hat{r}_j\right)$. Similarly, the expected return of the investor would change from $\theta^L\left(1-\theta^H\right)\hat{r}_j + \theta^H\left(1-\theta^L\right)\hat{r}_i$ to $\theta^H\left(1-\theta^H\right)\left(\hat{r}_j+\hat{r}_i\right)$ under disclosure. Let S_j be the expected surplus created within the relationship between investor and E_j through successful disclosure:

$$S_j := \left(\theta^H - \theta^L\right)\left[\left(1-\theta^H\right)V - \theta^H\hat{r}_i\right]. \tag{2.2}$$

It includes the entire surplus created by disclosure for $E_j's$ project but only partially takes into account the effect of disclosure on E_i, namely through the contractual exposure of the investor to $E_i's$ project, $\hat{r}_i$.

The investor will consider disclosure to j if and only if $S_j \geq 0$. The following lemma restates this result.

Lemma 1 *Given contract $\hat{r}_i$, the investor will prefer disclosure at $t=1$ if and only if θ^H is not too large:*

$$\theta^H \leq \theta^D := \frac{V}{V+\hat{r}_i}.$$

θ^H provides a measure of the probability that both entrepreneurs succeed given that disclosure has occurred. If θ^H is too high, the loss from simultaneous final research success outweighs the gain from sole success by entrepreneur j. Hence, disclosure will be desirable for the investor if and only if its cost, as measured by θ^H, is sufficiently low. Since the investor does not take into account the entire adverse impact of disclosure on E_i, $\theta^D \in \left(\frac{1}{2}, 1\right)$ and the investor's *ex post* optimal disclosure rule would lead to too much disclosure compared to the optimal *ex ante* rule. This result is in contrast to Bhattacharya and Chiesa (1995) where the investor always follows the *ex ante* optimal disclosure rule.

Next, consider E_i. Disclosure changes $E_i^{\prime}s$ expected return from $\theta^H\left(1-\theta^L\right)(V-\hat{r}_i)$ to $\theta^H\left(1-\theta^H\right)(V-\hat{r}_i)$. Denote by S_i the expected surplus created by successful disclosure for entrepreneur i :

$$S_i := -\left(\theta^H-\theta^L\right)\theta^H\left(V-\hat{r}_i\right) \tag{2.3}$$

Given limited liability, the following result is immediate.

Lemma 2 *Given any contract $\hat{r}_i$, entrepreneur i always prefers non-disclosure.*

Lemma 2 extends the analysis of the entrepreneur's *ex post* optimal disclosure rule of Section 2.3 to a setting in which contracts are renegotiated at $t=1$. The conflict between E_i and her investor over optimal *ex post* disclosure exists whenever $\theta^H \leq \theta^D$.

Since property rights are weak, the entrepreneur cannot prevent knowledge transfers with certainty. With probability $(1-\beta)$ the investor will successfully disclose interim knowledge at $t=1$ if $\theta^H \leq \theta^D$. As a result, the entrepreneur must decide whether to 'accommodate' this behaviour or renegotiate her contract $\hat{r}_i$ in order to prevent disclosure. We now examine when it is in the entrepreneur's interest to renegotiate contract $\hat{r}$. To do so, we first derive the surplus from bargaining over disclosure.

Suppose first that bargaining over disclosure between E_i and the investor has broken down at $t=1$. Then interim disclosure will create a surplus of $(1-\beta)\,S_j$ for the investor and E_j so that bargaining will occur if and only if $S_j>0$. The investor's return from bargaining with the failed entrepreneur is $\theta^H\left(1-\theta^L\right)\hat{r}_i+\frac{1}{2}\left(1-\beta\right)S_j$. Next, we turn to the bargaining between E_i and her investor. The investor's outside option is given by the payoff he can obtain with E_j. $E_i's$ payoff when disclosure is successful is given by $\theta^H\left(1-\theta^L\right)\left(V-\hat{r}_i\right)+\left(1-\beta\right)S_i$. If bargaining between the investor and E_i is successful, it creates a joint return of $\theta^H\left(1-\theta^L\right)V$. Subtracting the sum of the outside options, the surplus from renegotiating over disclosure is given by

$$-\left(1-\beta\right)\left[S_i+\frac{1}{2}S_j\right]=\frac{1}{2}\left[V\left(1-3\theta^H\right)+\theta_i^H\hat{r}_i\right] \tag{2.4}$$

so that the entrepreneur will prefer disclosure prevention whenever $S_i+\frac{1}{2}S_j\leq 0$. This result is restated in the following lemma.

Lemma 3 *Entrepreneur i will prefer to renegotiate in order to prevent disclosure whenever θ is sufficiently high:*

$$\theta^H\geq\theta^P:=\frac{V}{3V-\hat{r}_i}.$$

The intuition for this condition is similar to that of Lemma 1. When θ^H is sufficiently high, disclosure is too likely to result in joint final research success, rendering disclosure prevention *ex post* optimal for the entrepreneur with interim knowledge advantage. However, since the investor does not appropriate the total surplus from disclosure to $j's$ project, the surplus that E_i and the investor bargain over does not take into account the full cost of preventing disclosure. As a result, the entrepreneur's *ex post* optimal disclosure rule will lead to too much disclosure prevention relative to the *ex ante* optimal disclosure rule: $\theta^P\in\left(0,\frac{1}{2}\right)$.

The following proposition summarises the preceding discussion.

Proposition 1 *Limited liability and assumption 2 imply that there exist two thresholds* θ^D *and* θ^P, *with* $0 < \theta^D < \frac{1}{2} < \theta^P < 1$, *such that*

(i) if $\theta^H \in [0, \theta^P)$, *it is ex post optimal for the investor to disclose and the entrepreneur will accommodate such disclosure;*

(ii) if $\theta^H \in \left[\theta^D, \theta^P\right]$, *it is ex post optimal for the investor to disclose, while it is ex post optimal for the entrepreneur to prevent disclosure through contract renegotiations; and*

(iii) if $\theta^H \in (\theta^P, 1]$, *it is not ex post optimal for both the investor and the entrepreneur to not disclose at* $t = 1$.

This proposition establishes that the need to seek outside finance affects the disclosure discussed in section 2.3. In particular, outside finance implies that the investor inefficiently prefers disclosure when $\theta > \frac{1}{2}$ while the entrepreneur's reduced residual claim implies that her aversion to disclosure is tempered so that she would accommodate disclosure if θ^H is sufficiently low. The next sections examine whether disclosure in fact occurs in a particular region described in proposition 1 and how effort incentives are affected.

2.4.2 Accommodation of Disclosure

First, suppose that $\theta^H \in [0, \theta^P)$ so that the entrepreneur will not attempt to renegotiate contracts with the aim of preventing disclosure as it is sufficiently unlikely to result in joint final research success.

The impact of disclosure on expected returns at $t = 0$ can be decomposed into two components: the impact on expected returns in case of no extension finance and the impact on the expected incremental surplus created by extension finance.

First, when E_i does not receive extension finance, her expected return at $t = 0$ is given by

$$\theta^0 \left(1 - \theta_j^e - (1-\beta)(1-p_j) p_i \left(\theta^H - \theta^L\right)\right)(V - R_i)$$

which is unambiguously lower when disclosure is accommodated with probability 1.

Second, the expected surplus created by extension finance is now given by

$$\left[\left(\theta_i^e - \theta^0\right)\left(1 - \theta_j^e\right) + (1-\beta)\left(\theta^H - \theta^L\right)\left[p_j (1-p_i)\left(1-\theta^H\right) - p_i (1-p_j)\left(\theta^H - \theta^0\right)\right]\right] V - I_1.$$

The impact of disclosure on this surplus is *a priori* ambiguous.

Bargaining over extension finance will leave the entrepreneur with the entire surplus from extension finance so that total $E_i's$ total expected returns at $t = 0$ are given by

$$\begin{aligned} &\left[\theta_i^e \left(1 - \theta_j^e\right) + (1-\beta)\left(\theta^H - \theta^L\right)\left[p_j (1-p_i)\left(1-\theta^H\right) - p_i (1-p_j)\theta^H\right]\right] V \\ &\quad -\theta^0 \left(1 - \theta_j^e - (1-\beta)(1-p_j) p_i \left(\theta^H - \theta^L\right)\right) R_i - I_1 \end{aligned} \tag{2.5}$$

The resulting incentive compatibility constraint is

$$\begin{aligned} &p\left(\theta^H - \theta^L\right)\left[\left(1-\theta_j^e\right) - (1-\beta)\left(p_j\left(1-\theta^H\right) + (1-p_j)\theta^H\right)\right] V \\ &\quad +\theta^0 (1-\beta)(1-p_j) p \left(\theta^H - \theta^L\right) R_i \geq c. \end{aligned} \tag{2.6}$$

Finally, the investor's *ex ante* participation constraint is given by

$$\theta^0 \left(1 - \theta_j^e - (1-\beta)(1-p_j) p_i \left(\theta^H - \theta^L\right)\right) R_i \geq I_0. \tag{2.7}$$

The equilibrium contract is characterised in the following lemma.

Proposition 2 *Suppose that $\theta^H \in [0, \theta^P)$. In equilibrium, disclosure will occur with probability $(1-\beta)$ and the initial contract specifies repayment $R_i = \frac{I_0}{\theta^0\left(1-\theta^e-(1-\beta)(1-p)p\left(\theta^H-\theta^L\right)\right)}$. The entrepreneur will receive financing at $t = 0$ if*

$$V\left[1-\theta^e-(1-\beta)\left(p\left(1-\theta^H\right)+(1-p)\,\theta^H\right)\right] + \frac{(1-\beta)\,(1-p)\,\theta^0}{1-\theta^e-(1-\beta)\,(1-p)\,p\left(\theta^H-\theta^L\right)} I_0 \geq \frac{c}{p\left(\theta^H-\theta^L\right)}.$$

Proof: In equilibrium, $p_i = p_j = p$. The investor's participation constraint will hold with equality, determining the initial contract. The financing constraint is obtained by substituting for the equilibrium contract in the incentive compatibility constraint. ■

When disclosure is *ex post* optimal for the investor and θ^H is sufficiently low, the entrepreneur will accommodate disclosure. As a result, over this region the *ex ante* optimal disclosure rule is implemented. However, interim disclosure may lower effort incentives as it reduces the reward to high effort and increases the return to low effort.

Stronger property rights unambiguously lower expected returns for a given initial contract, that is, (2.5) is decreasing in β since $\theta^H < \frac{1}{2}$. This is because stronger property rights prevent *ex ante* optimal (and socially efficient) interim disclosure. The effect of stronger property rights on the incentive compatibility constraint is more complex. On the one hand, stronger property rights reduce the probability with which a knowledge advantage is dissipated and thus strengthens effort incentives. On the other hand, stronger property rights increase the probability that the repayment R_i must be made. The overall effect is ambiguous.[27] Finally, stronger property rights reduce the repayment R_i agreed upon in the initial contract.

[27] This ambiguity remains if we relax the assumption that the investor does not possess bargaining power over extension finance at the interim stage. If anything, according more bargaining power to the investor renders it more likely that stronger property rights reduce effort incentives.

In our setting, it is not easy to evaluate the relative impact of these effects.[28] However, we can establish the following result.

Proposition 3 *When*

$$\beta < \frac{\theta^0 (1-p) I_0 - (1-\theta^e) \left(p \left(1-\theta^H\right) + (1-p)\theta^H + p(1-p)\left(\theta^H - \theta^L\right)\right) V}{\left(p\left(1-\theta^H\right) + (1-p)\theta^H\right) p(1-p)\left(\theta^H - \theta^L\right)}$$

stronger property rights will increase the financing threshold in proposition 2. In this case, stronger property rights unambiguously reduce expected surplus.

Proof: Differentiate the financing threshold in proposition 2 with respect to β. The condition in Proposition 3 determines when this derivative is negative. ■

Proposition 3 establishes a sufficient condition such that stronger property rights reduce expected surplus whenever $\theta^H \leq \theta^D$. This condition is more likely to hold when property rights are weak, when the initial financing cost I_0 is large compared to final returns V and when p, the impact of effort on the likelihood of interim knowledge discovery, is small. For example, as p approaches 0, the numerator will be positive if $V\left(1-\theta^L\right)\theta^H V < \theta^0 I_0$, i.e. when θ^H is close to θ^0 and V is close to I_0, while the denominator approaches 0. In this case stronger property rights will unambiguously reduce expected returns of the entrepreneur because they reduce *ex ante* optimal disclosure and increase the financing threshold.

[28] Such an evaluation would be possible, for example, in an extension of our setting in which the parameter p, i.e. the 'productivity parameter' of effort in terms of likelihood of obtaining high interim knowledge, is drawn from a c.d.f $G(p)$ prior to $t = 0$. Such a setting would preserve the moral hazard problem while allowing us to precisely specify the expected *ex ante* impact of stronger property rights on the incentive compatibiliy constraint.

2.4.3 Prevention of Disclosure

This section concentrates on the case in which $\theta^H \in [\theta^D, \theta^P]$ so that the investor finds it *ex post* optimal to transfer interim knowledge across rivals. The entrepreneur with an interim knowledge advantage, by contrast, will prefer to renegotiate the extension finance contract $\hat{r}_i$ in order to prevent disclosure.

Let repayment r_i be the outcome of bargaining between E_i and the investor over disclosure. We begin by deriving the condition that ensures that r_i is *ex post* incentive compatible for the investor, that is, that r_i renders disclosure to E_j suboptimal for the investor once bargaining between the investor and entrepreneur i has concluded. This will be the case if the incremental surplus from *ex post* disclosure is negative, i.e. if

$$\theta^H r_i \geq \left(1-\theta^H\right) V. \tag{2.8}$$

We refer to this condition as the *ex post* incentive compatibility constraint. Any (renegotiated) contract that is intended to prevent disclosure at $t = 1$ must fulfill this condition. Recall that the contract that results from bargaining over extension finance is given by

$$\hat{r}_i = \frac{\theta^0}{\theta_i} R_i + \frac{I_1}{\theta^H \left(1-\theta^L\right)}$$

when E_i has an interim knowledge. Note that by substituting $\hat{r}_i$ into the definition of θ^D in Lemma 1, it follows that $\theta^H \hat{r}_i < \left(1-\theta^H\right) V$ when $\theta < \theta^D$ so that the contract resulting from bargaining over extension finance is never sufficient to prevent *ex post* disclosure. The following result can then be established.

Lemma 4 *Suppose that $\theta^H < \frac{1}{2}$. Then disclosure prevention through renegotiation at $t = 1$ is not ex post compatible. The entrepreneur must accommodate disclosure and the optimal contract is that described in Proposition 2.*

Suppose that $\frac{1}{2} \leq \theta^H \leq \theta^D$. Then the investor will always prefer to disclose and the entrepreneur will renegotiate contract $\hat{r}_i$ to prevent disclosure.

Proof: Suppose that $\theta^H < \frac{1}{2}$ and suppose that $r_i = V$. Then condition (2.8) does not hold. By contrast, when $\theta^H \geq \frac{1}{2}$ and $r_i = V$, condition (2.8) holds. As a result, it is feasible to write an *ex post* incentive compatible contract if and only if $\theta^H \geq \frac{1}{2}$. ■

When $\theta^H < \frac{1}{2}$, even pledging the entire project's revenue is not sufficient to render the renegotiated contract *ex post* incentive compatible as disclosure is socially efficient. As a result, regardless of the contract r_i agreed upon during bargaining over disclosure, the investor will disclose to E_j once bargaining has concluded. By contrast, when $\theta^D \geq \theta \geq \frac{1}{2}$, the investor will disclose unless he is offered an *ex post* incentive compatible contract at $t = 1$ that prevents disclosure. We now concentrate on this case.

Recall that bargaining between entrepreneur i and her investor over disclosure at $t = 1$ creates a surplus of $-(1-\beta)\left[S_i + \frac{1}{2}S_j\right] \geq 0$ in this region. Successful bargaining between the investor and i will thus result in an expected return to the investor of $\theta^H\left(1-\theta^L\right)\hat{r}_i + \theta^L\left(1-\theta^H\right)\hat{r}_j + \frac{1-\beta}{2}\left[\frac{1}{2}S_j - S_i\right]$ of which the investor will receive $\theta^L\left(1-\theta^H\right)\hat{r}_j$ from E_j. Thus, the disclosure-prevention contract must be designed such that

$$\theta^H\left(1-\theta^L\right)r_i \geq \theta^H\left(1-\theta^L\right)\hat{r}_i + \frac{1-\beta}{2}\left[\frac{1}{2}S_j - S_i\right], \tag{2.9}$$

where $\frac{1-\beta}{2}\left[\frac{1}{2}S_j - S_i\right] = \frac{1-\beta}{4}\left(\theta^H - \theta^L\right)\left[\left(1+\theta^H\right)V - 3\theta^H\hat{r}_i\right]$.

The *ex post* incentive compatibility constraint and constraint (2.9) place differing demands on the disclosure prevention contract r_i. Note, however, that the *ex post* incentive compatibility constraint (2.8) is independent of β since it merely weighs off gains against losses conditional on disclosure having been successful. Constraint (2.9), by contrast, is decreasing in β since minimum surplus appropriated by the investor depends on the severity of the threat to disclose, i.e. the probability that disclosure will be successful. This trade-off yields the following result.

Lemma 5 *If property rights are sufficiently strong, that is if*

$$\beta \geq \bar{\beta} := 1 - 4\left(\frac{1-\theta^L}{\theta^H - \theta^L}\right)\left(\frac{\left(1-\theta^H\right)V - \theta^H \hat{r}_i}{\left(1+\theta^H\right)V - 3\theta^H \hat{r}_i}\right).$$

then the ex post incentive compatibility constraint is binding and the renegotiated contract is given by $r_i = \frac{1-\theta^H}{\theta^H}V$. *Otherwise inequality (2.9) is binding and the renegotiated contract is given by* $r_i = \hat{r}_i + \frac{1-\beta}{4}\left(\frac{\theta^H-\theta^L}{1-\theta^L}\right)\left[\frac{1+\theta^H}{\theta^H}V - 3\hat{r}_i\right]$.

Proof: The threshold is obtained by comparing inequalities (2.8) and (2.9). The resulting optimal contracts result from the relevant investor participation constraints holding with equality. ■

We now investigate the *ex post* optimal contract and its effect on incentives for both of these cases.

Property rights are relatively strong: $\beta \geq \bar{\beta}$.

In this scenario, E_i's expected return from bargaining at $t = 1$ will be $\theta_i\left(1-\theta_j\right)\left(V - r_i\right)$. At $t = 0$, the expected return from bargaining at $t = 0$ is thus $\theta_i^e\left(1-\theta_j^e\right)V - I_1 -$

$p_i(1-p_j)\left[\left(1-\theta^H\right)V-\frac{I_1}{1-\theta^L}\right]$, where the last term represents the expected surplus extracted through the threat of disclosure. At $t=0$, the entrepreneur's total expected returns are

$$\theta^0\left(1-\theta_j^e\right)\left(V-R_i\right)+\left(\theta_i^e-\theta^0\right)\left(1-\theta_j^e\right)V-I_1-p_i\left(1-p_j\right)\left[\left(1-\theta^H\right)V-\frac{I_1}{1-\theta^L}\right]$$

The resulting incentive compatibility constraint is given by

$$p\left(\theta^H-\theta^L\right)\left(1-\theta_j^e\right)V-p\left(1-p_j\right)\left[\left(1-\theta^H\right)V-\frac{I_1}{1-\theta^L}\right]\geq c$$

while the investor's participation constraint is given by

$$\theta^0\left(1-\theta_j^e\right)R_i+p_i\left(1-p_j\right)\left[\left(1-\theta^H\right)V-\frac{I_1}{1-\theta^L}\right]\geq I_0,$$

reflecting the additional surplus extracted through the threat of disclosure. The equilibrium contract is characterised in the following lemma.

Proposition 4 *Suppose that $\beta\geq\bar{\beta}$ and that $\theta^H\in(\frac{1}{2},\theta^D]$. Then, in equilibrium, disclosure will not occur and the optimal initial contract is given by $R_i=\frac{I_0-p(1-p)\left[\left(1-\theta^H\right)V-\frac{I_1}{(1-\theta^L)}\right]}{\theta^0(1-\theta^e)}$. The entrepreneur will receive financing at $t=0$ if*

$$V\left[p\left(\theta^H-\theta^L\right)\left(1-\theta^e\right)-p\left(1-p\right)\left(1-\theta^H\right)\right]+\frac{p\left(1-p\right)}{1-\theta^L}I_1\geq c.$$

Proof: Follows that of Proposition 2.

The investor's threat to disclose allows him to expropriate some of the entrepreneur's surplus. The potency of this threat is not related to the strength of property rights which has two implications. First, the entrepreneur does not benefit from stronger property rights when $\beta \geq \bar{\beta}$. Second, weakening perfect property rights ($\beta = 1$) by only a small amount will impose a discontinuous penalty in terms of expected surplus on the entrepreneur. This effect arises out of the need to remove disclosure incentives for the investor after the contract has been renegotiated (constraint (2.8) must hold) so that, even β approaches 1, the investor must be left with additional surplus that is bounded away from 0.[29]

Property rights are relatively weak: $\beta < \bar{\beta}$.

When the entrepreneur does not have an interim knowledge advantage, her expected return from bargaining at $t = 1$ is given by $\theta_i (1 - \theta_j) (V - \hat{r}_i) = \theta_i (1 - \theta_j) V - \theta^0 (1 - \theta_j) R_i - I_1$ since $\hat{r}_i = \frac{\theta^0}{\theta_i} R_i + \frac{I_1}{\theta_i(1-\theta_j)}$. When the E_i does have an interim knowledge advantage, however, her expected return from bargaining at $t = 1$ is given by

$$\begin{aligned}\theta^H \left(1 - \theta^L\right) (V - r_i) = {} & \theta^H \left(1 - \theta^L\right) V - \theta^0 \left(1 - \theta^L\right) R_i - I_1 \\ & - \frac{1-\beta}{4} \left(\theta^H - \theta^L\right) \left[\left(1 + \theta^H\right) V - 3 \left(\theta^0 R_i + \frac{I_1}{\left(1 - \theta^L\right)}\right)\right]\end{aligned}$$

since $r_i = \hat{r}_i + \frac{1-\beta}{4} \left(\frac{\theta^H - \theta^L}{1-\theta^L}\right) \left[\frac{1+\theta^H}{\theta^H} V - 3\hat{r}_i\right]$ and $\hat{r}_i = \frac{\theta^0}{\theta_i} R_i + \frac{I_1}{\theta_i(1-\theta_j)}$. As a result, the entrepreneur's expected returns at $t = 0$ are given by

$$\begin{aligned}& \theta^0 \left(1 - \theta_j^e\right) (V - R_i) + \left(\theta_i^e - \theta^0\right) \left(1 - \theta_j^e\right) V - I_1 \\ & \quad - p_i \left(1 - p_j\right) \frac{1-\beta}{4} \left(\theta^H - \theta^L\right) \left[\left(1 + \theta^H\right) V - 3 - 3 \left(\theta^0 R_i + \frac{I_1}{\left(1 - \theta^L\right)}\right)\right]\end{aligned}$$

[29] This also implies that this effect is independent of the binary structure of our model and would survive if effort choice and interim knowledge were modelled as continuous variables.

yielding an incentive compatibility constraint of

$$p\left(\theta^H - \theta^L\right)\left(1 - \theta_j^e\right) V \\ - p\left(1 - p_j\right)\frac{1-\beta}{4}\left(\theta^H - \theta^L\right)\left[\left(1 + \theta^H\right) V - 3\left(\theta^0 R_i + \frac{I_1}{\left(1 - \theta^L\right)}\right)\right] \geq c.$$

The investor's participation constraint is given by

$$\theta^0\left(1 - \theta_j^e\right) R_i - p_i\left(1 - p_j\right)\frac{1-\beta}{4}\left(\theta^H - \theta^L\right)\left[\left(1 + \theta^H\right) V - 3\left(\theta^0 R_i + \frac{I_1}{\left(1 - \theta^L\right)}\right)\right] \geq I_0$$

which allows us to obtain the following result.

Proposition 5 *Suppose that $\beta < \bar{\beta}$, $\theta^H \in (\frac{1}{2}, \theta^D]$. Then, in equilibrium, interim disclosure will not occur and the optimal initial contract is given by $R_i = \frac{I_0 - p(1-p)\frac{1-\beta}{4}\left(\theta^H - \theta^L\right)\left[\left(1+\theta^H\right)V - 3\frac{I_1}{(1-\theta^L)}\right]}{\theta^0\left[\left(1-\theta^e\right) + \frac{3}{4}p(1-p)(1-\beta)\left(\theta^H - \theta^L\right)\right]}$. The entrepreneur will receive financing at $t = 0$ if*

$$V\left[\left(1 - \theta^e\right) - (1 - p)\frac{1-\beta}{4}\left(1 + \theta^H\right)\right] \geq \\ \frac{c}{p\left(\theta^H - \theta^L\right)} - \frac{3}{4}(1-p)(1-\beta)\left(1 + \frac{\frac{3}{4}p(1-p)(1-\beta)\left(\theta^H - \theta^L\right)}{\left[\left(1 - \theta^e\right) + \frac{3}{4}p(1-p)(1-\beta)\left(\theta^H - \theta^L\right)\right]}\right)\left(\frac{I_1}{\left(1 - \theta^L\right)} + I_0\right).$$

Proof: Follows that of Proposition 2.

Again, weak property rights allow the investor to threaten disclosure at $t = 1$ and expropriate surplus. As a result, effort incentives are weakened. In contrast to proposition 4, the strength of property rights reduces effort incentives. Weaker property rights result in a stronger adverse impact on effort incentives and, as a result, fewer projects will receive financing at $t = 0$.

2.4.4 Non-disclosure

Finally, we turn to the region $\theta^H \in (\theta^D, 1]$ for which it is not *ex post* optimal for either investor or entrepreneur to disclose at $t = 1$. In this case, the entrepreneur's expected returns at $t = 0$ are given by

$$\theta^0 \left(1 - \theta_j^e\right) (V - R_i) + \left(\theta_i^e - \theta^0\right) \left(1 - \theta_j^e\right) V - I_1$$

yielding an incentive compatibility constraint of $p_i \left(\theta^H - \theta^L\right) \left(1 - \theta_j^e\right) V \geq c$. The investor's participation constraint is given by $\theta^0 \left(1 - \theta_j^e\right) R_i \geq I_0$ which allows us to obtain the following result.

Proposition 6 *When $\theta > \theta^D$, then disclosure will not occur in equilibrium. The initial contract specifies a repayment $R_i = \frac{I_0}{\theta^0(1-\theta^e)}$ and entrepreneurs will receive finance at $t = 0$ if $V > \frac{c}{p\left(\theta^H - \theta^L\right)(1-\theta^e)}$.*

When the probability of final research success is very high, disclosure is so damaging that the investor will not undertake it. As a result, disclosure does not occur and there is no departure from *ex ante* efficiency. The strength of property rights is irrelevant over this region.

2.4.5 Discussion

This section has analysed the *ex post* incentives of the entrepreneur and her investor to engage in interim knowledge disclosure and has characterised the *ex post* optimal contracts that result from their bargaining over disclosure. We have argued that renegotiations over interim disclosure lead to the *ex ante* optimal disclosure rule: in equilibrium, the investor will disclose if and only if $\theta^H \leq \frac{1}{2}$. Weak property rights ensure that this disclosure is successful with probability $(1 - \beta)$ only. As a result, weak property rights have an ambiguous effect on overall surplus when $\theta^H \leq \frac{1}{2}$. On the one hand, weak property rights ensure that disclosure does occur with some probability although it is *ex post* suboptimal for the entrepreneur. In this respect, weaker property rights increase *ex ante* surplus. On the other hand, weaker property rights tend to reduce entrepreneurial effort incentives exactly because of disclosure. As a result, *ex ante* efficiency may be reduced. Proposition 3 argues that weaker property rights may well increase expected surplus when the impact of effort is small and start-up costs are high relative to possible returns.[30]

A second result of this section is that weak property rights may impose costs even though disclosure does not occur in equilibrium. When $\theta^D \geq \theta^H > \frac{1}{2}$, the entrepreneur will find it *ex post* optimal to prevent disclosure through renegotiation. As a result, the threat of disclosure allows the investor to extract additional surplus, thus reducing *ex ante* effort incentives and hence *ex ante* efficiency. We find that weak property rights have a non-continuous impact on this cost: when β is relatively low, strengthening property rights imposes an adverse effect on effort incentives. By contrast, when β is high (but not equal to one) the cost in terms of effort incentives is not affected by the strengths of property rights. In this sense, introducing a small amount of weakness in property rights may lead to a discontinuous impact on *ex ante* efficiency. In this context, the result of Proposition 3 also implies that the impact of

[30] Allowing for asymmetric projects would not affect the main results of this analysis but would allow for a more differentiated analysis that is not the focus of the current chapter.

Suppose, for example, that the two projects differ in their productivity of high interim knowledge, e.g. that $\theta_i^H \neq \theta_j^H$. Then the investor would prefer to disclose more often from the less productive entrepreneur to the more productive entrepreneur and vice-versa. Further, the more productive entrepreneur would have lower incentives to prevent knowledge disclosure since disclosure lowers his expected surplus by (relatively) less. On the other hand, this entrepreneur would also be able to prevent disclosure over a greater range of parameters since the expected surplus to be bargained over during disclosure renegotiations would be greater. The behaviour of a less productive entrepreneur would be affected in the opposite manner.

More asymmetric projects would also tend to render strong property rights less efficient since they would allow the less productive entrepreneur to prevent socially efficient disclosure more often.

IPR strength on expected returns may be non-monotonic in project's riskiness as measured by θ^H.

2.5 Extensions

In this section, we present two simple extensions to the model presented above. In the first extension, we allow the entrepreneur to choose between two different types of investors, one which can commit not to disclose at $t = 1$ and one which cannot (as in the previous section). This choice can be interpreted as one between disclosure prevention through institutional choice and through contractual means. In the second extension, we investigate the impact of weak property rights on the optimal size of the investor's portfolio. A larger portfolio of entrepreneurs allows the investor to extract more surplus at $t = 1$ as the threat of disclosure is more potent but imposes a cost in terms of effort provision.

In both extensions, we focus on the case in which $\theta^H \in (\frac{1}{2}, \theta^D]$ so that disclosure is not *ex ante* optimal and will not occur in equilibrium.[31] The investor's threat to disclose nevertheless allows him to extract surplus and the main aim of this section will be to investigate the impact of this threat on the choices outlined above.

To simplify notation, we will denote by D the amount of surplus extracted by the investor at $t = 1$ from an entrepreneur with interim knowledge advantage:

$$D = \begin{cases} \left(1 - \theta^H\right) V - \frac{I_1}{1-\theta^L} & \text{if } \beta \geq \bar{\beta} \\ \frac{1-\beta}{4} \left(\theta^H - \theta^L\right) \left[\left(1 + \theta^H\right) V - 3 \left(\theta^0 R_i + \frac{I_1}{\left(1-\theta^L\right)}\right)\right] & \text{otherwise} \end{cases} . \tag{2.10}$$

[31] The analysis for the case in which $\theta^H \leq \frac{1}{2}$ is conceptually similar, except that the trade-offs considered in this section would be uniformly resolved in favour of the option that allows disclosure as it is *ex ante* efficient.

2.5.1 Different Investor Relationships

In this extension, we allow the entrepreneur to choose the type of financing relationship she has with their investor. A financing relationship is characterised by whether or not the investor also possesses any interim knowledge produced by the entrepreneur and by the productive advice that is provided by the investor during final research.

To keep the analysis as succinct as possible we impose three assumptions. First, we allow the entrepreneur to choose between only two types of investors at $t = 0$, a 'close' and a 'distant' investor. The *close investor* is that of the preceding analysis, i.e. an investor who is intimately involved in the running of the business and is consequently exposed to any research output. In our parlance, the investor acquires any interim research produced. As a result, the close investor can threaten to disclose interim knowledge and we assume, as before, that he cannot commit at $t = 0$ not to disclose. The *distant investor*, by contrast, is not intimately involved in entrepreneur's business. The advantage of this distance is that he does not acquire any interim knowledge and cannot threaten to disclose.

The second simplification arises insofar as we do not explicitly model the investor's decision to provide advice to the entrepreneur after interim knowledge has been created.[32] With a distant investor, interim knowledge θ_i will result in final research success with probability $\gamma\theta_i$ where $\gamma \in (0, 1)$, whereas with a close investor, final success will be obtained with probability θ_i. In this sense, $(1 - \gamma)$ captures the advantage that access to interim knowledge

[32] Modelling this choice explicitly is straightforward but lengthy, and would not add qualitatively to our result as long as close involvement with an investor (*i*) enables him to observe the daily operation of a project and, as a result, (*ii*) allows him to give more focussed and specific advice that increases the project's prospects. See Casamatta (2003), Inderst and Mueller (2004) and Repullo and Suarez (2004) for theoretical analyses of this dimension in the context of venture capital finance, as well as Gompers and Lerner (2000) and Hellmann and Puri (2002) for empirical support.

bestows on the close investor's ability to advise. Note that probability of final success when extension finance is not obtained remains at θ^0 regardless of the financing relationship.[33]

Finally, both entrepreneurs in the industry are financed by the same investor who is chosen by entrepreneur i.[34]

The resulting trade-off faced by entrepreneur i in choosing a close investor is one between higher productivity of interim knowledge and the adverse effect of the investor's threat of disclosure on incentives. To make this trade-off as explicit as possible, we depart from the setting introduced in section 4.2 by assuming that if the entrepreneur does not exert effort, the probability of obtaining high interim knowledge θ^H is remains positive, i.e. $p_i = q$, where $0 < q < p$, when entrepreneurial effort is zero. Furthermore, to abstract from issues of inefficient investment, we amend assumption 2.

Assumption 2′: *The net present value of the entrepreneur's project at $t = 0$ is positive given low effort and given distant financing:* $\gamma\left(\theta^L + q\left(\theta^H - \theta^L\right)\right)\left(1 - \gamma\left[\theta^L + q\left(\theta^H - \theta^L\right)\right]\right)V > I_0 + I_1$.

Finally, we impose the following assumption.

Assumption 3: *The expected probability of interim and final research success is sufficiently small:* $p \leq \frac{1}{2}$ *and* $\theta^L + p\left(\theta^H - \theta^L\right) \leq \frac{1}{2}$.

This assumption is intuitive as it ensures that increasing effort from p to q also increases a project's expected returns.

[33] This assumption is for simplicity and implies that the closeness of the entrepreneur-investor relationship does not matter if interim knowledge is not used in the production of final research. Relaxing this assumption would not change our main results.

[34] This assumption may seem intuitive in a setting in which the entrepreneurs search for investors sequentially and in which an existing financing relationship in an industry confers a strong first-mover advantages on an investor.

The optimal contract with the close investor was characterised in the Propositions 4 and 5. In the amended setting of this section, the entrepreneur earns expected returns of

$$\left(1-\theta_j^e\right)\left(\theta_i^e V-\theta^0 R_i\right)-I_1-p_i\left(1-p_j\right)D,$$

where D is given by (3.22), and will exert high effort if

$$\left(1-\theta_j^e\right)V-\left(\frac{1-p_j}{\theta^H-\theta^L}\right)D\geq\frac{c}{(p-q)\left(\theta^H-\theta^L\right)}$$

while the investor offers an initial contract of $R_i=\frac{I_0}{\theta^0\left(1-\theta_j^e\right)}-\frac{p_i(1-p_j)}{\theta^0\left(1-\theta_j^e\right)}D$. We now describe the optimal contract for a distant investor. The expected return at $t=0$ of the entrepreneur is given by

$$\left(1-\gamma\theta_j^e\right)\left[\gamma\theta_i^e V-\theta^0 R_i\right]-I_1.$$

The entrepreneur's incentive compatibility constraint is $\gamma\left(1-\gamma\theta_j^e\right)V\geq\frac{c}{(p-q)\left(\theta^H-\theta^L\right)}$. The distant investor's participation constraint is given by $\theta^0\left(1-\gamma\theta_j^e\right)R_i\geq I_0$ so that the equilibrium initial contract specifies repayment $R_i=\frac{I_0}{\theta^0\left(1-\gamma\theta_j^e\right)}$.

Consider first the case in which both types of investors induce the same level of effort. Upon substitution of the optimal contract, the entrepreneur always prefers the close investor in this case. At $t=0$, the optimal contract is designed such that the expected repayments are the same under either financing relationship. The close investor is better placed to offer advice and Assumption 3 ensures that this translates into a higher expected surplus to the entrepreneur at $t=0$. Next, if a close financing relationship resulted in superior effort incentives to the entrepreneur, an entrepreneur would find the close investor an even more profitable proposition at $t=0$.

As a result, we focus on the case in which a distant financing relationship induces more effort than a close one. This case will arise when the close investor's threat of disclosure is particularly potent:

$$\gamma\left(1-\gamma\left[\theta^{L}+p\left(\theta^{H}-\theta^{L}\right)\right]\right)V \geq \frac{c}{\left(p-q\right)\left(\theta^{H}-\theta^{L}\right)} > \left(1-\left[\theta^{L}+p\left(\theta^{H}-\theta^{L}\right)\right]\right)V - \frac{1-q}{\theta^{H}-\theta^{L}}D. \tag{2.11}$$

This case will exist if γ is sufficiently large:

$$\gamma \geq \frac{1}{2\left[\theta^{L}+p\left(\theta^{H}-\theta^{L}\right)\right]}\left[1-\left(1-4\left[\theta^{L}+p\left(\theta^{H}-\theta^{L}\right)\right]\left[1-\left[\theta^{L}+p\left(\theta^{H}-\theta^{L}\right)\right]-\frac{1-q}{\theta^{H}-\theta^{L}}\frac{D}{V}\right]\right)^{\frac{1}{2}}\right]. \tag{2.12}$$

Suppose that conditions (2.11) and (2.12) hold. Then we can establish the following result.

Proposition 7 *Suppose close investors induce low effort and distant investors induce high effort. Then the entrepreneur will choose the close investor if and only if*

$$\gamma \geq \frac{1}{2p}\left[1-\left(1-4\left[q\left(1-q\right)\right]\left[1-\frac{D}{V}\right]\right)^{\frac{1}{2}}\right],$$

where D is defined by (3.22).

Proof: The condition follows from comparing the entrepreneur's expected payoff from a distant and close investor and solving the resulting quadratic equation in γ for γ for the upper and lower boundary on γ. Note that, by assumption 3, the upper boundary is larger than 1. Since $\gamma < 1$, it can be safely omitted. ■

The result in Proposition 7 is intuitive. The higher the productivity of interim knowledge under the distant investor, or, conversely, the less important the advice provided by the close investor, the more likely it is that the distant investor is chosen and the larger the interval of cost parameters over which this will be the case. Similarly, the more important effort is in interim research (high p and low q), the more often the entrepreneur will choose the distant investor. Finally, the more surplus can be extracted by the close investor from the entrepreneur if she has an interim knowledge advantage (if $\frac{D}{V}$ is high), the more often the entrepreneur will choose the distant investor. This also implies that as long as $\beta < \bar{\beta}$, an increase in the strength of property rights will lead the entrepreneur to choose close investors more often. This conclusion is consistent with the well-documented increase of venture capital financing in the U.S. after patenting laws were strengthened in the early 1990s (e.g. Kortum and Lerner (1998)) as well as the importance of legal origins on financing arrangements (e.g. Lerner and Schoar (forthcoming)).

2.5.2 The Size of the Investor's Portfolio

In this section, we allow the investor to decide whether to finance a small portfolio (one entrepreneur) or a large portfolio (two entrepreneurs) at $t = 0$.[35] A larger portfolio allows the investor to extract more surplus at the interim stage because he can threaten to disclose information across entrepreneurs. The disadvantage of a larger portfolio is that the threat of disclosure renders the incentivisation of the entrepreneur more difficult. This trade-off will determine the optimal size of the portfolio.

To investigate this trade-off, we return to the model as described in Section 4.2, with the exception that *ex ante* competition between investors no longer ensures that they earn zero expected profits at $t = 0$. Rather, we assume that there are not more investors than

[35] The subsequent analysis can be extended to a setting with more than two entrepreneurs which requires a more complex bargaining model. As long as the bargaining structure is such that a larger portfolio of entrepreneurs allows the investor to extract more surplus by threatening disclosure, the qualitative implications of our analysis are not affected by relaxing this assumption.

entrepreneurs and that the investor appropriates a share μ of the entrepreneur's expected surplus at $t = 0$.[36] Furthermore, we assume that if bargaining with the original investor over extension finance at $t = 1$ breaks down the entrepreneur cannot receive outside financing.[37] As a result, the entrepreneur and the investor receive an equal share of the surplus created through extension finance when bargaining at $t = 1$.

Consider first the case in which the investor finances a single entrepreneur. With the amended bargaining structure, the equilibrium outcomes are described in the following lemma.

Lemma 6 *When the bargaining structure is changed as described above and the investor finances a single entrepreneur, the expected returns at $t = 0$ are given by*

$$\begin{aligned} \textit{Investor} &: \quad \mu \left[\theta^0 \left(1 - \theta_j^e\right) V - I_0\right] + \frac{1+\mu}{2} \left[\left(\theta^i - \theta^0\right) \left(1 - \theta_j^e\right) V - I_1\right] \quad (2.13) \\ \textit{Entrepreneur} &: \quad (1-\mu) \left[\theta^0 \left(1 - \theta_j^e\right) V - I_0\right] + \frac{1-\mu}{2} \left[\left(\theta^i - \theta^0\right) \left(1 - \theta_j^e\right) V - I_1\right] \quad (2.14) \end{aligned}$$

As a result, the entrepreneur will exert effort in equilibrium if

$$\frac{1-\mu}{2} p \left(\theta^H - \theta^L\right) \left(1 - \theta^e\right) V \geq c. \quad (2.15)$$

Proof: Bargaining over extension finance at $t = 1$ creates a surplus $\left(\theta_i - \theta^0\right) \left(1 - \theta_j\right) V - I_1$ which is shared equally between entrepreneur and investor. As a result, the surplus that

[36] This specification can be seen as a reduced-form model of a more complicated setting in which the demand and supply for investment funds determines the investors' and entrepreneurs' relative bargaining power, such as Inderst and Mueller (2004).

[37] This assumption is consistent with the observation that, in equilibrium, the original investors also provide extension finance. As a result, when there are not more investors than entrepreneurs, all available funds are committed in equilibrium. A breakdown of bargaining will then result in the entrepreneur not receiving extension finance. Our results are not affected if this assumption is dropped.

is shared according to bargaining weights μ and $(1-\mu)$ is given by $\theta^0 \left(1-\theta_j^e\right) V - I_0 + \frac{1}{2}\left[\left(\theta^i - \theta^0\right)\left(1-\theta_j^e\right) V - I_1\right]$, i.e. the total surplus minus the share that will be expropriated at $t = 1$ by the investor. Expressions (2.13) and (2.14) follow, while the incentive compatibility constraint is obtained from (2.14). ■

Consider now the case in which the investor finances two entrepreneurs. In the absence of disclosure considerations (e.g. if $\theta^H > \theta^D$), payoffs remain the same as above and the choice between the two portfolio sizes is indeterminate. When $\theta^H \leq \theta^D$, payoffs are those given in the following lemma.

Lemma 7 *Suppose that $\theta^D \geq \theta^H > \frac{1}{2}$ and that the investor finances two entrepreneurs. Then expected returns at $t = 0$ are*

$$\begin{array}{ll} \textit{Investor:} & \mu\theta^0\left(1-\theta_j^e\right)V + \frac{1+\mu}{2}\left[\left(\theta^i-\theta^0\right)\left(1-\theta_j^e\right)V - I_1\right] + (1-\mu)\,p_i\left(1-p_j\right)D + I_1 + I_0 \\ \textit{Entrepreneur:} & (1-\mu)\,\theta^0\left(1-\theta_j^e\right)V + (1-\mu)\left[\frac{1}{2}\left[\left(\theta^i-\theta^0\right)\left(1-\theta_j^e\right)V - I_1\right] - p_i\left(1-p_j\right)D\right] \end{array}$$

where D is given by (3.22). As a result, the entrepreneur will exert effort in equilibrium if

$$(1-\mu)\,p\left(\theta^H-\theta^L\right)\left[\frac{1-\theta^e}{2}V - (1-p)\,D\right] \geq c. \tag{2.16}$$

Proof: The proof follows along similar lines as that of the preceding lemma. The only significant departure stems from the fact that at $t = 1$, the investor has expected returns $\frac{1}{2}\left[\left(\theta^i-\theta^0\right)\left(1-\theta_j^e\right)V - I_1\right] + p_i\left(1-p_j\right)D$. As a result, the surplus bargained over at $t = 0$ is given by $\theta^0\left(1-\theta_j^e\right)V + \frac{1}{2}\left[\left(\theta^i-\theta^0\right)\left(1-\theta_j^e\right)V - I_1\right] - p_i\left(1-p_j\right)D$, which is shared according to bargaining powers μ and $(1-\mu)$. The incentive constraint follows from the entrepreneur's expected return. ■

When comparing the expected returns for a given entrepreneurial effort, it is obvious that the investor will prefer the larger portfolio as it allows him to appropriate additional surplus of $(1-\mu)\,p\,(1-p)\,D$. Consider instead the situation in which (2.15) but not (2.16) holds, i.e. when the threat of disclosure lowers the effort exerted in a larger portfolio. Then the investor with a large portfolio would have to leave additional surplus to the entrepreneur to incentivise her, thus reducing her expected returns. The following proposition analyses the effect of this trade-off on *ex ante* returns and characterises the equilibrium choice of fund size.

Proposition 8 *Suppose that (2.15) but not (2.16) holds. Then, in equilibrium, the investor will choose to the large investment portfolio (two entrepreneurs) whenever*

$$\frac{\theta^e - p}{p\theta^e} \leq \frac{1-\theta^e}{2\,(1-p)}\frac{V}{D} - \frac{c}{p\left(\theta^H - \theta^L\right)(1-\mu)\,(1-p)\,D} \tag{2.17}$$

where the right-hand side of this inequality is positive.

Proof: It is useful to write the entrepreneur's expected return at $t=1$ as

$$\theta_i^e\left(1-\theta_j^e\right)\left(V-R_i\right) = (1-\mu)\,\theta^0\left(1-\theta_j^e\right)V + (1-\mu)\left[\frac{1}{2}\left[\left(\theta_i^e-\theta^0\right)\left(1-\theta_j^e\right)V - I_1\right] - p_i\left(1-p_j\right)D\right]$$

where R_i represents the payment to the investor in case of sole final research success and $\theta_i^e\left(1-\theta_j^e\right)R_i$ the share of expected surplus appropriated by the investor. The incentive compatibility constraint can then be written as $p\left(\theta^H-\theta^L\right)\left(1-\theta_j^e\right)\left(V-R_i\right) < c$. Denote by ϕ the surplus that would have to be left to the entrepreneur in case of success in order to induce effort

$$p\left(\theta^H - \theta^L\right)\left(1 - \theta_j^e\right)\phi = c - (1-\mu)\,p\left(\theta^H - \theta^L\right)\left(\frac{1-\theta_j^e}{2}V - (1-p)\,D\right).$$

Then, in equilibrium, the investor will prefer a large portfolio to a small portfolio if $\theta^e\left(1 - \theta^e\right)\phi < (1-\mu)\,p\,(1-p)\,D$ which can be rearranged into condition (2.17). Note that the right hand side of (2.17) is positive as long as (2.15) holds. ■

Inspection of condition (2.17) reveals the following comparative statics results. First, if effort is important relative to interim knowledge in producing final research success $(p > \theta^e)$, then the investor will always choose a large portfolio. This result is intuitive since p is a measure of the likelihood that the investor can threaten E_i with disclosure while θ^e is a measure of the probability with which he will have to leave additional surplus to incentivise E_i. When $p < \theta^e$, the investor is more likely to choose the large portfolio the lower the cost of effort c and the higher the incremental return to effort of a entrepreneur in a small portfolio. When amount of surplus expropriated through disclosure D is smaller, e.g. because property rights are relatively strong, the investor is more likely to choose a large portfolio since the surplus to be given up to incentivise the entrepreneur is small. Finally, the lower the *ex ante* bargaining power of the investor, the more likely it is that he will finance a large portfolio.

Our analysis implies that venture capitalist portfolios will be larger in times in which there is a strong demand for entrepreneurial skills rather than investment funds and when property rights are strong.

2.6 Conclusion

The aim of this chapter was to analyse the impact of weak property rights on the financing arrangements of entrepreneurs with their investors when investors finance a portfolios of projects. Our main conclusions are that, firstly, the entrepreneur will attempt to substitute for weak property rights by designing a contract that prevents knowledge disclosure and that this contract induces the efficient disclosure rule by the investor.

Secondly, we find that stronger property rights reduce the threat of expropriation by the investor and increase effort incentives. As a result, the impact of the strength of property rights on expected surplus may be non-monotonic, depending on whether disclosure is *ex ante* optimal or not. We provide conditions under which stronger property rights reduce expected surplus when the project is very risky but increase expected surplus otherwise. Furthermore, our analysis shows that a small departure from perfectly strong property rights may impose a discontinuous loss in expected surplus.

Finally, we relate the strength of the investor's disclosure threat to several organisational choices. We find that the entrepreneur is more likely to choose a distant investor when property rights are weak and that the investor is more likely to fund a larger portfolio of entrepreneurs when property rights are strong.

3

The Benefits of Shallow Pockets

3.1 Introduction

Venture capital finance frequently takes place in an environment in which informational problems are severe. Not only is it difficult for venture capitalists to assess the quality and potential of business plans submitted to them for funding, but once initial funding has taken place, entrepreneurs must be given adequate incentives and must be monitored (see, for instance, Gompers and Lerner (2000)). Much of the recent theoretical literature on venture capital finance has considered these issues as central to the provision and characteristics of venture capital funding. Contributions by Gompers (1995), Hellmann (1998) and Schmidt (2003) as well as Repullo and Suarez (1999), Inderst and Mueller (2004) and Casamatta (2003), for example, have concentrated on contractual means to mitigate agency problems.[1]

This chapter departs from the existing literature by considering non-contractual instruments to control agency problems, namely the initial size of the investor's funds. Limiting the funds available to the investor creates competition between her portfolio entrepreneurs

[1] For an empirical analysis of venture capital contracts see Sahlman (1990) as well as Kaplan and Stromberg (2003).

for cheap 'informed' (or 'inside') money at the refinancing stage. Although competition among entrepreneurs increases the investor's bargaining power during renegotiations, we find that competition may nevertheless enhance entrepreneurial effort incentives and allow the sorting of entrepreneurs according to their type. This, our main insight, arises from the fact that competition created by limited funds increases the responsiveness of the entrepreneur's payoff to the profits generated by his project.

We derive conditions under which such an increase in responsiveness can be achieved through the non-contractual means of limited funds. When this is the case, the benefit of improved incentives may outweigh the costs of inefficient refinancing by the initial investor, e.g. the increased cost of refinancing through uninformed outside investors or the failure of receiving funding for the second stage at all. We find that raising limited funds is an optimal strategy when the following two conditions hold: first, the probability that a given project fails at the interim stage is relatively high; second, the *incremental* returns from improving the project are relatively small compared to the absolute value of financial rewards if the project is a success. Intuitively, if the probability of failure is high this reduces the expected allocational inefficiency implied by limited funds. Similarly, when the incremental project payoff from an improvement is small compared to the overall payoff of a successful project, standard incentive contracts are relative weak in providing incentives. In this situation, creating competition through limited funds may provide more powerful incentives since even a small change in performance (due to the correct action) may be crucial in determining whether refinancing is obtained, and the (relatively large) financial rewards associated with it are reaped. These two conditions, i.e. the high failure rate and the high rewards in case of having the 'right idea' as opposed to some incremental improvements, may apply to some of the projects financed by venture capital.[2]

While the above discussion was clothed in terms of entrepreneurial moral hazard, we show that it is easily extended to an adverse selection setting. In particular, we show that separation between entrepreneurs is not possible when all entrepreneurs borrow from investors with deep pockets. When the two conditions described above are met and shallow pockets provide more responsiveness, limited funds can be used to separate entrepreneurs by type. Good entrepreneurs can separate themselves from bad entrepreneurs by exposing themselves to the risk of not receiving continuation finance when borrowing from an investor with shallow pockets - a risk that bad entrepreneurs are unwilling to take.

Venture capital funds and the partnership agreements governing them have several characteristics that suggest the relevance of a mechanism to create competition between a portfolio's projects. Most obviously, venture capital funds are generally close-ended so that, once raised, they cannot be easily augmented by taking on additional funds. This limits the size of the fund from an *ex ante* perspective. Moreover, partnership agreements very often contain covenants that reduce a venture capitalist's ability to raise further 'informed' funds and hence render the commitment to *ex post* competition more credible.[3]

There is also substantial evidence that venture capitalists are forced to engage in portfolio management, i.e. in decisions about which project to concentrate funds on, which implies

[2] The notion, for example, that venture capitalists are in the business of funding very risky projects with a high probability of failure is explicitly recognized in its alternative nomer 'risk capital'. Evidence of the low frequency with which truly successful projects are funded abounds and venture capitalists explicitly acknowledge that they 'go for the homerun' in order to offset the large number of failures in their portfolio. (See, for example, Bygrave and Timmons (1992) and Quindlen (2000).) Practitioners, in turn, frequently attest to the overruling importance of a project's 'fundamentals', i.e. what might be loosely described as having the 'right idea', a good business plan, and a sufficient target market size (See, e.g. Bygrave (1999) or Quindlen (2000)).

[3] See Bartlett (1995), Gompers and Lerner (2000), and Brooks (1999) for a more in-depth discussion of venture capital partnership agreements. These covenants include those that restrict the co-investment of different funds run by the same general partner in a particular project or the requirement that realized gains are immediately paid out to limited partners rather than re-invested into the fund. Such characteristics enable a venture capital fund to credibly commit to a given size *ex ante*.

that portfolio projects are engaged in exactly the kind of competition that is at the centre of our chapter. Silver (1985), for example, describes this paradox in detail and argues that *"... The need for greater amounts of venture capital, frequently not cited in the business plan, occurs sooner than expected. Because the Murphy's Law affliction attacks most venture capital portfolios, there arises a serious need for portfolio management."*

Related Literature

As noted above, existing papers on agency problems in venture capital financing have focused exclusively on contractual solutions. Instead, we focus on a non-contractual solution, i.e. the creation of competition by limiting the amount of initially raised funds. Instead of dealing with one entrepreneur in isolation, as is the case with the existing literature, this also requires considering the interaction between a venture capitalist's portfolio projects.

Gompers and Lerner (2000) and Lerner and Schoar (2002) provide an in-depth description of the characteristics of venture capital fund partnership agreements and argue that their purpose is to ameliorate agency problems between the general and limited partners of a venture capital fund. Our analysis is complementary as we point towards the implications of partnership agreements for the agency problems between the fund and portfolio entrepreneurs.[4]

Our chapter also contributes to the literature on how competition between different projects, or divisions in a conglomerate, affects incentives. This literature has considered the effect of an internal capital market on incentives to gather information about investment opportunities (Stein (2002)), to create cash flows (Brusco and Panunzi (2002)), or to cre-

[4] The related issue of what determines the optimal number of projects in a venture capital fund's portfolio is addressed in Kanniainen and Keuschnigg (2003), where the limited management capacity of the venture capitalist determines the optimal span.

ate new growth opportunities (Inderst and Laux (2001)).[5] These papers focus on whether a firm's divisions should be granted discretion over the use of their initially allocated or internally generated funds. In our setting, by contrast, investors compete to attract entrepreneurs and use the size of their initial funds as the main instrument to overcome agency problems.

Finally, our use of an *ex ante* commitment to stop refinancing, or to force refinancing through more expensive outside capital when a project is relatively worse, shares a certain familiarity with the soft-budget constraint literature, e.g. Dewatripont and Maskin (1995). In this literature, an investor with few funds can commit to *ex post* inefficient project abandonment when the borrower undertakes an opportunistic action, something which an investor with more funds cannot credibly achieve. Crucially, this mechanism relies on the assumption that the opportunistic action requires additional *ex post* funding relative to the desired action. In our setting, by contrast, it is the 'good action' which is rewarded by additional funding once we introduce competition for inside money.

The rest of this chapter is organized as follows. Section 2 describes the model. Section 3.3 analyzes when constrained finance increases the responsiveness of entrepreneurs' payoffs to the profitability of their project. Sections 3.4 and 3.5 embed this analysis in a moral hazard and adverse selection setting respectively. Section 3.6 considers the robustness of our results by discussing various changes to the model presented in Section 3.2. Section 3.7 concludes.

[5] In a related earlier contribution, Rotemberg and Saloner (1994) show how the joint incorporation of two projects can undermine the incentives from a promised (cash) payment that is made only if a generated research idea is realized.

3.2 The Model

3.2.1 Project Technologies

There are two types of agents, entrepreneurs and investors, and three periods, which we denote by $t = 0, 1, 2$. For simplicity we assume that all parties are risk neutral and do not discount future cash flows. Furthermore, there are more potential investors than entrepreneurs so that, *ex ante,* there is competition for entrepreneurs.[6]

Entrepreneurs have zero wealth and are risk neutral. Each entrepreneur has an idea that is embedded in a project which requires an investment $I_1 > 0$ at $t = 0$ and can be refinanced at cost $I_2 > 0$ at $t = 1$.[7] Refinancing is best understood as an extension of the project. Projects that are not refinanced continue on a smaller scale in a sense made precise below. The entrepreneur's project creates a verifiable return of either $R > 0$ or 0 at $t = 2$. The *ex ante* probability of either return is determined by two factors: the quality of the idea, i.e. the project's fundamentals, and the entrepreneur's type. Below we discuss two scenarios where the entrepreneur can either influence his type (moral hazard) or where his exogenous type is his private information (adverse selection).

Our specification of the project technology, to which we turn next, is meant to capture some of the salient features of risk capital financing. This comprises, in particular, the high failure rate and the importance of the right project 'fundamentals'. We have more to say on this when interpreting our main results in Sections 3 and 4.

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[6] We do not model subsequent product market competition between portfolio entrepreneurs. See Hellmann (2000) for an empirical description of the impact of venture capital finance on product market competition.

[7] Undertaking a project in stages has been justified on the basis of trading-off entrepreneurial moral hazard against investor monitoring costs (Gompers (1995)), limiting the entrepreneur's hold-up power in contract renegotiations (Neher (1999)), and allowing entrepreneurs to create a reputation for repayment (Egli, Ongena and Smith (2002)). Admati and Pfleiderer (1994) and Cornelli and Yosha (2003) trace out the implications of agency problems created by stage-financing on financial contract design. We make the realistic assumption that the project requires more than one injection of capital over time. We argue below that pre-committing $I_1 + I_2$ right at the outset is not optimal due to agency problems even under unconstrained financing, where sufficient funds are raised initially. In case of constrained financing, the aspect of stage-financing (without pre-committing funds) is a vital ingredient in the mechanism that creates competition.

We denote a project's interim type at $t = 1$ by $\psi \in \{n, l, h\}$. With probability $1 - \tau$, the idea turns out to be a failure at $t = 1$ and the project returns 0 with certainty. This state corresponds to interim type $\psi = n$. With probability τ, the idea turns out to be successful, in which case the project will create a positive return. This state corresponds to interim types $\psi \in \{l, h\}$. The size of the (positive) final return depends on whether the project receives additional funding and on how successful the idea was, i.e. whether the interim type is $\psi = l$ or $\psi = h$. Precisely, the probability of payoff R is given by p_ψ when refinancing takes place. Let $R_\psi := p_\psi R - I_2$ denote the expected net return from refinancing at $t = 1$. When refinancing does not take place, the success probability becomes p_0 irrespective of whether the interim type is l or h. Denote the expected return without refinancing by $R^0 := p_0 R$.[8] Hence, the incremental expected return to refinancing a project with interim type $\psi \in \{l, h\}$ is given by $r_\psi := R_\psi - R^0$.

Assumption 1: *Refinancing a project of interim type $\psi \in \{l, h\}$ is ex post efficient and creates positive incremental returns that are strictly higher for $\psi = h$: $r_h > r_l > 0$.*

Ex-ante, i.e. at $t = 0$, the entrepreneur's project can be of two types, $\theta \in \{b, g\}$. When the entrepreneur is 'good' $(\theta = g)$, his project has a higher probability of being of interim type h and a lower probability of being of interim type l than when the entrepreneur is 'bad' $(\theta = b)$. We denote by q_θ the conditional probability that a project is of type $\psi = h$ given that it was successful at the interim stage.

Assumption 2. *A good entrepreneur has a higher probability of obtaining a project with high interim type: $q_g > q_b$.*

[8] We argue in footnote 23 below that changes in this specification do not affect our results.

Before summarizing the specification of the project technology, our choices warrant some comments. Below we will show that creating competition by constraining finance is beneficial if τ, the probability of success, is not too high and if r_l, the low return under success, is not too small compared to the incremental return $r_h - r_l$. By the first condition, we attempt to capture the high failure rate of start-ups. By the second condition, we attempt to capture the notion that a 'good idea' is key and of relative more importance than achieving an incremental improvement.

Figure 3.1 summarizes the preceding discussion of the project technology.

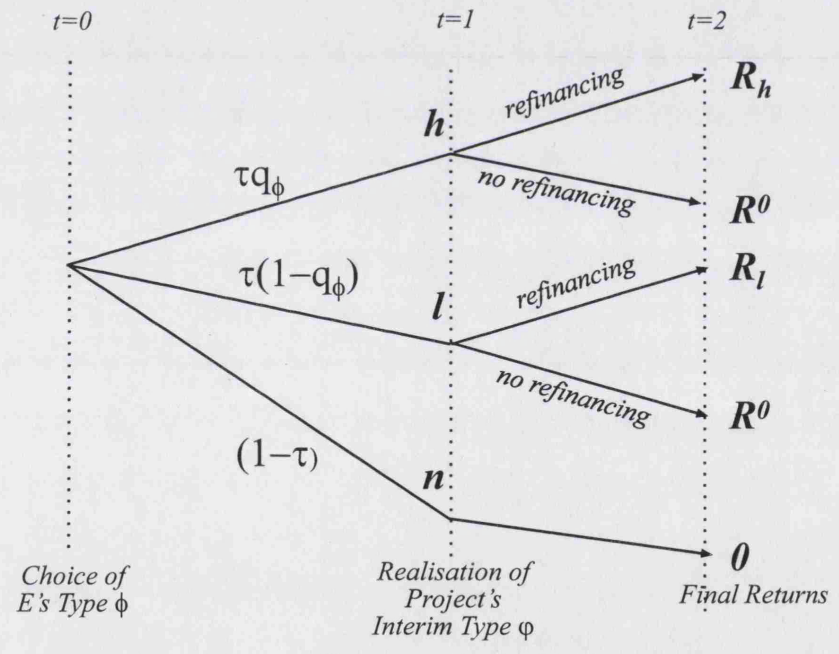

FIGURE 3.1. The Project Technology

Finally, we assume that providing start-up finance I_1 is *ex ante* efficient and feasible. In Section 3.4.2, we will investigate in detail when financing is feasible, i.e. when investors can break even. We postpone a statement of the precise conditions until then.

Note that under Assumptions 1 and 2, an entrepreneur of type g has a project with a higher *ex ante* net present value than that of entrepreneur b if refinancing takes place. In this chapter, we consider two ways in which the entrepreneur's type θ is determined. In the *adverse selection* setting, the entrepreneur's type is chosen by nature prior to $t = 0$, and is known only to the entrepreneur. In the *moral hazard* setting, by contrast, the entrepreneur himself chooses his type after having received financing at $t = 0$. This choice is his private information. Choosing type θ confers private benefits B_θ on the entrepreneur at $t = 2$, where we assume that $B_b = B > B_g = 0$.[9] These benefits are only obtained if the project is a success, but they cannot be enjoyed if $\psi = n$.[10] We also assume that $\theta = g$ is socially more efficient, i.e. that $(q_g - q_b)(r_h - r_b) > B$.

3.2.2 Financing

Investors compete at $t = 0$ to provide finance to entrepreneurs. They can raise finance at a fixed interest, which we normalize to zero. At $t = 1$, the initial investor observes (with the entrepreneur) the project's interim type ψ, while outside investors are not able to do so. This creates an informational advantage of the original investor over any outside investor that is crucial for our results.[11] Investors can initially raise sufficient funds such that it would not be necessary to raise additional funds at some later point of time. The central claim of this chapter, however, is that the ratio of funds raised *ex ante* to projects financed at the first stage is important in addressing agency problems.

[9] Without qualitatively changing results, we could likewise choose a specification where choosing $\theta = g$ involves costly effort.

[10] While this specification allows us to streamline the exposition, our qualitative results do not hinge on it.

[11] The underlying assumption here is that the financing relationship between entrepreneur and investor allows the investor a superior insight into the quality of the project and creates an informational advantage *vis-à-vis* outside investors.

We specify that each investor optimally provides start-up finance to two entrepreneurs.[12] Our analysis then concentrates on the issue of how much funds a venture capitalist raises at $t = 0$. Importantly, we do not preclude the investor from raising additional funds at $t = 1$ or approaching other outside investors for funds at that date. However, the asymmetric information between the inside and outside investors at $t = 1$ will render such financing more expensive.

The investors' crucial choice is then between what we term 'unconstrained finance' (or deep pockets) and 'constrained finance' (or shallow pockets). This financing choice is observable by entrepreneurs. Under unconstrained finance, investors raise sufficient funds at $t = 0$ to be able to refinance both portfolio projects at $t = 1$, i.e. $2I_1 + 2I_2$. Under constrained finance, in contrast, investors only raise $2I_1 + I_2$ at $t = 0$ [13], so that they are not able to refinance both projects with certainty at $t = 1$.[14] In this case, constrained finance will create competition (or a tournament) for inside money between the entrepreneurs.[15]

3.2.3 Contracts and Negotiations

In our setting, the initial contract specifies for entrepreneur i a share s_i of the final verifiable return R that accrues to the entrepreneur, with the investor receiving the remaining share $1 - s_i$. This sharing rule is renegotiated whenever refinancing takes place at $t = 1$.

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[12] By managing more than two projects, which represents the optimal span of the fund, the venture capitalist would spread himself to thin in the important start-up phase.

[13] Here, we assume that the project is non-divisible, i.e. if refinanced, it must be refinanced in its entirety. Relaxing this assumption, e.g. introducing a scalable project, does not affect the main insights of our model.

[14] We specify that the investor must invest I_2 in either of the two projects and that he cannot decide to invest $\frac{I_2}{2}$ in each of his portfolio investments. This restriction rules out syndicated investments in the model presented here but merely represents a simplification. Such syndication will not enable the investor to signal the projects interim type in a more complex model, in which type n has probability p_n of obtaining positive final payoffs so that the investor must invest a minimum stake $\hat{I}_2$ to signal type l or h. In such a setting, constrained finance would consist of raising investment funds $2I_1 + \hat{I}_2$ at the initial stage thus restricting the investor's ability to signal through syndication. Consistent with this characterisation, Anand and Galetovic (2000a) provide evidence that between 36% and 49% of a syndicate's members drop out in a given financing round.

[15] For an economic analysis of tournaments, beginning with the seminal work of Lazear and Rosen (1981), see McLaughlin (1988) and Prendergast (1999). To the best of our knowledge, the tournament literature has not addressed the issues raised in this paper.

This specification of contracts and (re-)negotiations rests on three restrictions. First, the investor cannot transfer any funds in excess of the initial investment I_1 for her share $1 - s_i$. (Or, in the words of contracting theory, up-front payments are not feasible.) Secondly, the entrepreneur cannot receive more than the cash flow realization of the project at $t = 2$. Finally, the refinancing decision is not part of the original contract.

It is the third of these restrictions that is truly important as it creates a bilateral hold-up problem that forces the entrepreneur and the investor to newly negotiate at $t = 1$. As we argue next, the restriction is quite realistic and, furthermore, follows from standard assumptions in the contracting literature. We then comment on the less important first and second restrictions.

To begin with, we assume that it is impossible for the agents to commit themselves not to renegotiate. This raises the question of where the agents' bargaining power emanates from in renegotiations. In case of the entrepreneur, his bargaining power simply stems from his ability to withdraw his inalienable and essential human capital from the project. That is, the entrepreneur is essential in order to continue the refinanced version of the project. The investor, by contrast, possesses bargaining power only to the degree that she has discretion over the refinancing decision. Such discretion arises as an endogenous characteristic of the contract when we allow for a large pool of fraudulent entrepreneurs that do not possess a real project (see Rajan (1992) for a similar use of this assumption). If the entrepreneur were to be given any say in the refinancing of the project, a fraudulent entrepreneur would be able to extract rents at the interim stage.

During the renegotiations in $t = 1$, both sides can therefore threaten to withhold their essential assets: financial and human capital, respectively.[16] In case of disagreement (or

[16] Of course, this story could be easily enriched by assuming that the initial investor also has to contribute her human capital at the refinancing stage.

break-down), the project can only continue at the small size and the expected payoff is shared as initially agreed (s_i). Hence, while renegotiations take place at $t = 1$, the initial contract is not meaningless. The initial contract determines both the outside options in the renegotiation game at $t = 1$ and how returns are split if refinancing does not take place.[17]

We discuss next the other restrictions on contracts. The first restriction of not allowing up-front transfers can be similarly justified through the existence of fraudulent entrepreneurs. Any up-front transfers would attract fraudulent entrepreneurs and are thus not optimal for the investor. Finally, relaxing the assumption that the entrepreneur cannot be paid more than the realized cash flow of his project would not impact on our central results. Such additional payments would only affect the outside option in the renegotiation game and would not affect the incentive or sorting problem. They would, however, allow the entrepreneur to keep the investor to zero expected profits when the simple sharing rule would not be sufficient, e.g. when the initial investment is very small compared to the NPV of the project. In Section 3.4.2, we will specify parameters for which we can impose this realistic restriction without loss of generality.

To summarize, the timeline or our model is presented in Figure 3.2.

[17] It would still be possible to specify at $t = 0$ two sharing rules contingent on whether refinancing occurs or not, say s_i^F and s_i^N, respectively. As either side has the ability to block the successful continuation of the larger project, the sharing rule for refinancing, s_i^F, would always be renegotiated and only the sharing rule without refinancing, s_i^N, would be relevant as an outside option. Note that any 'penalties' that would render it costly for the investor to renegotiate s_i^F are ruled out by appeal to a pool of fraudulent entrepreneurs. Finally, it could be argued that s_i^F should still be relevant as the entrepreneur could simply refuse to renegotiate the contract, knowing that the investor would be better off providing finance under s_i^F than continuing only with the small project. But such an argument defies the whole principle of (re-)negotiations and is not supported by standard models of the bargaining game (as considered in detail in Appendix B). While the investor may be better off by implementing the original agreement instead of not refinancing at all, she is still better off by proposing another and more profitable offer, which the entrepreneur accepts to avoid risk of breakdown or delay.

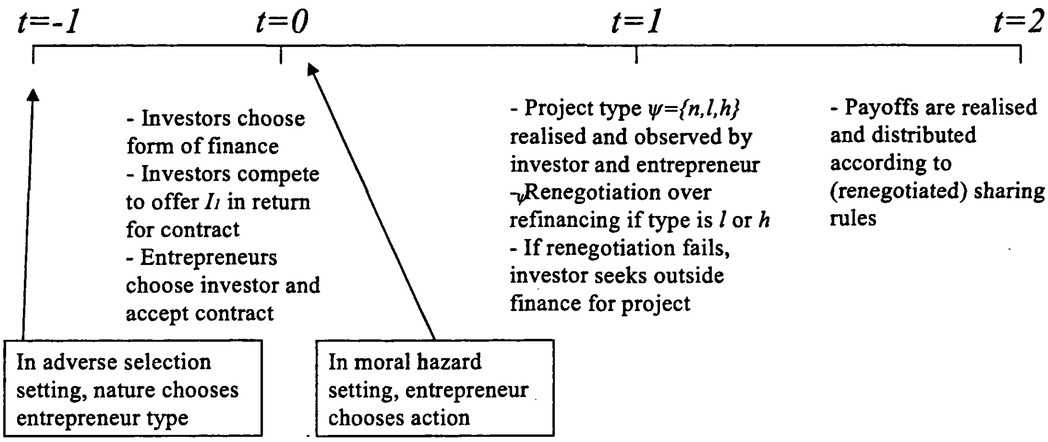

FIGURE 3.2. The Timeline

3.3 Refinancing and Renegotiation

3.3.1 Sources of Finance

At $t = 1$, the entrepreneur can obtain refinancing either from the informed inside investor or the uninformed outside investor. Under Assumption 1, refinancing is *ex post* efficient whenever the project has interim type l or h and is inefficient when the interim type is n.

Outside investors cannot infer the interim type of the entrepreneur. As projects of interim type n have zero success probability, investors and entrepreneurs do not strictly profit from luring an outside investor into refinancing an unsuccessful project. We assume, however, that this indifference is resolved in favor of seeking finance from outside investors.[18] As a result, outside investors are faced with a lemon's problem at $t = 1$ since they do not know the interim type of the project for which they are to provide funds. In particular, when τ, the probability of a project being of type l or h, is low, this lemon's problem is sufficiently strong to prevent outside investors from providing continuation finance to entrepreneurs.[19] In what follows, we assume that τ is sufficiently low such that outside finance is always too costly. In Section 3.6.2 we derive the precise conditions for when this is the case. There, we also relax this assumption and show that our qualitative results carry over to the case where projects are always refinanced, albeit sometimes with more costly outside finance.

3.3.2 Renegotiations at $t = 1$

This section characterizes the renegotiation game that arises out of the hold-up problem at $t = 1$ whenever a project is of interim type l or h. Importantly, we assume that renegotiations

[18] Note that this indifference is turned into a strict preference as soon as we were to introduce small private benefits from continuation or having a project that is 'in operation', for example.

[19] The inside investor could solve the adverse selection problem faced by the outside investors by raising additional funds $\Delta < I_2$ at $t = 0$ and by investing them in interim projects of type l or h as a signal to outside investors. As will become more apparent below, raising *ex ante* $\Delta + I_1$ is not in the investor's interest as it undermines the use of constrained finance as an incentive or sorting device.

at $t = 1$ are unstructured in the sense that it is not possible to commit at $t = 0$ to a particular renegotiation game at $t = 1$. Hence, we do not consider the optimal *ex ante* design of the bargaining game at $t = 1$. Instead, the renegotiation game used here is simply one that we consider natural in such an unstructured environment.

Renegotiations at $t = 1$ proceed in the following way:

$\mathbf{t'= 1}$: The investor picks entrepreneur E_i and negotiates with him over refinancing by investing I_2. If negotiations with E_i are successful, E_i receives funds I_2 in return for a renegotiated share of final cash flows.

$\mathbf{t'= 2}$: The investor next negotiates with the other entrepreneur, E_j. Under unconstrained finance, the investor negotiates with E_j over refinancing irrespective of the outcome at $t' = 1$. Under constrained finance, the investor can only renegotiate over refinancing if negotiations with E_i were unsuccessful. If refinancing is feasible and renegotiations are successful, E_j receives funds I_2 in return for a renegotiated share of final cash flows.

Bargaining outcomes are determined by Nash bargaining with equal bargaining powers. The robustness of our results to changes in the bargaining procedure is discussed in Section 3.6.1. There we also show how the outcome of our bargaining procedure can be generated as an equilibrium of a fully non-cooperative bargaining game with open time horizon.

3.3.3 Unconstrained Finance

Under unconstrained finance, the investor has raised sufficient funds *ex ante* to refinance all worthwhile projects. As a result, the investor cannot credibly threaten not to provide refinance to a project with interim type $\psi \in \{l, h\}$, irrespective of the type of the other portfolio project. As a result, the refinancing decision and the renegotiated payoffs for a particular entrepreneur are independent of the interim type of his competitor in the portfolio. In the renegotiations at $t = 1$, entrepreneur E_i and investor have outside options of $s_i R^0$ and $(1 - s_i) R^0$, respectively. Given interim type ψ_i, the surplus to be bargained over is r_{ψ_i}. As a result, the *ex post* payoff to entrepreneur i given his interim type ψ_i is $s_i R^0 + \frac{1}{2} r_{\psi_i}$, i.e. the sum of his outside option, $s_i R^0$, and half of the net surplus, r_{ψ_i}. The *ex ante* payoff resulting from these *ex post* returns is given in the following lemma.

Lemma 2. *Under unconstrained finance, the expected payoff to entrepreneur i at $t = 0$, given initial contract s_i and entrepreneurial type θ_i, is*

$$\tau \left\{ s_i R^0 + \frac{1}{2} \left[r_l + q_{\theta_i} \left(r_h - r_l \right) \right] \right\},$$

while the investor's expected payoff is

$$\tau \left\{ (1 - s_i) R^0 + \frac{1}{2} \left[r_l + q_{\theta_i} \left(r_h - r_l \right) \right] \right\} - I_1$$

per portfolio entrepreneur.[20]

Proof. At $t = 0$, the probability of interim type $\psi_i = l$ or $\psi_i = h$ is $\tau (1 - q_{\theta_i})$ and τq_{θ_i}, respectively. Hence, the entrepreneur's expected payoff is $\tau q_{\theta_i} (s_i R^0 + \frac{1}{2} r_h) + \tau (1 - q_{\theta_i})(s_i R^0 + \frac{1}{2} r_l)$ and the investor's expected payoff is $\tau q_{\theta_i} ((1 - s_i) R^0 + \frac{1}{2} r_h) + \tau (1 - q_{\theta_i})((1 - s_i) R^0 + \frac{1}{2} r_l) - I_1$, which transform to the respective payoffs. **Q.E.D.**

3.3.4 Constrained Finance

In contrast to unconstrained finance, the investor can now credibly threaten to use all funds for the other portfolio project if current negotiations fail. As a result, the outcome of

[20] *Without loss of generality, we concentrate on the investor's profit per portfolio entrepreneur for the remainder of the paper.*

renegotiations between E_i and the investor at $t = 1$ under constrained finance are dependent on the interim type of the other portfolio company, namely for two reasons: firstly, the interim type of E_j (the other entrepreneur) determines which entrepreneur is picked first to be bargained with; secondly, it also determines the investor's outside option in the bargaining game and hence the surplus to be bargained over.

Suppose that $E_j' s$ interim type is n, i.e. there is no profitable refinancing opportunity. Then negotiations with E_i are identical to those under unconstrained finance. Consider next the case where both entrepreneurs are of interim type l or h. We will now derive the bargaining outcome by analyzing the sequential bargaining game backwards. Suppose that E_j with $\psi_j \neq n$ is the last entrepreneur to be bargained with. If the limited funds have already been used up for E_i, the entrepreneur will only realize $s_j R^0$ while the investor realizes $(1 - s_j) R^0$ from this project. Alternatively, if funds are still available, we can apply results from the case with unconstrained finance and obtain that E_j realizes $s_j R^0 + \frac{1}{2} r_{\psi_j}$ while the investor realizes $(1 - s_j) R^0 + \frac{1}{2} r_{\psi_j}$.

Turn next to negotiations with E_i, who is picked first. In case of a breakdown, E_i receives just $s_i R^0$. Using our previous calculations, we know that in this case the investor's payoff is the sum of $(1 - s_i) R^0$ and $(1 - s_j) R^0 + \frac{1}{2} r_{\psi_j}$.[21] In case they reach an agreement, their joint surplus is the sum of R_{ψ_i} and $(1 - s_j) R^0$. Given that their net surplus is therefore just $r_{\psi_i} - \frac{1}{2} r_{\psi_j}$ [22], which is then split equally, we obtain that E_i receives a payoff of $s_i R^0 + \frac{1}{2} \left[r_{\psi_i} - \frac{1}{2} r_{\psi_j} \right]$.

We can now sum up these results.

[21] Note that the Nash bargaining solution assumes that both sides have the same information on the values of the surplus and of their outside options. In Section 3.6.1 we analyze a simpler version of the bargaining game which does not require that one entrepreneur knows the profitability of the other project. There, we obtain qualitatively similar results.

[22] The outside options in the bargaining game between E_i and the investor are $s_i R^0$ and $(1 - s_i) R^0 + (1 - s_j) R^0 + \frac{1}{2} r_{\psi_j}$, respectively. Also recall that $r_{\psi_i} = R_{\psi_i} - R^0$. Hence, the total surplus to be bargained over between E_i and the investor equals $R_{\psi_i} + (1 - s_j) R^0 - \{s_i R^0 + (1 - s_i) R^0 + (1 - s_j) R^0 + \frac{1}{2} r_{\psi_j}\}$, which is $r_{\psi_i} - \frac{1}{2} r_{\psi_j}$.

Lemma 3. *Take the case with constrained finance. If at least one project is of type n, then payoffs are as in Lemma 2. If both projects are successful, i.e. if $\psi_i \neq n$ and $\psi_j \neq n$, and if the investor picks E_i to bargain with first, the payoffs are as follows:*

i) $s_i R^0 + \frac{1}{2}\left[r_{\psi_i} - \frac{1}{2} r_{\psi_j}\right]$ *for* E_i;

ii) $s_j R^0$ *for* E_j;

iii) and $\left(1 - s_i\right) R^0 + \left(1 - s_j\right) R^0 + \frac{1}{2}\left[r_{\psi_i} + \frac{1}{2} r_{\psi_j}\right]$ *for the investor.*

Next, consider the issue of who is chosen first to be bargained with. First of all, note that the initial sharing rules, s_i, do not affect the investor's preference for either of the two projects. When interim types are not identical, the investor will then prefer to bargain first with the better interim type. When interim types are identical, we stipulate that the investor chooses each of the two entrepreneurs with equal probability. Lemma 4 summarizes the resulting *ex post* payoffs.

Lemma 4. *Under constrained finance,* E_i'*s payoff at* $t = 1$ *is*

i) $s_i R^0 + \frac{1}{8} r_h$ *if both projects are of interim type* h;

ii) $s_i R^0 + \frac{1}{2}\left[r_h - \frac{1}{2} r_l\right]$ *if* E_i'*s and* E_j'*s projects are of interim type* h *and* l*, respectively;*

iii) $s_i R^0$ *if* E_i'*s and* E_j'*s projects are of interim type* l *and* h*, respectively;*

iv) $s_i R^0 + \frac{1}{8} r_l$ *if both projects are of interim type* l*;*

v) 0 *if* i*'s project is of interim type* n*, regardless of the interim type of* E_j'*s project;*

vi) $s_i R^0 + \frac{1}{2} r_{\psi_i}$ *if* E_j'*s project is of interim type* n *and* E_i'*s project is of interim type* l *or* h*.*

As the final step of this analysis, we now derive the *ex ante* payoff for E_i. Note that this will depend on both entrepreneurs' interim types as their realizations will determine who is picked first. Given the *ex post* payoffs in the preceding lemma, the *ex ante* payoffs are then easily calculated.[23]

Lemma 5. *Under constrained finance, E_i's expected payoff at $t = 0$ given entrepreneurial types $\theta_i, \theta_j \in \{b, g\}$ and initial contract s_i is*

$$\tau\left\{s_i R^0 + \frac{1}{2}\left[r_l + q_{\theta_i}(r_h - r_l)\right]\right\} - \frac{\tau^2}{8}\left\{r_l\left(3 - q_{\theta_i} + q_{\theta_j}\right) + 3q_{\theta_i}q_{\theta_j}(r_h - r_l)\right\}.$$

The investor earns

$$\tau\left\{(1 - s_i)R^0 + \frac{1}{2}\left[r_l + q_{\theta_i}(r_h - r_l)\right]\right\} - \frac{\tau^2}{8}\left\{\left(1 + 3q_{\theta_j} - 3q_{\theta_i}\right)r_l + q_{\theta_i}q_{\theta_j}(r_h - r_l)\right\} - I_1.$$

Proof. Recall that the *ex ante* probabilities of interim states n, l, and h are $1-\tau$, $\tau(1 - q_\theta)$, and τq_θ, respectively. The asserted payoffs follow then immediately from substitution from Lemma 4. **Q.E.D.**

3.3.5 The Responsiveness Condition

The responsiveness of the entrepreneur's payoff to his type will be crucial in solving his agency problem, whether it be in a moral hazard or an adverse selection setting. The more responsive the entrepreneur's payoff is to his type, the easier it is to provide effort incentives or to induce self-selection. We now analyze how constrained and unconstrained finance compare in terms of the responsiveness they induce in the entrepreneur's payoff.

[23] Note that since R^0 is type-independent, the change in E_i's payoff due to a change in his type is independent of s_i (and R^0). Importantly, this implies that the initial contract cannot be used for sorting or incentive purposes. This feature is robust to the introduction of a type-dependent payoff R^0_ψ, as long as $R^0_h \geq R^0_l$. In such an extended setting, the responsiveness of E_i's payoff to his type ψ_i increases in s_i. As a result, the optimal contract would involve setting s_i as large as possible, subject to the investor's participation constraint. This is, however, exactly how s_i is determined in our simpler setting. Hence, although introducing type-dependency of R^0 would change the particular form of equation (3.1) it would not qualitatively affect results.

The responsiveness under unconstrained finance is easily derived from Lemma 2. Subtracting the entrepreneur's payoff for $\theta = b$ from that for $\theta = g$, we obtain

$$\frac{1}{2}\tau \left(q_g - q_b\right)\left(r_h - r_l\right). \tag{3.1}$$

Importantly, the responsiveness does not correspond to the full difference in project value as the hold-up problem at $t = 1$ allows the investor to extract half of the increase in value.

Under constrained finance, by contrast, entrepreneurs compete for scarce inside money. As a result, for a given sharing rule, the investor will extract more from a funded entrepreneur whenever the other type has a profitable refinancing opportunity (i.e. of interim type l or h). In other words, constrained finance embodies the investor with more bargaining power when entrepreneurs are forced to compete. Our key insight is that constrained finance can nevertheless increase the responsiveness of the entrepreneur's payoff to his type. Although the entrepreneur's total payoff is reduced (for a given type θ and sharing rule s) the difference in payoff across types b and g can be increased.

Under constrained finance, $E_i's$ payoff depends on the type of E_j as well as on his own. In what follows, we are interested in the case where, under constrained finance, both types will be $\theta = g$. Hence, set $\theta_j = g$. The responsiveness for constrained finance, i.e. the difference in payoffs for E_i if $\theta_i = g$ rather than $\theta_i = b$, is then given by

$$\frac{1}{2}\left(q_g - q_b\right)\tau\left\{\left(r_h - r_l\right) + \frac{\tau}{4}\left[r_l - 3q_g\left(r_h - r_l\right)\right]\right\} \tag{3.2}$$

according to Lemma 5. Subtracting expression (3.1) from expression (3.2) then allows us to establish the following proposition.

Proposition 1. *The responsiveness of the entrepreneur's ex ante payoff is higher under constrained finance if and only if*

$$r_h - r_l < \frac{r_l}{3q_g}. \tag{3.3}$$

We will subsequently refer to condition (3.3) as the 'Responsiveness Condition'. It is at the core of our analysis and describes the circumstances under which constrained finance is more adept at dealing with agency problems than unconstrained finance. In Section 3.6 we show how the responsiveness condition extends to alternative bargaining procedures.

The responsiveness condition captures the trade-off between two effects of competition for inside money that is introduced through constrained finance:

Competition Effect: Under constrained finance, not being picked first to be bargained with implies that the entrepreneur will not receive refinancing in equilibrium, in contrast to unconstrained finance. As a result, competition introduces an additional incremental return to being first to be bargained with, making the payoff more responsive to the entrepreneur's type.

Bargaining Power Effect: Under constrained finance, entrepreneurs compete for inside money and an investor can threaten to refinance the other entrepreneur when bargaining with her first pick. This creates additional bargaining power for the investor. As a result, the return to being refinanced is reduced and the responsiveness is lowered.

Unconstrained finance provides responsiveness through the difference in final project payoffs: $r_h - r_l$. Constrained finance, by contrast, creates responsiveness through an artificial 'jump' in payoffs induced by competition for refinancing funds. As a result, the above trade-off can be summarized as follows. If $r_h - r_l$ is high, then incentives under constrained finance are already substantial and competition for inside money mainly allows the investor to extract more surplus. Unconstrained finance provides more responsiveness. In contrast, if $r_h - r_l$ is low, the jump in payoffs created through the threat of no refinancing implies that unconstrained finance dominates constrained finance in responsiveness terms.

This interpretation is illustrated in Figures 3.3 and 3.4. (For simplicity, we deviate somewhat from our previous set-up and notation in these figures.)

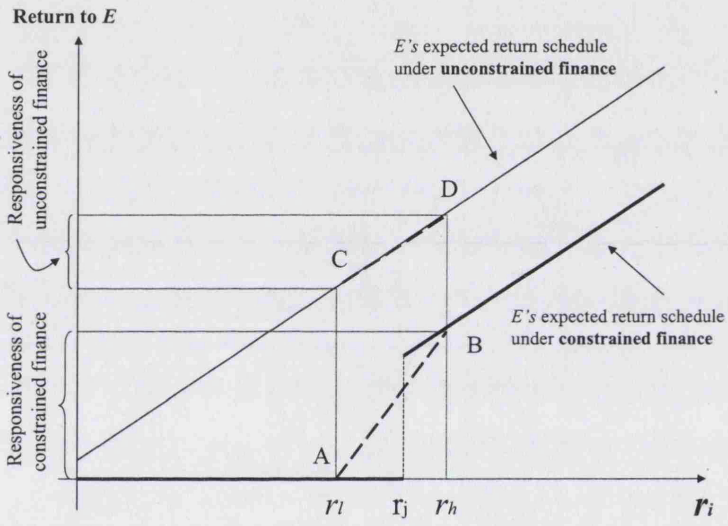

FIGURE 3.3. Situation in which the responsiveness condition holds.

In Figure 3.3, the line through points C and D represents the *ex ante* payoff under unconstrained finance as a function of r_i. The line through points A and B, by contrast, represents expected payoffs under constrained finance. Importantly, this payoff is not continuous in r_i but jumps as soon as it exceeds a 'threshold' r_j, i.e. the rival's prospects. This discontinuity captures the competition effect. It is very strong relative to the responsiveness provided by unconstrained finance when $r_h - r_l$ is very small and these payoffs are grouped around the threshold, i.e. when r_l is large. Furthermore, to the right of the discontinuity, the payoff profile under constrained finance is below that of unconstrained finance, albeit with the

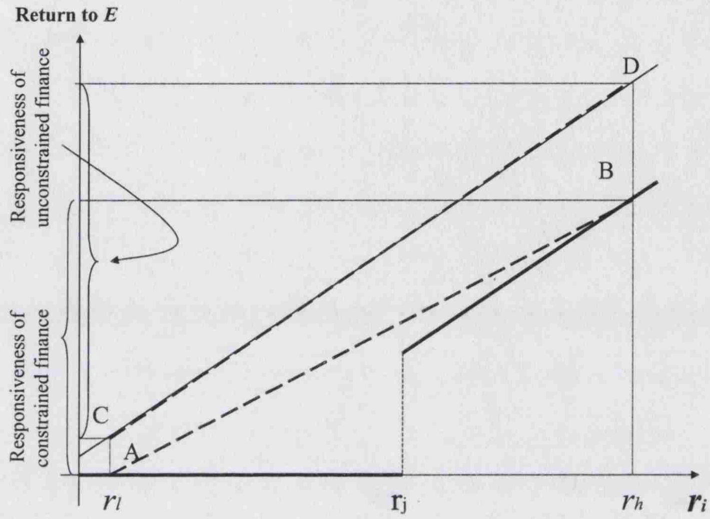

FIGURE 3.4. Situation in which the responsiveness condition does not hold.

same slope. This shift downwards in payoffs captures the bargaining power effect. When this effect is small, the responsiveness condition is more likely to hold.

Figure 3.4, by contrast, exhibits a setting in which the responsiveness of unconstrained finance outweighs that of constrained finance. Here, $r_h - r_l$ is too large relative to the competition effect and constrained finance cannot provide sufficient responsiveness.

Below, when completing the analysis of the model for the cases of moral hazard and adverse selection, we will describe in more detail the implications of Proposition 1 for the case of venture capital financing.

3.4 Moral Hazard

In the previous section, we established when constrained finance dominates unconstrained finance in terms of responsiveness. In this section, we will investigate when this increased responsiveness outweighs the negative impact of increased investor bargaining power and inefficient project continuation so that constrained finance dominates unconstrained finance from an *ex ante* point of view.

Recall that, in the moral hazard setting, the entrepreneur chooses her type $\theta \in \{b, g\}$ at $t = 0$. The choice of $\theta = b$ will result in private benefits B at $t = 2$ in case the project has success. Furthermore, we assumed that the good action $\theta = g$ is socially desirable.

3.4.1 Unconstrained vs. Constrained Finance

Because of the hold-up problem at $t = 1$, the entrepreneur is not a residual claimant to the entire incremental surplus of his choice of action. As a result, he will not choose the good action if

$$\frac{1}{2}(q_g - q_b)(r_h - r_l) < B \tag{3.4}$$

and the hold-up problem will lead to a suboptimal effort choice when this inequality is fulfilled. In what follows, we assume that the hold-up problem is sufficiently strong for this to be the case, so that the entrepreneur chooses the bad action under unconstrained finance.

We now assume that the project is financially viable. Hence, its expected NPV at $t = 0$ is positive and, what is more, there exists a sharing rule s for $i = 1, 2$ such that the investor can break even. In Section 3.4.2, we discuss in more detail the issue of financial viability and how this can be influenced by the choice between constrained and unconstrained financing. Under unconstrained financing, the project is financially viable if and only if

$$I_1 \leq \tau R^0 + \frac{1}{2}\tau (r_l + q_b(r_h - r_l)). \tag{3.5}$$

As is easily seen, the right-hand side of (3.5) represents the investor's expected payoff if $s_i = 0$ and if the entrepreneur chooses the bad action. (Recall that the choice of s_i does not affect the choice of θ_i.) Furthermore, we assume that adjusting s_i is sufficient to extract all profits from the investor, i.e. that investors compete themselves down to zero profits at $t = 0$. In analogy to (3.5) this is the case if

$$I_1 \geq \frac{1}{2}\tau \left(r_l + q_b \left(r_h - r_l\right)\right), \tag{3.6}$$

where the right-hand side of (3.6) now represents the investor's expected payoff if $s_i = 1$.[24] We will now take (3.5) and (3.6) as given.

The equilibrium contract for each project $i = 1, 2$ specifies now the sharing rule s_i which allows investors to just break even.

Lemma 6. *With moral hazard, the equilibrium contract under unconstrained financing specifies the sharing rule*

$$s_i = 1 + \frac{1}{2}\left(\frac{r_l + q_b \left(r_h - r_l\right)}{R^0}\right) - \frac{I_1}{\tau R^0},$$

which leaves the investor with zero profits and the entrepreneur with the expected payoff

$$\tau \left[R^0 + r_l + q_b \left(r_h - r_l\right) + B\right] - I_1.$$

Proof. Condition (3.4) implies that $\theta_i = b$. From Lemma 2, the investor's expected payoff is zero if

$$\tau \left\{ \left(1 - s_i\right) R^0 + \frac{1}{2}\left[r_l + q_b \left(r_h - r_l\right)\right] \right\} - I_1 = 0,$$

[24] In case (3.6) does not hold, investors would have to make an up-front transfer to the entrepreneur in order to receive only zero profits. Applying standard arguments from the contracting literature, we ruled out the feasibility of such transfers. However, even if investors made positive profits our results would be qualitatively unchanged. The only difference this would make is that we would have to introduce an additional case distinction when determining the equilibrium contract.

which we can solve for s_i. As the investor just breaks even, the payoff of E_i is just the sum of net profits and B. **Q.E.D.**

When unconstrained finance cannot provide sufficient incentives for the good action but the responsiveness condition does not hold, constrained finance clearly cannot induce the good action, either. When both forms of finance lead to the same action, however, unconstrained finance always dominates as it does not suffer from the *allocational inefficiency* created by constrained finance - namely, its failure to provide refinancing to all projects of interim type l or h.

We assume now that the responsiveness condition (3.3) holds. If the additional incentives provided through constrained finance are sufficient, in particular when

$$\frac{1}{2}(q_g - q_b)(r_h - r_l) + \frac{1}{8}\tau\left[r_l - 3q_g(r_h - r_l)\right] > B, \tag{3.7}$$

then both entrepreneurs will find it strictly optimal to choose action $\theta_i = g$. In other words, inequality (3.7) ensures that there exists a unique, symmetric pure-strategy Nash equilibrium where both projects are of the good type.[25] In what follows, we assume that inequality (3.7) holds.

Regarding financial viability, we must now assume in analogy to (3.5) that the original investment is not too large. It is easily established that this is the case if

$$I_1 \leq \tau R^0 + \frac{1}{2}\tau\left(r_l + q_b(r_h - r_l)\right) - \frac{\tau^2}{8}\left(r_l + q_g^2(r_h - r_l)\right). \tag{3.8}$$

[25] This follows immediately from Lemma 5, which reveals that it was also strictly optimal for E_i to choose $\theta_i = g$ if the E_j chose $\theta_j = b$. For

$$B \in \left[\frac{1}{2}\tau(q_g - q_b)(r_h - r_l) - \frac{1}{8}\tau^2\left[r_l - 3q_g(r_h - r_l)\right], \frac{1}{2}\tau(q_g - q_b)(r_h - r_l) - \frac{1}{8}\tau^2\left[r_l - 3q_b(r_h - r_l)\right]\right]$$

there exist two equilibria in asymmetric pure strategies and one equilibrium in mixed strategies. For reasons of brevity, we do not consider this region.

Moreover, to ensure that giving investors a sufficiently low initial share of cash flow rights is sufficient to bring them down to zero profits, we must assume in analogy to (3.6) that

$$I_1 \leq \frac{1}{2}\tau\left(r_l + q_b\left(r_h - r_l\right)\right) - \frac{\tau^2}{8}\left(r_l + q_g^2\left(r_h - r_l\right)\right). \tag{3.9}$$

Again we take (3.8) and (3.9) as given. We then have the following result.

Lemma 7. *With moral hazard, the equilibrium contract under constrained financing specifies the sharing rule*

$$s_i = 1 + \frac{1}{2}\left(\frac{r_l + q_g\left(r_h - r_l\right)}{R^0}\right) - \frac{I_1}{\tau R^0} - \frac{\tau}{8R^0}\left[r_l + q_g^2\left(r_h - r_l\right)\right],$$

which leaves the investor with zero profits and the entrepreneur with the expected payoff

$$\tau\left[R^0 + r_l + q_g\left(r_h - r_l\right)\right] - I_1 - \frac{\tau^2}{2}\left[r_l + q_g^2\left(r_h - r_l\right)\right].$$

Proof. Given conditions (3.3) and (3.7), $\theta_i = \theta_j = g$ holds under constrained finance. From Lemma 5, the investor's expected payoff is zero when

$$\tau\left\{\left(1 - s_i\right)R^0 + \frac{1}{2}\left[r_l + q_g\left(r_h - r_l\right)\right]\right\} - \frac{\tau^2}{8}\left\{r_l + q_g^2\left(r_h - r_l\right)\right\} - I_1 = 0,$$

which we can solve for s_i. From Lemma 5, $E_i^{\prime}s$ expected payoff under constrained finance and with $\theta_i = \theta_j = g$ is

$$\begin{aligned} & \tau\left\{s_i R^0 + \frac{1}{2}\left[r_l + q_g\left(r_h - r_l\right)\right]\right\} - \frac{\tau^2}{8}\left\{3r_l + 3q_g^2\left(r_h - r_l\right)\right\} \\ = \ & \tau\left[R^0 + r_l + q_g\left(r_h - r_l\right)\right] - I_1 - \frac{\tau^2}{2}\left[r_l + q_g^2\left(r_h - r_l\right)\right]. \end{aligned}$$

Q.E.D.

Comparing the payoffs under unconstrained finance and constrained finance, we can finally establish the following result.

Proposition 2. *Suppose the following conditions hold in the case with moral hazard. First, the responsiveness condition (3.3) is fulfilled, implying that constrained financing is better at creating incentives. Second, (3.4) and (3.7) hold, implying that constrained financing is also necessary to create sufficient incentives. Then constrained finance will dominate unconstrained finance ex ante, i.e. it will be the equilibrium choice of all investors, if and only if*

$$\tau < 2\frac{(r_h - r_l)(q_g - q_b) - B}{r_l + (r_h - r_l)q_g^2}. \tag{3.10}$$

Proof. Under conditions (3.3), (3.4) and (3.7), constrained finance will dominate unconstrained finance if the entrepreneur's payoff from Lemma 7 is larger than that from Lemma 6:

$$\tau\left[R^0 + r_l + q_g\left(r_h - r_l\right)\right] - I_1 - \frac{\tau^2}{2}\left[r_l + q_g^2\left(r_h - r_l\right)\right] > \tau\left[R^0 + r_l + q_b\left(r_h - r_l\right) + B\right] - I_1,$$

which transforms to (3.10). **Q.E.D.**

Condition (3.10) is intuitive as constrained finance, *ceteris paribus*, is more likely to dominate if the allocational inefficiency it induces is relatively small in expected terms. This is the case when τ, the probability of having a successful idea, is small.[26] As we have argued in the Introduction, this condition may well apply to the venture capital industry, where the likelihood that a project returns positive profits is widely acknowledged to be small.

In determining the optimality of constrained financing, Proposition 2 is complemented by the responsiveness condition of Proposition 1. This condition requires that the incremental return $r_h - r_l$ is relatively small compared to r_l. If this were not the case, incentives based on the differential in project returns across actions would be sufficient to elicit the correct effort. When $r_h - r_l$ is small, however, these incentives are small. Here, i.e. where the potential of incremental improvements is relatively low compared to the absolute level of returns when successful, constrained finance increases responsiveness by ensuring that the loser of a competition for limited funds is not refinanced. Our results may go some way towards explaining some of the features related to financial constraints in venture capital funds, which we mentioned in the introduction.

3.4.2 Financial Viability

Until now we have assumed that the investor can break even. Clearly, this need not be true, in which case the project would not be financed *ex ante.* Recall now that the investor's return depends on the initial contract, the project's interim type, and her bargaining power in the negotiations for refinancing. Importantly, as we have seen in the previous sections,

[26] This effect is further accentuated by the presence of the term q_g^2 in the denominator of the right-hand side, which captures the likelihood with which constrained finance will create this allocational inefficiency once both projects are successful at $t = 1$. Clearly, the lower q_g^2, the less restrictive the condition in Proposition 2.

the investor's *ex post* bargaining power may be increased under constrained finance relative to unconstrained finance. When this increase in bargaining power is sufficient to outweigh the loss of *ex ante* returns due to inefficient refinancing, constrained finance will render projects financially viable that would not have been financed under unconstrained finance.

To make this intuition more precise, we compare the respective conditions when projects are financially viable under the two financing regimes, i.e. conditions (3.5) and (3.8). We obtain the following result.

Proposition 3. *Constrained finance allows the investor to appropriate a larger absolute amount of expected returns during renegotiations than unconstrained finance when*

$$\tau < 4\frac{(q_g - q_b)(r_h - r_l)}{r_l + (r_h - r_l)\, q_g^2}. \tag{3.11}$$

Proof. From conditions (3.5) and (3.8), the investor's expected payoff is greater under constrained finance than unconstrained finance if

$$\tau\left[R^0 + \frac{1}{2}(r_l + q_b(r_h - r_l))\right] - \frac{\tau^2}{8}\left(r_l + q_g^2(r_h - r_l)\right) - I_1 > \tau\left[R^0 + \frac{1}{2}(r_l + q_b(r_h - r_l))\right] - I_1,$$

which transforms to (3.11).

Q.E.D.

As in Proposition 2, this condition is more likely to be fulfilled if the probability of incurring the allocational inefficiency generated by constrained finance is low, i.e. if both τ and q_g^2 are low. While constrained finance certainly implies that the investor appropriates a larger share of a given amount of *ex post* returns, its impact on the size of *ex ante* returns is ambiguous - inefficient project continuation lowers expected returns for a given level of effort while improved effort incentives increase expected returns.

In case condition (3.11) holds, there is a strictly positive wedge between the two conditions (3.5) and (3.8). Then, for intermediate values of I_1, it is only possible to finance the projects with constrained financing. For lower values of I_1, where both conditions hold, both modes of financing are feasible, while for higher values, where condition (3.8) no longer holds either, it is not possible at all to finance the projects.

Note, furthermore, that the condition on τ in Proposition 3 is less strict than that on τ in Proposition 2. This implies that, over a range of values, the entrepreneur would have preferred unconstrained finance if financial viability had not been an issue. When unconstrained financing is, however, not feasible, the entrepreneur has no choice but to seek funding from a constrained investor.

3.5 Adverse Selection and Constrained Finance

In this section, the entrepreneur's type θ is chosen by nature just prior to $t = 0$. With probability α, nature chooses the good type $\theta = g$ while the likelihood of $\theta = b$ is $(1 - \alpha)$. As investors do not observe individual types, investors face an adverse selection problem at $t = 0$. It is now helpful to briefly recall the game played by investors in $t = 0$. We consider a large pool of potential investors, i.e. it is (the entrepreneurs') ideas that are in short supply. Investors raise funds of value $2I_1 + 2I_2$ or $2I_1 + I_2$ and try to attract entrepreneurs by offering sharing rules, s. Each successful investor finances exactly two projects.[27]

[27] Formally, we could imagine that entrepreneurs can shop around between different investors whose offers, s_i, are made conditional on the fact that they can finance two entrepreneurs.

Suppose first that all entrepreneurs are financed by financially unconstrained investors. Then the following result is immediate.[28]

Lemma 8. *Suppose all investors are financially unconstrained. Then the unique equilibrium is a pooling equilibrium where all entrepreneurs, regardless of their type, receive the same contract s. Entrepreneurs of types $\theta = g$ and $\theta = b$ are randomly matched in the investors' funds.*

We now argue that allowing investors to choose between constrained and unconstrained finance may enable them to separate type $\theta = g$ from type $\theta = b$ entrepreneurs.

Consider thus the case of constrained finance. As stated above, initial sharing rules s_i do not affect the investor's preferences regarding which project she would like to refinance. Consequently, separation between types $\theta = g$ and $\theta = b$ can not be achieved by offering a menu of initial sharing rules. Each type will strictly prefer the highest sharing rule. Recall next from Proposition 1 that when responsiveness condition (3.3) holds, the payoff differential across types is larger under constrained than unconstrained finance. This establishes that condition (3.3) is a necessary - albeit not yet sufficient - condition for separation across entrepreneurial types. To allow for separation, the difference in responsiveness across financing regimes must be large enough so that separation can be achieved at sufficiently favourable terms for $\theta = g$. Additionally, the allocational inefficiency created by constrained finance cannot be too large. Otherwise the constrained investor will be unable to offer a mutually profitable contract that achieves separation.[29]

In addition to these conditions, we have the standard condition arising in screening models of this type that the *ex ante* probability α of being $\theta = g$ cannot be too high. Otherwise,

[28] Note that we assume throughout this section that projects are always financially viable under both forms of financing.

[29] Note that in this model we do not have a continuous and unbounded sorting variable that would allow separation at some point while ensuring that the constrained investor's participation constraint always holds with equality.

a pooling equilibrium offers financial terms that are not sufficiently worse than those in a separating equilibrium and would be preferred by $\theta = g$.

The following proposition establishes conditions under which these requirements are jointly met and separation is achieved.

Proposition 4. *Consider the following separating equilibrium: type $\theta = b$ receives unconstrained finance, while $\theta = g$ receives constrained finance. Suppose that the responsiveness condition (3.3) holds. Then this separating equilibrium exists and is the unique pure-strategy equilibrium if*

$$\tau \leq \frac{(q_g - q_b)(r_h - r_l)}{r_l + q_g^2 (r_h - r_l)}$$

and if

$$\alpha \leq \min\left[\frac{\tau}{8}\frac{r_l - 3q_g (r_h - r_l)}{r_h - r_l}, \frac{1}{2}\left(1 - \tau\frac{r_l + q_g^2 (r_h - r_l)}{(q_g - q_b)(r_h - r_l)}\right)\right].$$

Proof. See Appendix A.

3.6 Robustness of the Responsiveness Condition

3.6.1 Alternative Bargaining Procedures

In Section 3.3, we found that responsiveness can increase under constrained finance. Even though constrained finance accords more bargaining power to the investor, which, at first glance, only seems to worsen the hold-up problem, what matters in terms of responsiveness are not absolute returns but the difference in returns across entrepreneurial types.

We now argue that these results are robust to changes in the bargaining procedure. We proceed as follows. We first present a much simplified bargaining procedure. Subsequently, we set up a fully non-cooperative framework with an open time horizon.

A simpler bargaining procedure

Consider the following bargaining procedure:

t′ = 1 : The investor picks entrepreneur E_i for refinancing.

t′ = 2 : The investor negotiates separately with each entrepreneur, E_i and E_j. If the investor has constrained funds and if negotiations with E_i fail, it is too late to use the funds to refinance E_j instead.

In this bargaining game neither of the two entrepreneurs needs information about the profitability of the other entrepreneur. In the case of unconstrained finance it is immediate that the outcome is identical to that of our previous bargaining game. If the investor's funds are constrained, we can also use previous results and obtain that the chosen entrepreneur E_i realizes payoff $s_i R^0 + \frac{1}{2} r_{\psi_i}$ for $\psi_i \neq n$. The other entrepreneur just realizes $s_j R^0$ in this case, provided of course that $\psi_j \neq n$. Consequently, the responsiveness condition becomes now

$$r_h - r_l < \frac{r_l}{q_g}. \tag{3.12}$$

Note that condition (3.12) is less strict that the original condition (3.3).

A bargaining procedure with open time horizon

The renegotiation procedures that we presented so far are relatively simple but not open-ended in the sense that the investor cannot infinitely 'shuttle' back and forth between entrepreneurs and play them against each other *ad infinitum*. Clearly, merely positing such a game is a short-cut. Suppose instead that we have the following bargaining game:

t′ = 1 : The investor picks an entrepreneur, say E_i, and makes him an offer of I_2 in return for a share of the final payoff.

t′ = 2 : It is up to E_i to decide on the offer. If E_i accepts, then further negotiations proceed only between the investor and the other entrepreneur, E_j. In this case, we return to $t' = 1$ in the next period, with the restriction that the investor must then choose E_j. If E_i rejects, then he can make a counter-offer. In this case we proceed to $t' = 3$.

t′ = 3 : It is now up to the investor to respond to the offer of E_i. If she accepts, then further negotiations proceed only between the investor and E_j. In this case, we return to $t' = 1$ in the next period, with the restriction that the investor must then choose E_j. If the investor rejects, we return to period $t' = 1$, where the investor can now still choose between both entrepreneurs.

To make coming to an immediate agreement attractive in this setting, we introduce some frictions. We suppose that there is an exogenous risk of negotiations breaking down. Let $1 - \delta$ denote the probability with which negotiations will break down when either of the parties rejects an offer. (The break-down only affects the two parties which are currently negotiating.) We show in Appendix B that this bargaining game has an equilibrium in which we obtain immediate agreement and where, as $\delta \to 1$, equilibrium payoffs are the same as those derived in the previous sections.

This may, at first, seem surprising. In particular, in case both entrepreneurs are of the same type, say $\psi_1 = \psi_2 = h$, one may ask why the investor does not deviate and go to the other entrepreneur who would be eager to be financed even under less favorable conditions. However, the other entrepreneur, say E_j, would optimally not accept any offer that makes him just a little better off than without refinancing. Instead, he would reject such an offer and use the opportunity to propose to the investor a new contract that makes the investor just as well off as when going back to E_i.[30]

Determinants of responsiveness

If the investor starts to bargain with E_i under constrained financing, the other entrepreneur's project still represents a valuable outside option in our basic bargaining model studied in Section 3. This limits the payoff that can be extracted by the 'winner', E_i. In contrast, in the simple bargaining procedure introduced at the beginning of this section the alternative project represents no longer a viable opportunity once the investor has picked the winning project. Intuitively, in the latter case payoffs are more sensitive to entrepreneurs' types, which is captured by a less stringent responsiveness condition. The opposite extreme would be the case where the investor could 'line up' the two entrepreneurs and engage them in open competition for the limited funds. It is straightforward that this would sharply reduce the responsiveness.[31]

In total, the responsiveness under constrained financing is higher the less the investor can manage to play entrepreneurs against each other in order to extract a better deal from the entrepreneur who finally receives refinancing. The bargaining game analyzed in Section 3 represents a 'middle ground' between the extreme case of 'Bertrand competition' between entrepreneurs and the case where the presence of the other entrepreneur does not improve at all the investor's bargaining position, which was the case with the procedure introduced at the beginning of this section.[32]

[30] The investor's outside option is even worse in the simple procedure studied at the beginning of this section, where we assumed that the investor can not (re-)allocate her limited funds to the other entrepreneur once she has failed to come to an agreement with her first choice. It can be shown that an equilibrium of the game with open time horizon generates the same responsiveness (3.12) if frictions are due to impatience, i.e., if δ is the discount factor used by all parties. (However, in general we do not recoup the exact payoffs as in the one-shot game.) This extreme result is a reflection of the 'outside option principle' in alternating-offer games with discounting (Binmore, Rubinstein, and Wolinsky (1986)).

[31] Formally, this could be captured by allowing the investor to make an offer simultaneously to the two entrepreneurs.

[32] While it would be useful to have some guidance which bargaining procedure was more realistic in certain circumstances, this must ultimately remain a futile task. In most economic situations people simply do not move according

3.6.2 Outside Finance

In this section, we relax the condition in Lemma 1, which ensures that the lemon's problem for outside finance at $t = 1$ was sufficiently strong such that projects could only be profitably refinanced by the inside investor. We now show that our main insights extend to the case where outside financing is feasible. Intuitively, what now drives our results is no longer the impossibility to refinance the project but, instead, the higher costs of doing so by drawing on fresh outside funds. Recall that outside funds are more expensive as new investors are uninformed about the interim type of the project, ψ. As unsuccessful projects ($\psi = n$) will also seek fresh funds, successful projects ($\psi = l$ or $\psi = h$) will be pooled with these inferior projects, leading to a dilution of the insiders' ownership stakes.

Suppose then that, under constrained finance, a project with interim type $\psi = l$ or $\psi = h$ did not receive refinancing from the inside investor, although this would be *ex post* profitable. In contrast to our previous analysis, we now assume that the lemon's problem is sufficiently small so that an equilibrium exists in which both interim types $\psi = l$ and $\psi = h$ find it profitable to be refinanced by outside investors. This is the case if projects are sufficiently likely to succeed, i.e. if τ is sufficiently large. (Precise conditions are derived in the proof of the following proposition).[33] The detailed derivation of this threshold is delegated to Proposition 5.

Outside investors will now charge all three interim types the same conditions for receiving I_2. This is merely a reflection of the fact that outside investors cannot observe the interim

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to a well-specified game form. The strength of the postulated competition effect must, therefore, remain an empirical issue.

[33] But even in this case there still exists an equilibrium where no outside financing is raised. This is the case if any attempt to raise fresh funds is interpreted by outside investors as a signal that $\psi = n$. Similarly, there may exist an equilibrium in which only $\psi = n$ and - provided that both projects are successful - $\psi = h$, who has more to gain from refinancing, will receive outside financing. Such a multiplicity of equilibria is standard in games of signaling. For the purpose of our robustness analysis, we can conveniently ignore these issues.

type. We denote the repayment requirement by outside investors by D. As outside investors compete themselves down to zero profits, D is determined by their requirement to break even.[34] A formal derivation of D is relegated to the proof of the following Proposition.

The repayment that must be made to the outside investor, D, reduces what the original investor and the entrepreneur can share. Again, we assume that the two 'insiders' will equally share the gains from refinancing.[35] The net surplus to inside investors from securing outside refinancing is then simply

$$\lambda_\psi := p_\psi(R - D) - R^0.$$

Recall that the net surplus from refinancing with inside funds is $r_\psi := p_\psi R - R^0 - I_2$. As is immediate, the high interim type will always face a lemon's premium, i.e. $r_h > \lambda_h$. For the low interim type this depends on the relation between τ, the overall probability of success, and q_g, the conditional probability of $\psi = h$. It is reasonable to assume that the first effect still dominates. As we show in the proof of the following Proposition, this assumption is compatible with assuming that both successful interim types, l and h, prefer outside finance to not refinancing at all. The following Proposition then establishes the equivalent of condition (3.3) in the presence of outside refinancing.

Proposition 5. *In an equilibrium where outside financing is preferred by all interim types to not refinancing at all, the responsiveness is higher under constrained finance if and only*

[34] The precise game we have in mind for the refinancing stage with outside investors at $t = 1$ is one where projects first express their need for outside funding and where there is, subsequently, competition by investors for providing the required funds, I_2.

[35] In other words, the investor and the entrepreneur have joint ownership and control rights over the project. This represents a realistic specification for the case of venture capital finance. Our insights on the robustness of the responsiveness condition extend, however, to the case where the entrepreneur could decide unilaterally to obtain outside finance in order to expand the project. In this case, the entrepreneur would have to leave the investor only with claims of value $(1 - s) R^0$.

if

$$(r_h - \lambda_h) - (r_l - \lambda_l) < \frac{r_l - \lambda_l}{3q_g}. \tag{3.13}$$

Proof. See Appendix A.

The responsiveness condition is now expressed in terms of the lemon premium $r_\psi - \lambda_\psi$ since the entrepreneur and inside investor bargain over the cost differential between inside and outside refinancing in this setting. However, it retains its fundamental structure from Proposition 1. This reveals the crucial driver behind the responsiveness condition: not obtaining refinancing from the insider is costly. Whether this cost is incurred because of a loss in surplus due to a lemon's premium in the outside market or due to non-continuation is irrelevant for the central mechanism of our model.

3.7 Conclusion

Much of the literature on the financing of entrepreneurial firms is concerned with the design of contracts to mitigate entrepreneurial agency problems. This chapter, by contrast, concentrates on a non-contractual solution. When an investor funds a portfolio of entrepreneurs, we show that this investor can use the depth of his financial pockets to overcome entrepreneurial agency problems. Limiting the amount of funds raised *ex ante* credibly commits the investor to induce a tournament among portfolio projects for (cheaper) inside funds. Interestingly, although this tournament increases the investor's *ex post* bargaining power, we show that it can also increase entrepreneurial effort incentives or allow investors to screen out bad entrepreneurs when contracts cannot achieve either. As a result, shallow pockets may improve on the second-best outcome despite creating an allocational inefficiency in the form of inefficient project continuation.

The main mechanism at work in this result is the fact that shallow pockets ('constrained finance') are able to render the entrepreneur's expected returns more sensitive to the payoff from his project than deep pockets ('unconstrained finance'). When the increase in effort incentives induced by this superior 'responsiveness' is sufficient to outweigh the allocational inefficiency created by constrained finance, investors will choose shallow pockets.

In an adverse selection setting, the increased responsiveness of entrepreneurial payoff to type under shallow pockets is shown to create a single-crossing property that is absent when the investor has deep pockets. As a result, shallow pockets allow good entrepreneurs to separate themselves from bad entrepreneurs by exposing themselves to competition for refinancing.

Furthermore, the model presented in this chapter could be extended to a setting which includes both moral hazard and adverse selection. In such a setting, our model would suggest the same solution, namely shallow pockets, to solve both agency problems - in contrast to some recent contributions in which moral hazard and adverse selection problems require conflicting actions by the principal (see, for example, Morrison and White (forthcoming)).

Anecdotal evidence suggests that the mechanism presented in this chapter plays a role in the design of venture capital funds. These are typically close-ended and governed by covenants that render additional fund-raising at a later life-cycle stage of a fund difficult. So-called 'down-rounds', in which the worst-performing start-ups must raise additional funds at reduced valuations from outside investors are a testimony to the fact that venture capitalists 'manage' their portfolio and distribute funds according to performance.

3.A Proofs

3.A.1 Proof of Proposition 4

Let s_C and s_U denote the equilibrium contracts offered by unconstrained and constrained investors, respectively. A separating equilibrium in which type $\theta = g$ borrows from constrained investors and type $\theta = b$ borrows from unconstrained investors will exist if, firstly, s_C and s_U are incentive compatible, secondly, participation constraints for investors and entrepreneurs are fulfilled, and thirdly, there are no other contracts with which investors could make more (i.e. strictly positive) profits. We will now consider each of these constraints in turn.

First, consider incentive compatibility. In equilibrium, the unconstrained investor attracts $\theta = b$ only and her participation constraint must be binding so that, proceeding as for Lemma 6, we obtain

$$s_U = 1 + \frac{1}{2}\frac{r_l + q_b (r_h - r_l)}{R^0} - \frac{I_1}{\tau R^0}. \tag{3.14}$$

Now consider s_C. Incentive compatibility for type $\theta = b$ implies that the constrained investor offers s_C such that type $\theta = b$ weakly prefers unconstrained finance:

$$\tau\left\{s_U R^0 + \frac{1}{2}\left[r_l + q_b (r_h - r_l)\right]\right\}$$
$$\geq \tau\left\{s_C R^0 + \frac{1}{2}\left[r_l + q_b (r_h - r_l)\right]\right\} - \frac{\tau^2}{8}\left\{(3 - q_b + q_g) r_l + 3q_g q_b (r_h - r_l)\right\},$$

which transforms to

$$s_C \leq s_U + \frac{\tau}{8}\frac{(3 + q_g - q_b) r_l + 3q_g q_b (r_h - r_l)}{R^0}. \tag{3.15}$$

where s_U is defined in equation (3.14).

Incentive compatibility for type $\theta = g$, in turn, implies that type g weakly prefers s_C:

$$\tau\left\{s_C R^0 + \frac{1}{2}\left[r_l + q_g\left(r_h - r_l\right)\right]\right\} - \frac{\tau^2}{8}\left\{3r_l + 3q_g^2\left(r_h - r_l\right)\right\}$$
$$\geq \tau\left\{s_U R^0 + \frac{1}{2}\left[r_l + q_g\left(r_h - r_l\right)\right]\right\},$$

which transforms to

$$s_C \geq s_U + \frac{\tau}{8}\frac{3r_l + 3q_g^2\left(r_h - r_l\right)}{R^0}. \tag{3.16}$$

Note that these incentive compatibility conditions (3.15) and (3.16) are compatible with each other if and only if $\frac{r_l}{3q_g} > r_h - r_l$, i.e. if and only if the responsiveness condition holds.

Consider next participation constraints. Entrepreneurs always realize non-negative payoffs, while the construction of s_U ensures that unconstrained investors break even. Finally, the constrained investor's expected payoff is non-negative if

$$\tau\left\{\left(1 - s_C\right) R^0 + \frac{1}{2}\left[r_l + q_g\left(r_h - r_l\right)\right]\right\} - \frac{\tau^2}{8}\left\{r_l + q_g^2\left(r_h - r_l\right)\right\} - I_1 \geq 0,$$

which transforms to

$$s_C \leq s_U + \frac{1}{2}\frac{\left(q_g - q_b\right)\left(r_h - r_l\right)}{R^0} - \frac{\tau}{8}\frac{r_l + q_g^2\left(r_h - r_l\right)}{R_0}. \tag{3.17}$$

Condition (3.17) is compatible with the incentive compatibility constraint for $\theta = g$ (3.16) if

$$s_U + \frac{1}{2}\frac{\left(q_g - q_b\right)\left(r_h - r_l\right)}{R^0} - \frac{\tau}{8}\frac{r_l + q_g^2\left(r_h - r_l\right)}{R_0} \geq s_U + \frac{\tau}{8}\frac{3r_l + 3q_g^2\left(r_h - r_l\right)}{R^0},$$

which transforms to

$$\tau \leq \frac{(q_g - q_b)(r_h - r_l)}{r_l + q_g^2 (r_h - r_l)}. \tag{3.18}$$

Finally, the existence of the separating equilibrium requires that investors cannot make strictly positive profits from another offer. As we have argued that a self-selecting menu of contracts is not feasible, the other feasible offer is a pooling contract to all entrepreneurs. The zero-profit pooling offer is given by

$$s_P = 1 + \frac{1}{2}\frac{r_l + (\alpha q_g + (1-\alpha) q_b)(r_h - r_l)}{R^0} - \frac{I_1}{\tau R^0}.$$

For type g to prefer s_C (and constrained finance) to s_P (and unconstrained finance) it must hold that

$$\tau \left\{ s_C R^0 + \frac{1}{2}[r_l + q_g (r_h - r_l)] \right\} - \frac{\tau^2}{8}\left\{3r_l + 3q_g^2 (r_h - r_l)\right\} \geq \tau \left\{ s_P R^0 + \frac{1}{2}[r_l + q_g (r_h - r_l)] \right\},$$

which transforms to

$$s_C \geq s_P + \frac{\tau}{8}\frac{3r_l + 3q_g^2 (r_h - r_l)}{R^0}.$$

This condition is compatible with (3.15) if

$$s_U + \frac{\tau}{8}\frac{(3 + q_g - q_b) r_l + 3q_g q_b (r_h - r_l)}{R^0} \geq s_P + \frac{\tau}{8}\frac{3r_l + 3q_g^2 (r_h - r_l)}{R^0},$$

which transforms to

$$\alpha \leq \frac{\tau}{8}\frac{r_l - 3q_g (r_h - r_l)}{r_h - r_l}, \tag{3.19}$$

and with the zero-profit constraint (3.17) if

$$s_U + \frac{1}{2}\frac{(q_g - q_b)(r_h - r_l)}{R^0} - \frac{\tau}{8}\frac{r_l + q_g^2(r_h - r_l)}{R_0} \geq s_P + \frac{\tau}{8}\frac{3r_l + 3q_g^2(r_h - r_l)}{R^0},$$

which transforms to

$$\alpha \leq \frac{1}{2}\left[1 - \tau\frac{r_l + q_g^2(r_h - r_l)}{(q_g - q_b)(r_h - r_l)}\right]. \tag{3.20}$$

We can now sum up conditions. Firstly, if the responsiveness condition together with (3.18) hold, there exists an offer made by constrained investors such that (i) only type g prefers this offer to that made by unconstrained investors to type b and (ii) constrained investors break even. Secondly, if (3.19) and (3.20) jointly hold, the separating equilibrium cannot be destabilized by a (more profitable) pooling offer.

3.A.2 Proof of Proposition 5

In this proof we also state the exact conditions such that any equilibrium prescribes that both successful interim types will *not* seek outside finance in case of constrained finance. This was the case analyzed in Section 3.

We first describe more formally the operation of the market for outside finance. Projects, represented by the respective entrepreneurs and the original investor, first express their willingness to seek outside financing and investors subsequently compete to provide funds I_2 in return for being paid $D \leq R$ in case of success. Because of their lack of information, outside investors cannot condition D on the project's interim type. Our equilibrium concept is that of a perfect Bayesian equilibrium, where investors rationally anticipate which projects seek outside finance. Given these shared beliefs, investors compete themselves down to zero profits.

We further assume that ownership of the project is jointly held by the entrepreneur and the inside investor, so that surplus net of the repayment to outside investors is shared equally between them. This specification is not crucial to our model, although it seems characteristic of venture capital financing.[36]

We already know that unsuccessful types, $\psi = n$, will always seek outside finance. As outside investors have rational beliefs, it is then immediate that in equilibrium successful types, i.e. $\psi = l$ and $\psi = h$, have a strict preference for using inside funds in case of unconstrained financing.

Turn now to the case of constrained finance. Suppose that some entrepreneur has not received inside money. (We turn later to the question which entrepreneur is chosen.) Recall that without refinancing both $\psi = l$ and $\psi = h$ realize $R^0 > 0$. It is only weakly optimal to obtain outside finance in case

$$p_\psi \left[R - D\right] - R^0 \geq 0. \tag{3.21}$$

A necessary condition for (3.21) to hold is $D < R$. Given $R - D > 0$ and $p_h > p_l$, it is then immediate that $\psi = h$ prefers outside finance strictly whenever $\psi = l$ only prefers it weakly. This implies that we only have the following equilibrium candidates: (i) no successful type is refinanced with outside money; (ii) only $\psi = h$ and $\psi = n$ are refinanced with outside funds; and (iii) both successful types - and also $\psi = n$ - are refinanced with outside funds.[37]

Note next that by $p_h > p_l$ and as outside investors must break even, $\psi = h$ is sure to pay a lemon's premium under outside finance. If $\psi = l$ also pays a lemon's premium as τ is sufficiently low, this premium is nevertheless strictly smaller than that for $\psi = h$. This strengthens the argument in Section 3 by which the investor will choose $\psi = h$ over $\psi = l$

[36] In an alternative setting, in which the entrepreneur retains all ownership, he must leave the inside investor with $(1 - s_i)\, R^0$. Our qualitative results extend also to this setting.

[37] We restrict attention to pure-strategy equilibria.

if both projects are successful. We are now in a position to consider the various equilibrium candidates.

Equilibrium where no successful project is refinanced by outside investors

This is trivially always an equilibrium. If outside investors believe that no successful types seek outside finance the market for outside finance shuts down completely.

Equilibrium where all successful projects are refinanced by outside investors

We next characterize the equilibrium beliefs of outside investors, which we denote by $\pi(\psi)$. With probability $\tau^2 q_{\theta_i} q_{\theta_j}$, both projects are of type h, in which case also the project seeking outside finance is h: $\pi(h) = \tau^2 q_{\theta_i} q_{\theta_j}$. The project seeking outside finance is of type n whenever at least one project is unsuccessful such that $\pi(n) = 1 - \tau^2$.[38] With the residual probability $\pi(l) = \tau^2(1 - q_{\theta_i} q_{\theta_j})$, outside investors believe that the project is of type l. To break even D must satisfy

$$D[\tau^2 q_{\theta_i} q_{\theta_j} p_h + \tau^2(1 - q_{\theta_i} q_{\theta_j}) p_l] = I_2. \tag{3.22}$$

To validate that we have characterized an equilibrium, we must verify that both successful types weakly prefer outside finance and that (3.22) generates a value $D \leq R$. By our previous arguments we know that out of these three conditions the incentives for $\psi = l$ generate the most stringent requirements. From (3.21) and (3.22) it must hold that

$$p_l \left[R - \frac{I_2}{\tau^2 q_{\theta_i} q_{\theta_j} p_h + \tau^2(1 - q_{\theta_i} q_{\theta_j}) p_l} \right] \geq R^0,$$

which transforms to

[38] In case $\psi_i = \psi_j = n$ we specify that the inside investor proposes only one project to outside investors as they could otherwise immediately conclude that both projects are unsuccessful. (Note that in this case the inside investor would ask for outside finance even though she has still I_2 in her coffers.)

$$\tau^2 \geq \left[\frac{I_2}{p_l R - R^0}\right]\left[\frac{1}{q_{\theta_i} q_{\theta_j} p_h + (1 - q_{\theta_i} q_{\theta_j}) p_l}\right]. \tag{3.23}$$

Before proceeding to the analysis of the remaining equilibrium candidate, we turn to the assertion that, for low values of τ that are still compatible with (3.23), $\psi = l$ also has to pay a lemon's premium. This is the case if $p_l R - I_2$ exceeds $p_l [R - D]$, where we have to substitute D from (3.22). Reorganizing terms, we obtain from

$$p_l \left[R - \frac{I_2}{\tau^2 q_{\theta_i} q_{\theta_j} p_h + \tau^2 (1 - q_{\theta_i} q_{\theta_j}) p_l}\right] < p_l R - I_2$$

the requirement

$$\tau^2 < \frac{p_l}{q_{\theta_i} q_{\theta_j} p_h + (1 - q_{\theta_i} q_{\theta_j}) p_l}. \tag{3.24}$$

As $I_2 < p_l R - R^0$, which must hold by $r_l > 0$, (3.23) and (3.24) are jointly satisfied for intermediate values of τ.

Equilibrium where only $\psi = n$ and $\psi = h$ are refinanced by outside investors

The outside investors' beliefs are now given by $\pi(l) = 0$, $\pi(n) = \frac{1-\tau^2}{(1-\tau^2)+\tau^2 q_{\theta_i} q_{\theta_j}}$, and $\pi(h) = \frac{\tau^2 q_{\theta_i} q_{\theta_j}}{(1-\tau^2)+\tau^2 q_{\theta_i} q_{\theta_j}}$. To break even, D must solve

$$D \frac{\tau^2 q_{\theta_i} q_{\theta_j}}{(1 - \tau^2) + \tau^2 q_{\theta_i} q_{\theta_j}} = I_2. \tag{3.25}$$

Substituting (3.25) into (3.21), type h weakly prefers outside finance at these conditions if

$$p_h \left[R - I_2 \frac{(1 - \tau^2) + \tau^2 q_{\theta_i} q_{\theta_j}}{\tau^2 q_{\theta_i} q_{\theta_j}}\right] \geq R^0,$$

which transforms to

$$\tau^2 \geq \left[\frac{I_2}{p_h R - R^0}\right] \left[\frac{1}{q_{\theta_i} q_{\theta_j} + (1 - q_{\theta_i} q_{\theta_j}) \frac{I_2}{p_h R - R^0}}\right]. \tag{3.26}$$

For our purposes, i.e. as we merely want to rule out this equilibrium candidate, it is sufficient to stop here.

Having characterized all candidate equilibria, it remains to show that for all sufficiently low values of τ the only equilibrium is that without outside finance. This follows from conditions (3.23) and (3.26).

The responsiveness condition with outside finance

Suppose now that condition (3.23) holds, so that all interim types $\psi \in \{n, l, h\}$ can seek refinancing from outside investors if inside funds are not available. We now derive responsiveness condition (3.13).

First, we turn to the entrepreneur's payoff from negotiating refinancing with the inside investor. If $E_j's$ *interim* type is n, negotiations with E_i are identical to those under unconstrained finance.[39] Suppose instead that both entrepreneurs are of *interim* type l or h and that E_j with $\psi_j \neq n$ is the last entrepreneur to be bargained with. If the limited funds have already been used for E_i, the entrepreneur will only realize $s_j R^0 + \frac{1}{2}\lambda_{\psi_j}$ while the investor realizes $(1 - s_j) R^0 + \frac{1}{2}\lambda_{\psi_j}$ from this project.

Alternatively, if the funds are still available, E_j and the investor bargain over the cost savings from internal finance $r_{\psi_j} - \lambda_{\psi_j}$ so that E_j realizes the sum of $s_j R^0 + \frac{1}{2}\lambda_{\psi_j}$ and $\frac{1}{2}(r_{\psi_j} - \lambda_{\psi_j})$, which transforms to $s_j R^0 + \frac{1}{2} r_{\psi_j}$. The investor, on the other side, realizes the

[39] Recall that the success probability of n is zero. We assumed that continuing the project (with outside finance) generates arbitrarily small private benefits, implying that owners of a type-n project are no longer indifferent between seeking outside finance or not.

sum of $(1-s_j)\,R^0+\frac{1}{2}\lambda_{\psi_j}$ and $\frac{1}{2}\left(r_{\psi_j}-\lambda_{\psi_j}\right)$, which transforms to $(1-s_j)\,R^0+\frac{1}{2}r_{\psi_j}$. Turn next to negotiations with E_i who was picked first. In case of breakdown of the negotiations for inside funds, E_i receives $s_iR^0+\frac{1}{2}\lambda_{\psi_i}$, while the investor's payoff is equal to the sum of $(1-s_i)\,R^0+\frac{1}{2}\lambda_{\psi_i}$ and $(1-s_j)\,R^0+\frac{1}{2}r_{\psi_j}$.[40] In case they reach agreement, the joint surplus is $R_{\psi_i}+(1-s_j)\,R^0+\frac{1}{2}\lambda_{\psi_j}$. Subtracting the outside options of the two sides yields the net surplus $r_{\psi_i}-\lambda_{\psi_i}-\frac{1}{2}(r_{\psi_j}-\lambda_{\psi_j})$. As E_i gets half of it, his payoff is the sum of $s_iR^0+\frac{1}{2}\lambda_{\psi_i}$ and $\frac{1}{2}[r_{\psi_i}-\lambda_{\psi_i}-\frac{1}{2}(r_{\psi_j}-\lambda_{\psi_j})]$, which becomes $s_iR^0+\frac{1}{2}[r_{\psi_i}-\frac{1}{2}(r_{\psi_j}-\lambda_{\psi_j})]$.

Using this and the payoff $s_jR^0+\frac{1}{2}\lambda_{\psi_j}$ for E_j, we can next calculate the resulting *ex post* payoffs. When both entrepreneurs are of type h, E_i is picked first with probability $\frac{1}{2}$, implying that his payoff equals $s_iR^0+\frac{1}{2}[r_h-\frac{1}{2}(r_h-\lambda_h)]$ with probability $\frac{1}{2}$ and $s_iR^0+\frac{1}{2}\lambda_h$ with probability $\frac{1}{2}$, which adds up to $s_iR^0+\frac{1}{8}(r_h+3\lambda_h)$. When $\psi_i=h$ and $\psi_j=l$, then E_i receives inside refinancing for sure and earns $s_iR^0+\frac{1}{2}[r_h-\frac{1}{2}(r_l-\lambda_l)]$. When $\psi_i=l$ and $\psi_j=h$, by contrast, E_i has to go to the outside market where he will earn $s_iR^0+\frac{1}{2}\lambda_l$. Finally, when both entrepreneurs are of type l, E_i is again picked first with probability $\frac{1}{2}$ and we obtain for his payoff $s_iR^0+\frac{1}{8}(r_l+3\lambda_l)$.

Finally, we turn to *ex ante* payoffs. Substitution of *ex post* payoffs yields E_i's *ex ante* payoff:

$$\begin{aligned}&\tau\left[s_iR^0+\frac{1}{2}\left[r_l+q_{\theta_i}\left(r_h-r_l\right)\right]\right]\\&-\frac{\tau^2}{8}\left[\left(r_l-\lambda_l\right)\left(3-q_{\theta_i}+q_{\theta_j}\right)+3q_{\theta_i}q_{\theta_j}\left[r_h-\lambda_h-\left(r_l-\lambda_l\right)\right]\right]\end{aligned}$$

[40] An alternative scenario would be where the break-down of negotiations is 'complete', implying that the two sides also cannot agree to obtain outside finance. However, this does not affect our results as the entrepreneur's payoff from negotiating with the inside investor would remain unchanged at $s_iR^0+\frac{1}{2}[r_{\psi_i}-\frac{1}{2}(r_{\psi_j}-\lambda_{\psi_j})]$.

Now, let $\theta_i = g$. The responsiveness of $E_i's$ payoff to his project's profitability under constrained finance is then

$$\frac{1}{2}\tau\left(q_g-q_b\right)\left(r_h-r_l\right)-\frac{\tau^2}{8}\left(q_g-q_b\right)\left[3q_g\left(r_h-\lambda_h-\left(r_l-\lambda_l\right)\right)-\left(r_l-\lambda_l\right)\right].$$

This exceeds the responsiveness under unconstrained finance if and only if condition (3.13) holds. **Q.E.D.**

3.B Bargaining Procedures with Open Time Horizon

In this section, we formulate and solve the bargaining game with an open time horizon. To save space we focus on the case with constrained finance. The case with unconstrained finance is similar but more immediate. It also convenient to introduce the following additional notation. If there is no refinancing of project i, denote the respective payoffs by y_i for the investor and by z_i for E_i, i.e. $y_i := (1-s_i)R^0$ and $z_i := s_iR^0$. If there is refinancing their joint surplus from project i is denoted by v_i, i.e. $v_i := R_{\psi_i} - I_2$. The respective net surplus is denoted by $w_i := v_i - (y_i + z_i)$.

Recall next the bargaining procedure. First, the investor picks an entrepreneur, E_i, and makes an offer x. In the next period E_i can respond. If E_i accepts, the bargaining game ends as there are no funds available for E_j. If E_i rejects he can make a counter-offer, to which the investor can respond in the following period. If the investor rejects the counter-offer, she can pick again one of the two entrepreneurs and make a (new) offer etc..

Recall also that we capture bargaining frictions as follows. Suppose the investor currently negotiates with E_i. If E_i rejects the offer and makes a counter-offer, this offer will only be received by the investor with probability δ. With probability δ negotiations between the two parties break down, in which case project i will not be expanded. Note that a break-down of negotiations with E_i does not affect the possibility of negotiating with E_j. Also, the same risk of break-down exists if the investor reacts to the offer of E_i.[41]

We now analyze the bargaining game. Our aim is to characterize a (subgame perfect) equilibrium that generates the payoffs used in the main text as $\delta \to 1$. We start with histories where there has been breakdown with one entrepreneur, say entrepreneur j. As a consequence, only E_i remains and there are still funds for refinancing. The characterization of equilibrium strategies is standard. For the sake of completeness, we specify strategies in some detail. We characterize an offer by the payoff X it leaves to E_i. If it is the investor's turn, she always makes the offer X_i^I. If she has to respond, she accepts any X satisfying

$$v_i - X \geq (1-\delta)y_i + \delta(v_i - X_i^I). \tag{3.27}$$

E_i always makes the offer X_i^E and accepts any X satisfying

$$X \geq (1-\delta)z_i + \delta X_i^E. \tag{3.28}$$

X_i^I and X_i^E are determined by using equalities in (3.27) and (3.28) and substituting $X = X_i^E$ into (3.27) and $X = X_i^I$ into (3.28). In other words, the proposer extracts the maximum feasible payoff while still ensuring acceptance. We then obtain that the investor offers

$$X_i^I = \frac{z_i + v_i\delta - \delta y_i}{1+\delta}, \text{ with } \lim_{\delta \to 1} X_i^I = z_i + \frac{w_i}{2},$$

[41] Modelling bargaining frictions by a risk of break-down is standard. In contrast to the case with delay, it ensures that the two sides' outside options are always of relevance. That bargaining with the risk of break-down, but not bargaining with delay, can support the axiomatic Nash bargaining solution with threatpoints has been shown by Binmore, Rubinstein, and Wolinsky (1986).

which is accepted immediately by E_i.

Turn now to histories where there has not yet been any break-down. We specify that the investor always makes an offer to the entrepreneur with the highest net surplus, w_i. In case of indifference, we make the following specification. In the very first period, $t' = 1$, the invesor randomizes with equal probability. Later, he will always pick with probability one this particular entrepreneur E_i.[42] The investor now makes the offer x_i^I and accepts any counter-offer x by E_i satisfying

$$(v_i - x) + y_j \geq (1-\delta)\left[y_i + (v_j - X_j^I)\right] + \delta(v_i - x_i^I + y_j).$$

Observe that after break-down, which happens with probability $1-\delta$, the investor realizes the outside option y_i with E_i and continues to bargain with E_j. In this case we know that she has to leave E_j with X_j^I and, thereby, realizes $v_j - X_j^I$. If no break-up occurs, we work again with the assumption that the investor's next offer to E_i, i.e. x_i^I, will be accepted for sure. We will check below that it is optimal for the investor to again approach E_i and for E_i to accept.

E_i now always makes the offer x_i^E and accepts any x satisfying[43]

$$x \geq (1-\delta)z_i + \delta x_i^E.$$

[42] This specification for resolving the investor's indifference is only for convenience. Letting the investor randomize with equal probability in all future rounds would not change results as $\delta \to 1$.

[43] Note that this is identical to the condition that we employed for analyzing histories with break-down. This follows as the entrepreneur rightly expects that the investor will approach him again next time, provided there was no break-down. We have more to say on the investor's option to approach a different entrepreneur below.

Proceeding in the standard way, i.e. by choosing x_i^I and x_i^E to make the respective responder just indifferent, we obtain

$$\begin{aligned}(v_i - x_i^E) + y_j &= (1-\delta)\left[y_i + (v_j - X_j^I)\right] + \delta(v_i - x_i^I + y_j), \\ x_i^I &= (1-\delta)z_i + \delta x_i^E,\end{aligned}$$

and after substitution

$$x_i^I = \frac{z_i + \delta v_i + \delta y_j - \delta(y_i + v_j - X_j^I)}{1+\delta}, \text{ with } \lim_{\delta\to 1} x_i^I = \frac{z_i + v_i + y_j - y_i - v_j + X_j^F}{2}.$$

Hence, for $\delta \to 1$ the entrepreneur who is chosen first, E_i, realizes

$$x_i^I = z_i + \frac{1}{2}\left[(v_i - z_i - y_i) - (v_j - X_j^I - y_j)\right].$$

Substituting

$$v_j - X_j^I - y_j = v_j - \frac{v_j + z_j - y_j}{2} - y_j = \frac{1}{2}(v_j - (z_j + y_j)),$$

we obtain

$$x_i^I = z_i + \frac{1}{2}\left[w_i - \frac{1}{2}w_j\right].$$

This matches our result in the main text for the 'reduced' bargaining procedure.

By construction of the offers, to confirm that we have characterized an equilibrium we only have to consider histories where (i) both entrepreneurs are still around and (ii) where the investor deviates and makes an offer to the non-preferred entrepreneur j. For these histories, we make the following specifications. The investor offers x_j^I and accepts from E_j

any x satisfying

$$(v_j - x) + y_i \geq (1-\delta)(y_j + (v_i - X_i^I)) + \delta(v_i - x_i^I + y_j).$$

Note that this inequality takes into account that the investor will switch back to E_i in case she rejects the offer of E_j. E_j makes the offer x_j^E and accepts any x satisfying

$$x \geq (1-\delta)z_j + \delta x_j^E.$$

Making the responders again indifferent, we obtain

$$\begin{aligned}(v_j - x_j^E) + y_i &= (1-\delta)(y_j + (v_i - X_i^I)) + \delta(v_i - x_i^I + y_j), \\ x_j^I &= (1-\delta)z_j + \delta x_j^E,\end{aligned}$$

yielding

$$x_j^I = (1-\delta)z_j + \delta\left[v_j + y_i - (1-\delta)(y_j + (v_i - X_i^I)) - \delta(v_i - x_i^I + y_j)\right].$$

Recall that we want to confirm that, given these payoffs, the investor does not find it profitable to deviate and make an offer to j if no break-down has yet occurred with E_i. If the investor does not deviate she obtains $(v_i - x_i^I) + y_j$. If she does deviate the payoff is $(v_j - x_j^I) + y_i$. Hence we need to show that

$$(v_i - x_i^I) + y_j \geq (v_j - x_j^I) + y_i. \tag{3.29}$$

Substituting for x_i^I and x_j^I, requirement (3.29) transforms to $(w_i - w_j)(1-\delta) \geq 0$, which holds by assumption.

There is an indirect and more intuitive way to see that (3.29) must hold. Recall first that x_i^I and x_j^I are determined just to ensure acceptance by the respective entrepreneur, i.e., we have $x_i^I = (1-\delta)z_i + \delta x_i^E$ and $x_j^I = (1-\delta)z_j + \delta x_j^E$. Likewise, recall that x_j^E and x_i^E are chosen such that the investor is just indifferent between accepting and rejecting. As, following rejection, the investor returns to bargaining with E_i in both cases, we have that $v_i - x_i^E + y_j = v_j - x_j^E + y_i$, implying $x_i^I - x_j^I = (z_i - z_j) + \delta(w_i - w_j)$. Substituting this into (3.29) yields again the requirement $(w_i - w_j)(1-\delta) \geq 0$.

4

Communication as an Incentive Device

4.1 Introduction

Communication of knowledge, ideas, and research results have played a central role in the recent literature on partnerships and joint ventures[1], on the optimal organisation of R&D[2] as well as in the literature on "learning organisations".[3] A feature common to these models is that communication creates spillovers that alter the production function of a firm, joint venture, or researcher, and allow them to use inputs more productively, for example, by coordinating research tasks among different researchers (Combs (1993)), by allowing experts to screen new ideas (Biais and Perotti (2003)) or by allowing workers to specialise in knowledge acquisition within an organisation (Garicano (2000)).

By contrast, the model presented in this chapter offers a rationale for communication and knowledge exchange, even though communication does not create spillovers and does not

[1] See, for example, Gallini and Wright (1990), Bhattacharya, Glazer, and Sappington (1992), Combs (1993), Cassiman, Perez-Castrillo, and Veugelers (2002), Jansen (2001), Navaretti, Bussoli, Graevenitz, and Ulph (1999) and Pastor and Sandonis (2002). For seminal work on research joint ventures see Katz (1986) and D'Aspremont and Jacquemin (1988) as well as De Bondt (1996) for a survey of the resulting literature.

[2] See, for example, Anton and Yao (1994, 1995), Anand and Galetovic (2000b), Gans and Stern (2000, 2002), Rosenkranz and Schmitz (1999, 2003) and Biais and Perotti (2003).

[3] See, for example, Senge (1994) and Garicano (2000).

per se increase the surplus that can be created within an organization. In our model, two agents form a partnership that creates interim knowledge which is then used to create final research output. When partners in a research joint venture face a hold-up problem at the interim stage, communication merely affects their relative bargaining power as it influences their ability to conduct research outside the partnership. However, in contrast to the existing literature, communication does not allow the partnership to use interim knowledge more productively in final research. In particular, communicating knowledge to another agent increases the recipient's bargaining power at the interim stage and consequently lowers that of the sender. As a result, communication lowers the share of surplus appropriated by the sender. Nevertheless, an agent may find it optimal to commit to communication at the *ex ante* stage as it increases the recipient's incentives to create interim knowledge, thus increasing the size of the expected surplus.

We find that the benefits of communication as an *ex ante* incentive device outweighs its costs in terms of *ex post* loss of bargaining power when there are sufficiently strong increasing returns to knowledge, when communication is not too perfect and when the agents' *ex ante* moral hazard problem is neither too weak nor too severe.

The analysis most closely related to ours is that of Rosenkranz and Schmitz (1999) and Rosenkranz and Schmitz (2003) who also consider the impact of knowledge disclosure in a model with interim hold-up. Their focus, however, is on the optimal allocation of property rights. In their model, the amount of communicable knowledge is fixed so that communication will occur if and only if it increases the sender's *share* of the surplus created. Moreover, the impact of communication on the collaborative surplus is critical in determining the optimality of communication. In our model, by contrast, communication will occur even if it reduces the share of the surplus appropriated by an agent during renegotiations as long as it provides sufficient additional effort incentives to the other agent.

4.2 The Model

Two symmetric agents, indexed by $i \in \{A, B\}$, can each pursue a research project, either each on their own or both joined together in what we term a "partnership". In this chapter, a "partnership" is simply defined by the fact that the two agent's enter into a profit-sharing agreement.[4]

In the following, we assume that the profit sharing agreement the two agents enter into when forming a partnership consists of a sharing rule that is contingent on the existence of the partnership. In particular, this characterisation rules out the inclusion of clauses into the partnership agreement that govern that agents' behaviour after the partnership has broken down.[5]

The research project undertaken either by the two agents separately or by the partnership formed by them consists of two stages. In the first stage, agents can acquire knowledge that can then be used to produce final research during the second stage. Final research success, in turn, determines payoffs.

[4] Thus, we do not consider the additional organisational or contractual characteristics frequently associated with this nomer. See, for example, Hansmann (1996) for an overview of the form and function of business organisations with a particular focus on the structure of private partnerships and other producer cooperatives.

[5] This, for example, specifically rules out the consideration of non-compete clauses that restrict competition between agents in case of a break down of the partnership. Allowing for such clauses, it might be argued, may reduce the efficacy of the mechanism proposed in this chapter in improving the agents' effort incentives, as any knowledge communicated during the lifetime of the partnership would be unproductive for the duration of the non-compete clause.

However, allowing for non-compete clauses will not crucially affect our analysis for two reasons. First, as, for example, Anton and Yao (1994) argue, there are severe legal limits on the enforceability of such contracts and thus on their ability to restrict *ex post* competition. Secondly, and more importantly, it is precisely the main argument of this chapter that, in some circumstances, agents in a partnership benefit *ex ante* from stronger *ex post* competition outside the partnership.

4.2.1 The First Stage ($t = 0$)

At $t = 0$, agents A and B decide whether to form a partnership.[6] An agent can then acquire knowledge, denoted by h_i, for executing a particular research task. For simplicity, knowledge can be either high $(h_i = h)$ or low $(h_i = 0)$. Knowledge acquisition is stochastic and the probability that $h_i = h$ is given by the effort θ^i exerted by agent i. The effort choice θ^i is not observable, and hence not contractible. Effort is binary[7] - $\theta^i \in \{\theta, \theta + \delta\}$, $\theta + \delta \in (0, 1)$ - and associated with the following cost function $c(\theta^i)$

$$c\left(\theta^i\right) = \begin{cases} c \text{ if } \theta^i = \theta + \delta \\ 0 \text{ if } \theta^i = \theta \end{cases}.$$

Knowledge h_i is observable but not verifiable and embedded in the agent. As a result, contracts cannot be made contingent on knowledge realisations and the agent can decide to withdraw her knowledge from the research partnership.

As argued in chapter 2, there exists a difference between *observing* and *possessing* knowledge. An agent's observation that another agent has a particular knowledge level h_i does not translate into an ability to use that knowledge productively. Productive use or, in our parlance, possession of knowledge can be achieved only by a deliberate transfer from another agent who possesses that knowledge. In contrast to chapter 2, the model presented in this chapter assumes that property rights are well defined so that an agent will transfer her knowledge if and only if it is in her interest.[8]

Communication

[6] We could allow for agents to form a partnership at a later stage. What is crucial for our results is that communication, as described in this section, is not feasible unless a partnership has been formed.

[7] Allowing for a continuous effort choice would not affect the central intuition behind our results but reduce notational clarity.

[8] See Anton and Yao (1994) and Anand and Galetovic (2000b) for an analysis of the optimal organisation of R&D when property rights are not perfect.

We label such a transfer of knowledge as 'communication' by the agent. It can only occur when a partnership has been formed. The focus of our analysis will be the agents' choice of communication policy, denoted by π_i. For the purposes of this paper, we interpret π_i as the probability with which agent $i's$ knowledge is communicated to agent j and let $\pi_i \in \{0, \pi\}$.[9] By definition, communication can only take place once knowledge acquisition has occurred. However, it is questionable that an agent will have incentives to communicate at that stage.[10] As a result, we will concentrate on the agents' choice of communication policy at $t = 0$. In this sense, we talk of *communication policy as a commitment at* $t = 0$ *to communicate at a later stage.* Such a commitment to communicate may, for example, be created through a company's internal organisation[11] or through the physical location of the research activity[12], although we remain agnostic throughout the analysis on the precise means of achieving this. In this sense, communication policy may be thought of as a commitment to 'exposure' of research results to another agent.

Communication matters as it may increase the knowledge level of an agent at $t = 1$. To this end, we distinguish between the *pre-communication* knowledge, h_i, and the *post-communication* level of knowledge, which we denote by H_i. Suppose that agent i commits to a communication policy π_i and creates knowledge h_i at the end of $t = 0$. Then if communication is successful, agent j will possess post-communication knowledge $H_j = h_j + h_i$ at $t = 1$. If communication is unsuccessful, $H_j = h_j$. Since knowledge is non-rival, communication by i does not deplete $i's$ knowledge level.

[9] An alternative interpretation would be one in which π_i represents the share of knowledge that is communicated. This interpretation would require a more complicated payoff structure and would, given risk neutrality, not affect our results.

[10] See, for example, the analysis contained in Chapter 1.

[11] For example, the company may insist on regular meetings between the agents to coordinate and present research results or it may impose a joint supervisor who may play a similar intermediary role in terms of knowledge transmission as that of the investor analysed in Chapter 1.

[12] Agents could be forced to undertake research in physically distant locations, thus minimising the likelihood of involuntary spillover. Alternatively, when research is conducted in the same laboratory, for example, agents are likely to learn a lot about each other's research progress.

4.2.2 *The Second Stage* ($t = 1$)

At the second stage, post-communication knowledge H_A and H_B is used to conduct final research. Since knowledge is embedded in an agent, agents can decide to continue research on their own. As a result, both agent's have hold-up power and A and B will renegotiate contract terms at this stage.

Payoffs: What matters to our analysis are an agent's expected returns at $t = 1$. As a result, we do not model final payoffs explicitly, although Appendix A provides a detailed example in which final payoffs are modelled explicitly.

Expected returns from research at $t = 1$ depend on the knowledge held by both agents. To be more precise, expected returns depend on both the distribution of pre-communication and post-communication knowledge levels and on whether research is conducted within the partnership or separately (i.e. whether renegotiations at $t = 1$ were successful or not).

In general, we denote by $V(h_A, h_B; H_A, H_B)$ the expected value of the research project at $t = 1$ when it is conducted within the partnership of A and B. By contrast, let $w^i(h_A, h_B; H_A, H_B)$ denote the expected value of the research project at $t = 1$ to agent i when research is conducted separately. We impose several assumptions on this payoff structure.[13]

[13] Appendix A presents a simple extensive-form model of final stage interactions between the agents with expected returns that fulfill these assumptions. The interpretation put forward there is the following:

At $t = 0$, agents A and B can acquire expertise h at differing research research tasks. At $t = 1$, each research task must be concluded successfully to generate a positive payoff at $t = 2$. Communication of, say, $B's$ expertise in task B to agent A enables A to undertake task B and vice-versa. However, there are no returns to scale to both agents working on a particular research task in a partnership.

When A and B work in a partnership, each agent concentrates on her task. As a result, pre-communication knowledge levels matter for expected returns while post-communication payoffs are irrelevant. When A and B split at $t = 1$, each agent engages in both research tasks simultaneously. As a result, post-communication knowledge levels matter.

Assumption 1: *The expected returns* ***within*** *a partnership depend only on pre-communication knowledge levels*

$$V(h_A, h_B; H_A, H_B) = V(h_A, h_B) \text{ and}$$

$$V(h, h) = V > V(h, 0) = V(0, h) = v > V(0, 0) = 0.$$

This assumption implies that communication cannot improve returns within the partnership and distinguishes our analysis from the literature that emphasises payoff complementarities realised through communication (see, for example, Combs (1993), Rosenkranz and Schmitz (1999) and Ulph and Katsoulacos (1999)). Assumption 1 would rule out any role for communication in this literature.

Assumption 2: *An agent's expected returns* ***outside*** *the partnership depend only on post-communication knowledge levels:*

$$\begin{aligned} w^A(h_A, h_B; H_A, H_B) &= w^A(H_A, H_B) \text{ for agent } A \\ w^B(h_A, h_B; H_A, H_B) &= w^B(H_A, H_B) \text{ for agent } B \end{aligned}$$

Furthermore, it is (i) decreasing in the other agent's knowledge

$$\begin{aligned} w^A(\cdot, 0) &> w^A(\cdot, h) > w^A(\cdot, 2h) \text{ for agent } A \\ w^B(0, \cdot) &> w^B(h, \cdot) > w^B(2h, \cdot) \text{ for agent } B \end{aligned}$$

and (ii) increasing in the agent's own knowledge advantage

$$\begin{aligned} w^A(2h,h) &> w^A(h,h) \text{ and } w^A(h,0) > w(0,0) = 0 \text{ for agent } A \\ w^A(h,2h) &> w^A(h,h) \text{ and } w^A(0,h) > w(0,0) = 0 \text{ for agent } B \end{aligned}$$

This specification clarifies to role of communication in this model. Communication does not affect the partnerships ability to generate surplus at $t = 2$. Rather, communication affects the agents' ability to conduct research outside the partnership and influences their bargaining power in renegotiations over final returns at $t = 1$. More precisely, Assumption 2 implies that communication by A to B will increase $B's$ *post-communication* knowledge with the consequence that $A's$ payoff from separate research is reduced while $B's$ payoff is increased. Hence, communication from A to B improves $B's$ but worsens $A's$ relative knowledge position *ceteris paribus.*

Figure 4.1 summarises the timing of the game as presented above:

4.2.3 Renegotiation

To the degree that both agents possess knowledge at $t = 1$ and can undertake research independently, they possess hold-up and thus bargaining power. We assume that agents cannot commit at $t = 0$ to not renegotiate at $t = 1$. Furthermore, as knowledge levels are observable, there is no asymmetric information at $t = 1$. Bargaining over the expected surplus at $t = 1$ is then assumed to take place according to Nash bargaining with equal bargaining powers.

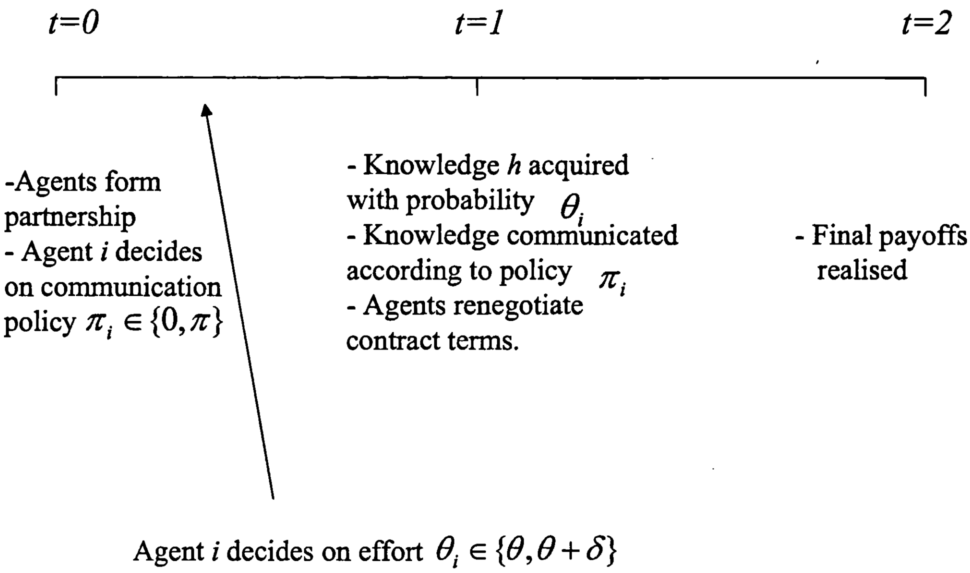

FIGURE 4.1. The Timeline.

Agent i has pre-communication knowledge h_i and post-communication knowledge H_i. Given Assumptions 1 and 2, the surplus from renegotiation is $V(h_i, h_j) - w^i(H_i, H_j) - w^j(H_i, H_j)$.[14] Let $S^i(h_i, h_j; H_i, H_j)$ be defined as the surplus appropriated by agent i through renegotiations at $t = 1$:

$$S^i(h_i, h_j; H_i, H_j) := \frac{1}{2}\left[V(h_i, h_j) + w^i(H_i, H_j) - w^j(H_i, H_j)\right] \tag{4.1}$$

It is, by assumption 2, increasing in the agent's own knowledge advantage as well as decreasing in the other agent's knowledge. To simplify the subsequent analysis, we impose the following natural assumption:[15]

Assumption 3: *An agent without knowledge does not contribute to the surplus created within a partnership:*

$$w^A(0, \cdot) = w^B(\cdot, 0) = 0.$$

This assumption states that a partnership creates an incremental value over separate research if and only if *both agents* have knowledge. It also implies that $w^A(h, 0) = w^B(0, h) = v$, so that the sole agent with knowledge appropriates the entire surplus while the agent without any knowledge earns zero returns from a partnership

$$S^A(0, h; 0, h) = S^B(h, 0; h, 0) = 0 \text{ and } S^A(h, 0; h, 0) = S^B(0, h; 0, h) = v.$$

[14] Note that any sharing rule agreed upon by the agents at $t = 0$ will be renegotiated at $t = 1$. Moreover, since the enforcement of such a sharing rule is contingent on the partnership's continuation, it does not influence outside options nor the surplus bargained over.

[15] Assumption 3 is merely a normalisation that simplifies notation. Our main results are unaffected if it is relaxed.

To streamline the subsequent analysis, let R^i denote the expected return to agent i at $t = 0$:

$$
\begin{aligned}
R^A &:= \theta^A \theta^B (\pi^A \left[\pi^B S^A (h, h; 2h, 2h) + \left(1 - \pi^B\right) S^A (h, h; h, 2h)\right] \\
&\quad + \left(1 - \pi^A\right) \left[\pi^B S^A (h, h; 2h, h) + \left(1 - \pi^B\right) S^A (h, h; h, h)\right]) \\
&\quad + \theta^A \left(1 - \theta^B\right) \left[\pi^A S^A (h, 0; h, h) + \left(1 - \pi^A\right) S^A (h, 0; h, 0)\right] \\
&\quad + \left(1 - \theta^A\right) \theta^B \left[\pi^B S^A (0, h; h, h) + \left(1 - \pi^B\right) S^A (0, h; 0, h)\right]
\end{aligned}
$$

and

$$
\begin{aligned}
R^B &:= \theta^B \theta^A (\pi^B \left[\pi^A S^B (h, h; 2h, 2h) + \left(1 - \pi^A\right) S^B (h, h; 2h, h)\right] \\
&\quad + \left(1 - \pi^B\right) \left[\pi^A S^B (h, h; h, 2h) + \left(1 - \pi^A\right) S^B (h, h; h, h)\right]) \\
&\quad + \theta^B \left(1 - \theta^A\right) \left[\pi^B S^B (0, h; h, h) + \left(1 - \pi^B\right) S^B (0, h; 0, h)\right] \\
&\quad + \left(1 - \theta^B\right) \theta^A \left[\pi^A S^B (h, 0; h, h) + \left(1 - \pi^A\right) S^B (h, 0; h, 0)\right]
\end{aligned}
$$

Finally, define

$$
\begin{aligned}
\Delta^A &: = w^A (2h, h) - w^B (2h, h) \\
\Delta^B &: = w^B (h, 2h) - w^A (h, 2h)
\end{aligned}
$$

as the difference in payoffs between the agents in the case in which one agent possess both agents' knowledge while the other only possesses one agent's knowledge and in which the agents have separated at $t = 1$. Symmetry between the agents then implies that $\Delta^A = \Delta^B$so that the subsequent discussion will use $\Delta := \Delta^A = \Delta^B$ for simplicity.

4.3 Analysis of Constrained Optimal Communication Policy

In this section, we first derive expected returns at $t = 0$ and then examine incentives to exert effort. Finally, we derive the optimal communication policy.

4.3.1 Expected Returns

We first focus on the surplus from renegotiation at $t = 1$, as given by definition (4.1). Pre-communication knowledge levels h_A and h_B determine the gross surplus created in a partnership while post-communication knowledge levels H_A and H_B determine the outside options of a particular agent and hence her net returns.

In general, we can discern two cases: either both agents have the same level of *post-communication* knowledge ($H_A = H_B$) or not ($H_A \neq H_B$).

First, suppose $H_A = H_B$. Then both agents have the same outside option when bargaining at $t = 1$ so that both agents will extract the same net surplus during renegotiations. By (4.1), expected returns will then depend solely on pre-communication knowledge levels, h_A and h_B.

Post-communication knowledge levels will be the same if both agents possessed pre-communication knowledge and either both communicated successfully or both failed to communicate. In this case, an agent's expected return is $S^i(h, h; h, h) = S^i(h, h; 2h, 2h) = \frac{1}{2}V$. Alternatively, post-communication knowledge levels will be the same if an agent with pre-communication knowledge communicated it to an agent whose knowledge acquisition at $t = 0$ failed. In this case, expected payoffs are $S^i(h, 0; h, h) = S^i(0, h; h, h) = \frac{1}{2}v$.

Second, suppose $H_A \neq H_B$. In this case, the agent with more post-communication knowledge will appropriate more of the surplus generated by the partnership because of her superior outside option. Post-communication knowledge levels may differ either because both agents had pre-communication knowledge h but only one communicated successfully or because one agent had superior pre-communication knowledge and did not communicate it. Suppose that $H_A > H_B$. If $H_A = h$ and $H_B = 0$, then by Assumption 3 $S^A(h, 0; h, 0) = v$ and $S^B(h, 0; h, 0) = 0$. If $H_A = 2h$ and $H_B = h$, then $S^A(h, h; 2h, h) = \frac{1}{2}(V + \Delta)$ and $S^B(h, h; 2h, h) = \frac{1}{2}(V - \Delta)$.

As these payoffs indicate, it is not obvious that the surplus from continuing the partnership is positive. If $H_A = H_B = 2h$, the agents will renegotiate to continue the partnership if and only if $V \geq w^i(2h, 2h) + w^j(2h, 2h)$. If $H_A = H_B = h$ this requires $v \geq w^i(h, h) + w^j(h, h)$. Finally, if $H_A = 2h$ and $H_B = h$ or if $H_A = h$ and $H_B = 2h$, agents will continue the partnership if and only if $V \geq \Delta$. In this section, we restrict ourselves to the case in which the surplus from continuing the partnership is always positive by imposing the following assumption.

Assumption 4: $V > 2v$ *and* $V > \Delta$.

Appendix B provides conditions under which our results are unaffected when $V < 2v$ and $V < \Delta$ so that the surplus from continuing the partnership is negative at $t = 1$ and both agents conduct final research on their own.

Given assumption 4, the expected return to the partnership at $t = 0$ is given by

$$\theta^A\theta^B V + \left[\theta^A\left(1 - \theta^B\right) + \theta^B\left(1 - \theta^A\right)\right] v - c\left(\theta^A\right) - c\left(\theta^B\right) \tag{4.2}$$

Note that assumption 4 implies that the marginal social return to effort by either agent is positive.

Consider agent A.[16] Her expected return can now be written as

$$R^A = \theta^A \left[v + \frac{\theta^B}{2} (V - 2v) \right] - \theta^A \pi^A \left[\frac{v}{2} + \frac{\theta^B}{2} (\Delta - v) \right] + \theta^B \pi^B \left[\frac{v}{2} + \frac{\theta^A}{2} (\Delta - v) \right] - c\left(\theta^A\right) \tag{4.3}$$

Agent $A's$ expected return consists of three components. The first term is independent of the communication policies chosen and consists of the expected surplus created through $A's$ knowledge - $\theta^A v$ - plus half the expected incremental surplus from combining both agents' knowledge - $\frac{\theta^A \theta^B}{2} (V - 2v)$. The second term captures the effect of $A's$ own communication policy: it lowers $A's$ expected return by $-\theta^A \pi^A \frac{v}{2}$ when A possesses knowledge and by $-\frac{\theta^A \theta^B}{2} \pi^A (\Delta - v)$ when both possess knowledge. Finally, the third term represents the impact of $B's$ communication policy. It raises $A's$ expected return by $\theta^B \pi^B \frac{v}{2}$ when B has knowledge and by $\frac{\theta^B \theta^A}{2} \pi^B (\Delta - v)$ when both possess knowledge.

For given effort choices, communication from A to B reduces $A's$ payoff because it increases $B's$ post-communication knowledge at $t = 1$, thus increasing $B's$ outside option and simultaneously lowering $A's$ outside option. Since communication does not affect the gross surplus created within the partnership, $A's$ expected return is reduced. By the same reasoning, communication from B to A increases $A's$ expected return as it improves $A's$ bargaining position and worsens that of B.

The main implication of this discussion is that, *if effort choices were fixed, an agent does not have an incentive to communicate* as it would merely erode her surplus. To put it differently, communication lowers *ex post* bargaining power so that, *ceteris paribus,* there are no incentives to communicate. The remainder of this paper is dedicated to demonstrating

[16] The analysis for agent B is analogous since the agent's are symmetric.

that, *ceteris non paribus,* this intuition may not hold any longer. To this end, we first derive the optimal choice of effort and then analyse the optimal communication policy.

Before proceeding, we quickly establish that it is indeed in the agents' interest to form a partnership at $t = 0$. The expected return of agent A when no partnership is formed at $t = 0$ is given by

$$\theta^A \left[\theta^B w^A (h, h) + \left(1 - \theta^B\right) v\right] - c\left(\theta^A\right) \tag{4.4}$$

so that we can establish the following result.

Lemma 1 *In equilibrium, agents will always prefer to form a partnership at* $t = 0$.

Proof: For agent A, the lemma follows from a comparison of (4.3) and (4.4) as well as the fact that strategies will be symmetric in equilibrium. *Ex ante* symmetry between agents A and B also implies that B will prefer the partnership at $t = 0$. ■

As a result, we proceed under the assumption that the agents have formed a partnership.

4.3.2 Choice of Effort

The agent chooses her effort after communication policies have been committed to. Assumption 4 implies the existence of a moral hazard problem as the return of the partnership is increasing in either agent's effort.

Consider now agent A.[17] From (4.3), the incremental return to her effort, given communication policies π^A and π^B, is

$$\delta\left(v+\theta^B\frac{V-2v}{2}\right)+\delta\left(\pi^B\theta^B\frac{\Delta-v}{2}\right)-\delta\pi^A\left(\frac{v}{2}+\theta^B\frac{\Delta-v}{2}\right) \tag{4.5}$$

and consists of three components. The first factor - $v+\theta^B\frac{V-2v}{2}$ - is independent of communication and captures the incremental return to $A's$ knowledge when B does not have any knowledge, v, as well as the impact of $B's$ acquisition of knowledge on $A's$ incremental return, namely $\frac{V-2v}{2}$. $B's$ acquisition of knowledge increases the partnership's expected return from v to V but lowers $A's$ bargaining power so that she can only extract half of the surplus. The net effect is positive when $V>2v$, a situation we refer to as *increasing returns to knowledge.*

The second and third component capture the impact of communication on incremental returns to effort. Recall that communication by B improves $A's$ post-communication knowledge and $A's$ bargaining power and vice versa. Hence, the second component - $\pi^B\theta^B\frac{\Delta-v}{2}$ - is a measure of how much communication by B contributes to $A's$ incremental return: if B has knowledge, but does not communicate, then $A's$ incremental return is $\frac{V}{2}$; when B does communicate, her incremental return is $\frac{V+\Delta}{2}-\frac{v}{2}$. As a result, communication affects $A's$ incremental return by $\frac{\Delta-v}{2}$. If this effect is positive, we refer to it as *increasing returns to communication.*

Finally, the third component captures the effect of $A's$ communication on her effort incentives. As expected, own communication reduces effort incentives, because it dissipates returns of sole possession of knowledge from v to $\frac{v}{2}$ and because it depletes surplus when

[17] Again, *ex ante* symmetry between agents A and B implies that the analysis for B proceeds analogously.

both possess knowledge by strengthening $B's$ bargaining power when there are increasing returns to communication.

Note that $A's$ incremental return to effort depends positively on $B's$ effort if $\frac{V-2v}{2} + \left(\pi^B - \pi^A\right) \frac{\Delta - v}{2} > 0$, e.g. when there are increasing returns to knowledge and to communication. In this case, effort choices are strategic complements.

To conclude, agent A will exert effort if

$$v + \theta^B \frac{V-2v}{2} + \pi^B \theta^B \frac{\Delta - v}{2} - \pi^A \left[\frac{v}{2} + \theta^B \frac{\Delta - v}{2}\right] \geq \frac{c}{\delta} \tag{4.6}$$

for a given pair of communication policies, π^A and π^B, as well as given $B's$ effort level θ^B.

To streamline the following exposition, let

$$\phi := v + \frac{\theta}{2}(V - 2v) - \frac{c}{\delta}$$

denote the *incremental return to effort to an agent when no communication occurs* $\left(\pi^A = \pi^B = 0\right)$ *and when the other agent exerts low effort.*

As a result, we can write agent $A's$ incentive compatibility constraint (4.6) as

$$\phi \geq -\left(\theta^B - \theta\right) \frac{V-2v}{2} + \pi^A \left[\frac{v}{2} + \theta^B \frac{\Delta - v}{2}\right] - \pi^B \theta^B \frac{\Delta - v}{2}.$$

Since agents are *ex ante* symmetric, inspection of (4.6) allows us to draw the following conclusions.

Lemma 2 *An agent's incremental return to effort is decreasing in her own communication. It is increasing in the other agent's communication if there are increasing returns to* *communication* ($\Delta > v$). *If there are increasing returns to knowledge* ($V > 2v$), *the agents' effort levels are strategic complements given a symmetric communication policy.*

4.3.3 Choice of Communication Policy

First, consider the socially optimal communication policy. Recall that the *ex ante* returns of the partnership are given by equation (4.2). Since the communication policies π^A and π^B do not enter the overall return of the project directly, the implication is that the first-best communication policy is not uniquely defined in our setting in the absence of an entrepreneurial agency problem.

Consider then the optimal communication policy in the presence of the entrepreneurial moral hazard problem. Assumption 4 implies that high effort by either agent increases total surplus, so that communication will be socially optimal whenever it induces high effort by either or both of the agents. We now turn to an analysis of the agents' private incentives to communicate.

Agent $A's$ communication policy has a direct negative impact on $A's$ surplus as it reduces her bargaining position at $t = 1$ relative to B. Because it changes relative bargaining positions, it also has an impact on each agent's effort incentives. In particular, for a given level of effort by B, communication reduces $A's$ effort incentives. The effect on $B's$ effort incentives, by contrast, depends on the returns to communication. Additionally, when, as per assumption 4, the agent's effort choices are strategic complements, there is also an 'indirect' effect, as an increase in $B's$ effort will improve $A's$ incremental return. The optimal communication policy trades off these effects against each other.

One immediate implication of this discussion is that a necessary condition for communication to improve $A's$ surplus is that communication increases $B's$ effort choice. As Lemma 2 indicates, this will be the case if and only if there are increasing returns to communication, i.e. if $\Delta > v$.

Suppose then that $\Delta > v$ so that communication increases $B's$ incremental return to effort. When this increase is insufficient to change $B's$ choice of effort, communication is inefficient and will not occur in equilibrium.

Proposition 1 *Suppose that $\Delta > v$. If the incentive problem is very weak so that*

$$\phi \geq 0$$

or if it is very severe so that

$$\phi < -\delta \left(\frac{V - 2v}{2} \right) - (\theta + \delta) \pi \frac{\Delta - v}{2},$$

neither agent will communicate in equilibrium: $\pi^A = \pi^B = 0$.

Proof: Suppose that $\pi^A = \pi^B = 0$. Then communication will not occur in equilibrium if both agents exert high effort in the absence of communication, i.e. if $v + \frac{\theta}{2}(V - 2v) \geq \frac{c}{\delta}$ or if communication by A does not increase $B's$ effort incentives sufficiently to induce higher effort even if A exerts high effort, i.e. if $v + \frac{\theta + \delta}{2}[V - 2v + \pi(\Delta - v)] < \frac{c}{\delta}$ which can be rearranged to yield the second condition. ■

Proposition 1 implies that communication by A will induce higher effort by B if and only if

$$0 \geq \phi > -\pi\theta\frac{\Delta - v}{2}, \tag{4.7}$$

that is, whenever there are sufficiently strong increasing returns to communication. Condition (4.7) also represents a necessary condition for communication to be socially optimal.

The following proposition states the main result of the paper. It describes when a deviation from non-communication is profitable and when it will lead to an equilibrium in which both agents communicate.

Proposition 2 *Suppose increasing returns to communication are sufficiently strong so that condition (4.7) holds. Then a deviation from non-communication is profitable for A if*

$$\pi \leq \frac{\delta (V - 2v)}{v + (\theta + \delta)(\Delta - v)}. \tag{4.8}$$

Communication by both agents $\left(\pi^A = \pi^B = \pi\right)$ *will be a symmetric pure strategy equilibrium if, in addition*

$$\pi (\theta + \delta) \frac{\Delta - v}{2} + \frac{1}{2}\left[\pi v - \delta (V - 2v)\right] \geq \phi > \frac{1}{2}\left[\pi v - \delta (V - 2v)\right]. \tag{4.9}$$

If

$$0 \geq \phi > \pi (\theta + \delta) \frac{\Delta - v}{2} + \frac{1}{2}\left[\pi v - \delta (V - 2v)\right] \tag{4.10}$$

then there are multiple equilibria including a symmetric mixed-strategy equilibrium in which each agent will choose communication policy π *with probability* $p = \delta\frac{v+\left(\theta+\frac{\delta}{2}\right)(V-2v)}{\pi\frac{\theta+\delta}{2}[v+(\theta+\delta)(\Delta-v)]}$.

In both cases, both agents will exert high effort in equilibrium: $\theta^A = \theta^B = \theta$.

Proof: Suppose that $\Delta > v$ and that condition (4.7) holds, Furthermore, we assume that $\pi^A = \pi^B = 0$ and that each agent expects the other agent to not exert high effort in the absence of communication so that $\theta^A = \theta^B = \theta$.[18] We now construct an equilibrium in which both agents will communicate. First, we show when communication is a profitable deviation from the above strategies. Then we examine when communication is a symmetric Nash equilibrium strategy.

First, suppose that A communicates. Then $\pi^A = \pi$ will increase θ^B from θ to $\theta + \delta$ under condition (4.7). Given that $\pi^B = 0$, $B's$ higher effort increases $A's$ surplus by $\theta\frac{\delta}{2}(V - 2v)$ while $\pi^A = \pi$ lowers her surplus by $-\theta\pi\left[\frac{v}{2} + \frac{\theta+\delta}{2}(\Delta - v)\right]$. As a result, the net effect of communication by A on her total surplus is non-negative if $\pi \leq \frac{\delta(V-2v)}{v+(\theta+\delta)(\Delta-v)}$ so that communication is a profitable deviation in this case. By symmetry, B will also find it optimal to communicate in order to induce effort by A when this condition holds.

Second, consider communication as an equilibrium strategy. Recall that, since $\Delta > v$, A's communication induces higher effort by B which increases $A's$ incremental return to effort under assumption 4. Then communication by both is a pure strategy equilibrium if this incremental return is not sufficient to induce high effort by A, i.e. if $\frac{c}{\delta} > v + \frac{\theta+\delta}{2}(V - 2v) - \pi\left[\frac{v}{2} + \frac{\theta+\delta}{2}(\Delta - v)\right]$ and if the incremental return given communication by both is sufficient to induce high effort by both, i.e. if $v + \frac{\theta+\delta}{2}(V - 2v) - \pi\frac{v}{2} \geq \frac{c}{\delta}$. Condition (4.9) summarises these two constraints.

If $v + \frac{\theta+\delta}{2}(V - 2v) - \pi\left[\frac{v}{2} + \frac{\theta+\delta}{2}(\Delta - v)\right] \geq \frac{c}{\delta}$, then $B's$ higher effort induces A to exert more effort in the absence of communication by B. Because of this complementarity, there are multiple equilibria over this range. In particular, there will be a mixed strategy

[18] Note that because effort choices are strategic complements there always exists an equilibrium for the parameter ranges that we consider in which both agents expect each other to exert high effort and, as a result, find it profitable to exert high effort without communication. This existance of multiple equlibria is standard in games with complementarities. For the purpose of our existance analysis, we can ignore the above equilibrium.

equilibrium in which both agents choose communication policy π with probability

$$p = \delta \frac{v + \left(\theta + \frac{\delta}{2}\right)(V - 2v)}{\pi \frac{\theta + \delta}{2}\left[v + (\theta + \delta)(\Delta - v)\right]}.$$

Finally, in a symmetric equilibrium, both agents prefer communication to non-communication at $t = 0$ since it induces higher effort by both agents. ■

Proposition 2 describes the conditions under which communication is a symmetric equilibrium strategy. Its main implication is that it may be optimal for an agent to commit at the *ex ante* stage to lowering her *ex post* bargaining power. Although such a commitment lowers the *share of the surplus* that she appropriates, it increases her partner's effort incentives and thus the *size of the surplus.* As such, it provides a role for communication policy as an incentive device and argues that communication may occur in partnerships even in the absence of any positive impact on the gross surplus generated.

Conditions (4.7) and (4.8) indicate that such an equilibrium will exist if there are increasing returns to communication ($\Delta > v$) and as long communication is not too perfect. When communication is too perfect, the reduction in the *share of surplus* due to communication outweighs the increase in the *size of surplus.* As a result, it is not profitable to deviate from non-communication and communication is not an equilibrium strategy. Figure 4.2 illustrates the equilibria described in Propositions 1 and 2. Finally, it follows from proposition 2 that communication is socially optimal whenever conditions (4.9) and (4.10) hold, i.e. whenever it induces high effort in equilibrium. This will be the case even if condition (4.8) were not to hold, so that socially optimal communication might not occur when the communication mechanism is too efficient (π is too high).

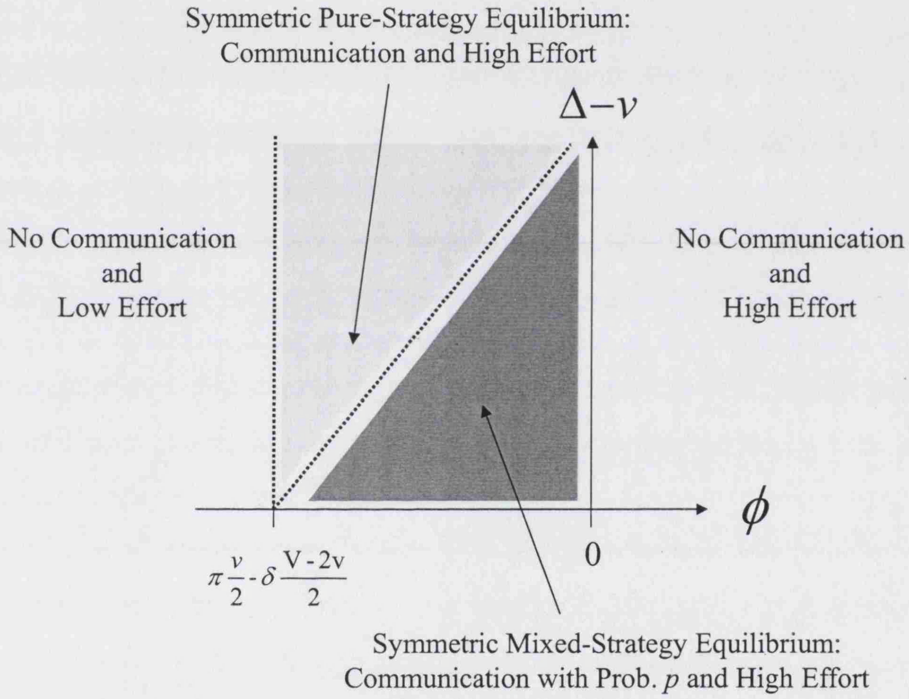

FIGURE 4.2. Equilibria as described by Proposition 1 and Proposition 2.

4.4 Conclusions

This paper analyses a model in which two agents form a partnership, exert effort to acquire research knowledge and have the ability for an *ex ante* commitment to share research knowledge at a later stage. Such communication does not affect the surplus that can be achieved within the partnership but merely alters the agents' bargaining power. As a result, communication by an agent reduces her *ex post* bargaining power and thus her *ex ante* expected surplus.

The main result of this paper is communication may nevertheless be *ex ante* optimal as it can serve as an incentive device for the other agent in the partnership. Communication to her increases her effort incentives and, if these are sufficiently important, the *size* of the surplus created in the partnership increases sufficiently to outweigh the communicating agent's loss of *share* of surplus. This will if there are increasing returns to possessing more information and if communication is not too perfect.

4.A Foundations for the Payoff Structure

In this appendix, we provide a more detailed model of final returns that fulfills Assumptions 1 and 2.

Suppose that final research success at $t = 2$ is obtained if two separate interim research tasks, α and β, are completed successfully. Each agent is equipped with the same initial ability to complete each task, $\underline{h}$. At $t = 1$, each agent can acquire additional knowledge h in one of these tasks. We assume that $h > 2\underline{h}$, i.e. that initial knowledge is low relative to the additional knowledge that can be subsequently acquired.

Without loss of generality, assume that agent A (agent B) can acquire additional know-how that is relevant to task α (task β) only. However, at $t = 1$, agents can communicate their expertise in their respective task to each other. Denote by H_i^α and H_i^β the post-communication knowledge of agent i in tasks α and β, respectively.

When agents decide to continue the partnership at $t = 1$, a given task is pursued by an agent with the highest post-communication knowledge of it. If $H_A^j = H_B^j$, then one agent is chosen at random. If agents separate, each agent pursues both tasks to his best ability.

Final research is worth P to a sole innovator. If there are multiple inventors, Bertrand-competition ensures that profits are zero.

A partnership at $t = 1$ will be worth

$$
\begin{aligned}
V &:= (\underline{h} + h)^2 P && \text{if both agents have acquired additional knowledge} \\
v &:= (\underline{h} + h)\, \underline{h} P && \text{if one agent has acquired additional knowledge} \\
v_0 &:= \underline{h}^2 P && \text{if neither agent has acquired additional knowledge}
\end{aligned}
$$

These payoffs conform to assumption 1 except that $v_0 > 0$. The assumption that $h > 2\underline{h}$ ensures that $V > 2v$.

When agents separate at = 1, agent A has expected returns of $H_A^\alpha H_A^\beta \left(1 - H_B^\alpha H_B^\beta\right) P$. These that our reduced-form expected return definitions of section 4.2 are given by

$$
\begin{array}{cc}
(\underline{h}+h)^2\left(1-(\underline{h}+h)\,\underline{h}\right)P = w^A(2h,h) & (\underline{h}+h)\,\underline{h}\left(1-(\underline{h}+h)^2\right)P = w^A(h,2h) \\
(\underline{h}+h)\,\underline{h}\left(1-(\underline{h}+h)\,\underline{h}\right)P = w^A(h,h) & (\underline{h}+h)\,\underline{h}\left(1-\underline{h}^2\right)P = w^A(h,0) \\
\underline{h}^2\left(1-\underline{h}^2\right)P = w^A(0,0) & \underline{h}^2\left(1-(\underline{h}+h)\,\underline{h}\right)P = w^A(0,h)
\end{array}
$$

Payoffs for agent B can be derived analogously. The agent's payoffs are increasing in her own knowledge and decreasing in the other agents knowledge and thus fulfill the conditions of assumption 2, with the exception that $w^A(0,h) > 0$ and $w^A(0,0) > 0$.

Suppose that the final research stage requires a cost $C = \underline{h}^2 P$. It follows that $v_0 = 0$ and that an agent without additional knowledge at either task will not enter final research, i.e. $w^A(0,h) - C < 0$ and $w^A(0,0) - C < 0$. As a result, assumptions 1 and 2 are entirely fulfilled by these payoffs.

Finally, note that

$$\Delta := w^A(2h,h) - w^B(h,2h) = (\underline{h}+h)\,hP$$

so that $V > \Delta$ and $\Delta > v$, thus fulfilling assumption 4 as well as exhibiting increasing returns to knowledge.

4.B Relaxing Assumption 4

Suppose that Assumption 4 did not hold. In particular, assume that agents did not continue partnerships at $t = 1$ at all. Then agent $A's$ expected return at $t = 0$ can be written as

$$
\begin{aligned}
R^A = \theta^B \pi^B w^A(h,h) + \theta^A \left[v + \pi^A \left(w^A(h,h) - w^A(h,0)\right)\right] \\
+ \theta^A \theta^B [w^A(h,h) - w(h,0) + \pi^B \left(w^A(2h,h) - 2w^A(h,h)\right) \\
+ \pi^A \left(w^A(h,2h) - w^A(h,h) - w^A(h,0)\right)] \\
+ \theta^A \theta^B \pi^A \pi^B \left[\left(w^A(2h,2h) - w^A(h,2h)\right) - \left(w^A(2h,h) - w^A(h,h)\right)\right].
\end{aligned}
$$

As a result, the incremental return to effort of agent A is given by

$$
\begin{aligned}
&\delta \left[v + \theta^B \left(w^A(h,h) - v\right)\right] + \delta \pi^B \theta^B \left(w^A(2h,h) - 2w^A(h,h)\right) \\
&+\delta \pi^A \left(w^A(h,h) - w^A(h,0)\right) + \left(w^A(h,2h) - w^A(h,h) - w^A(h,0)\right) \\
&+\delta \pi^A \pi^B \theta^B \left[\left(w^A(2h,2h) - w^A(h,2h)\right) - \left(w^A(2h,h) - w^A(h,h)\right)\right].
\end{aligned}
$$

The structure of this incremental return is very similar to that of (4.5). For the mechanism of Proposition 2 to work, we require that communication by the other agent has a positive effect on the incremental return to effort and that effort choices by the two agents are strategic complements.

Communication from A to B has a positive effect on $B's$ incremental return to effort absent $B's$ communication if

$$
w^B(h,2h) - w^B(h,h) > w^B(h,h)
$$

This condition requires that there are increasing returns to knowledge in the sense that the incremental effect of owning both agents' knowledge over just that of one agent is greater than the incremental from knowing one agent's knowledge rather than none.

Given that B does not communicate, higher effort by B reduces $A's$ incremental return to effort by

$$\delta\left(v - w\left(h, h\right)\right) > 0.$$

Hence, effort choices are not strategic complements absent mutual communication. If B were to communicate as well as increase her effort, however, $A's$ effort incentives are increased if

$$w^A\left(2h, h\right) - w^A\left(h, h\right) > -\frac{\pi}{(1-\pi)} w^A\left(h, h\right) + \frac{\pi}{1-\pi}\left(w^A\left(2h, h\right) - w^A\left(2h, 2h\right)\right) + \frac{v - w^A\left(h, h\right)}{\pi\left(1-\pi\right)}.$$

This condition holds when there are sufficiently strong increasing returns to communication. If this is the case, the mechanism described in Proposition 2 holds in a setting in which a partnership is never continued at $t = 1$.

References

ADMATI, A. R., AND P. PFLEIDERER (1994): "Robust Financial Contracting and the Role of Venture Capitalists," *The Journal of Finance*, 44(2), 371–402.

ANAND, B. N., AND A. GALETOVIC (2000a): "Information, Non-Excludability and Financial Market Structure," *Journal of Business*, 73(3), 357–402.

——— (2000b): "Weak Property Rights and Hold-Up in R&D," *Journal of Economics and Management Strategy*, 9(4), 615–642.

ANTON, J. J., AND D. A. YAO (1994): "Expropriation and Inventions: Appropriable Rents in the Absence of Property Rights," *American Economic Review*, 84, 190–209.

——— (1995): "Start-Ups, Spin-Offs and Internal Projects," *Journal of Law, Economics and Organization*, 11, 362–378.

——— (2002): "The Sale of Intellectual Property: Strategic Disclosure, Property Rights and Incomplete Contracts," *Review of Economic Studies*, 69(3), 513–531.

——— (2004): "Little Patents and Big Secrets: Managing Intellectual Property," *RAND Journal of Economics*, 35(1), 1–22.

ARPING, S. (2002): "Cannibalization and Incentives in Venture Financing," *mimeo*, University of Lausanne.

BACCARA, M., AND R. RAZIN (2004): "From Thought to Practice: Appropriation and Endogenous Market Structure with Imperfect Intellectual Property Rights," *mimeo*, NYU.

BARTLETT, J. W. (1995): *Equity Finance: Venture Capital, Buyouts, Restructurings and Reorganizations.* John Wiley and Sons, New York.

BESEN, S. M., AND L. J. RASKIND (1991): "An Introduction to the Law and Economics of Intellectual Property," *Journal of Economic Perspectives*, 5, 3–27.

BHATTACHARYA, S., AND G. CHIESA (1995): "Proprietary Information, Financial Intermediation and Research Incentives," *Journal of Financial Intermediation*, 4, 328–357.

BHATTACHARYA, S., J. GLAZER, AND D. E. SAPPINGTON (1992): "Licensing and the Sharing of Knowledge in Research Joint Ventures," *Journal of Economic Theory*, 56, 43–69.

BHATTACHARYA, S., AND R. J. RITTER (1983): "Innovation and Communication: Signalling with Partial Disclosure," *Review of Economic Studies*, 50, 331–346.

BIAIS, B., AND E. PEROTTI (2003): "Entrepreneurs and New Ideas," *mimeo*, University of Toulouse.

BINMORE, K., A. RUBINSTEIN, AND A. WOLINSKY (1986): "The Nash Bargaining Solution in Economic Modelling," *RAND Journal of Economics*, 17, 176–188.

BLOCK, Z., AND I. MACMILLAN (1993): *Corporate Venturing: Creating Businesses Within the Firm.* Harvard Business School Press, Boston, Mass.

BROOKS, J. (1999): "Fund-Raising and Investor Relations," in *The Venture Capital Handbook*, ed. by W. D. Bygrave, M. Hay, and J. B. Peeters, pp. 95–117. Prentice Hall, London, UK.

BRUSCO, S., AND F. PANUNZI (forthcoming): "Reallocation of Corporate Resources and Managerial Incentives in Internal Capital Markets," *European Economic Review.*

BYGRAVE, W. D. (1999): "Returns on Venture Capital," in *The Venture Capital Handbook*, ed. by W. D. Bygrave, M. Hay, and J. B. Peeters, pp. 307–342, London, UK. Prentice Hall.

BYGRAVE, W. D., AND J. A. TIMMONS (1992): *Venture Capital at the Crossroads.* Harvard Business School Press, Cambridge, Mass.

CASAMATTA, C. (2003): "Financing and Advising: Optimal Financial Contracts with Venture Capitalists," *Journal of Finance*, 48(5), 2059–2086.

CASSIMAN, B., D. PEREZ-CASTRILLO, AND R. VEUGELERS (2002): "Endogeneizing Know-How Flows Through the Nature of R&D Investments," *International Journal of Industrial Organization*, 20, 775–799.

CESTONE, G., AND L. WHITE (2003): "Anti-Competitive Financial Contracting: The Design of Financial Claims," *Journal of Finance*, 58(5), 2109–42.

CHESBROUGH, H. (2000): "Making Sense of Corporate Venture Capital," *Harvard Business Review*, 80(3).

Combs, K. L. (1993): "The Role of Information Sharing in Cooperative Research and Development," *International Journal of Industrial Organization*, 11, 535–551.

Cornelli, F., and O. Yosha (2003): "Stage Financing and the Role of Convertible Debt," *Review of Economic Studies*, 70(1), 1–32.

D'Aspremont, C., S. Bhattacharya, and L.-A. Gerard-Varet (2000): "Bargaining and Sharing Innovative Knowledge," *Review of Economic Studies*, 67(2), 255–271.

D'Aspremont, C., and A. Jacquemin (1988): "Cooperative and Noncooperative R&D in Duopoly with Spillovers," *American Economic Review*, 78, 1133–1137.

De Bondt, R. (1996): "Spillovers and Innovative Activities," *International Journal of Industrial Organization*, 15, 1–28.

Dewatripont, M., and E. Maskin (1995): "Credit and Efficiency in Centralised and Decentralised Economies," *The Review of Economic Studies*, 62, 541–555.

Egli, D., S. Ongena, and D. C. Smith (2004): "On the Sequencing of Projects, Reputation Building, and Relationship Finance," *mimeo*, Tilburg University.

Gallini, N. T., and B. D. Wright (1990): "Technology Transfer under Asymmetric Information," *RAND Journal of Economics*, 21, 147–160.

Gandal, N., and S. Scotchmer (1993): "Coordinating Research Through Research Joint Ventures," *Journal of Public Economics*, 51, 173–193.

Gans, J. S., D. H. Hsu, and S. Stern (2002): "When Does Start-Up Innovation Spur the Gale of Creative Destruction?," *RAND Journal of Economics*, 33(4), 571–586.

GANS, J. S., AND S. STERN (2000): "Incumbency and R&D Incentives: Licensing the Gale of Destruction," *Journal of Economics and Management Strategy*, 9(4), 485–511.

GARICANO, L. (2000): "Hierarchies and the Organization of Knowledge in Production," *Journal of Political Economy*, 108(5), 874–904.

GOMPERS, P., AND J. LERNER (2000): *The Venture Capital Cycle.* MIT Press, Cambridge, Mass.

GOMPERS, P. A. (1995): "Optimal Investment, Monitoring and the Staging of Venture Capital," *Journal of Finance*, 50(5), 1461–1489.

HANSMANN, H. (1996): *The Ownership of Enterprise.* Harvard University Press, Cambridge, MA.

HELLMANN, T. (1998): "The Allocation of Control Rights in Venture Capital Contracts," *The Rand Journal of Economics*, 29, 57–76.

HELLMANN, T., AND M. PURI (2000): "The Interaction Between Product Market and Financial Strategy: The Role of Venture Capital," *Review of Financial Studies*, 13(4), 959–84.

——— (2002): "Venture Capital and the Professionalization of Start-Up Firms: Empirical Evidence," *Journal of Finance*, 57(1), 169–97.

INDERST, R., AND C. LAUX (2001): "Incentives in Capital Markets: Capital Constraints, Competition and Investment Opportunities," *mimeo*, LSE.

INDERST, R., AND H. MUELLER (2004): "The Effect of Capital Market Characteristicson the Value of Start-Up Firms," *Journal of Financial Economics*, 72(2), 319–56.

JANSEN, J. (2001): "Strategic Information Revelation and Revenue Sharing in an R&D Race," *Wissenschaftszentrum Berlin Discussion Paper IV 01-06.*

KANNIAINEN, V., AND C. KEUSCHNIGG (2003): "The Optimal Portfolio of Start-Up Firms in Venture Capital Finance," *Journal of Corporate Finance*, 9, 521–534.

KAPLAN, S. N., AND P. STROMBERG (forthcoming): "Characteristics, Contracts and Actions: Evidence from Venture Capitalist Analyses," *Journal of Finance.*

KATZ, M. L. (1986): "An Analysis of Cooperative Research and Development," *RAND Journal of Economics*, 17, 527–544.

KORTUM, S., AND J. LERNER (1998): "Stronger Protection or Technological Revolution: What is Behind the Recent Surge in Patenting?," *Carnegie-Rochester Conference Series on Public Policy*, 48, 247–304.

LANJOUW, J. O., AND M. SCHANKERMAN (2001): "Characteristics of Competition: A Window on Patent Litigation," *RAND Journal of Economics*, 32(1), 129–151.

——— (2004): "Enforcing Intellectual Property Rights," *Journal of Law and Economics*, pp. 45–74.

LAZEAR, E. P., AND S. ROSEN (1981): "Rank-Order Tournaments and Optimum Labor Contracts," *Journal of Political Economy*, 89(5), 841–864.

LERNER, J. (1994): "The Importance of Patent Scope: An Empirical Analysis," *RAND Journal of Economics*, 25, 319–333.

LERNER, J., AND A. SCHOAR (2004): "The Illiquidity Puzzle: Theory and Evidence from Private Equity," *Journal of Financial Economics*, 72, 3–40.

——— (forthcoming): "Does Legal Enforcement Affect Financial Transactions?: The Contractual Channel in Private Equity," *Quarterly Journal of Economics.*

McLaughlin, K. J. (1988): "Aspects of Tournament Models: A Survey," *Research in Labor Economics*, 9, 225–256.

Morrison, A. D., and L. White (forthcoming): "Crises and Capital Requirements in Banking," *American Economic Review.*

Navaretti, G. B., P. Bussoli, G. V. Graevenitz, and D. Ulph (1999): "Information Sharing, Research Co-Ordination and Membership of Research Joint Ventures," *mimeo*, University College London.

Neher, D. V. (1999): "Staged Financing: An Agency Perspective," *Review of Economic Studies*, 66, 255–274.

Pastor, M., and J. Sandonis (2002): "Research Joint Ventures Vs. Cross Licensing Agreements: An Agency Approach," *International Journal of Industrial Organization*, 20, 215–249.

Perez-Castrillo, J. D., and J. Sandonis (1996): "Disclosure of Know-How in Research Joint Ventures," *International Journal of Industrial Organization*, 15, 51–75.

Prendergast, C. (1999): "The Provision of Incentives in Firms," *Journal of Economic Literature*, 37(1), 7–63.

Quindlen, R. (2000): *Confessions of a Venture Capitalist.* Warner Books, New York.

Rajan, R. G. (1992): "Insiders and Outsiders: The Choice Between Informed and Arm's-Length Debt," *Journal of Finance*, 47(4), 1367–1400.

Repullo, R., and J. Suarez (2004): "Venture Capital Finance: A Security Design Approach," *Review of Finance*, 8, 75–108.

Rosenkranz, S., and P. W. Schmitz (1999): "Know-How Disclosure and Incomplete Contracts," *Economics Letters*, 63, 181–185.

Rosenkranz, S., and P. W. Schmitz (2003): "Optimal Allocation of Ownership Rights in Dynamic R&D Alliances," *Games and Economic Behavior*, 43(1), 153–173.

Rotemberg, J. J., and G. Saloner (1994): "Benefits of Narrow Business Strategies," *American Economic Review*, 84(5), 1330–1349.

Sahlman, W. (1990): "The Structure and Governance of Venture Capital Organizations," *Journal of Financial Economics*, 27, 473–521.

Schankermann, M., and S. Scotchmer (2001): "Damages and Injunctions in Protecting Intellectual Property," *RAND Journal of Economics*, 32(1), 199–220.

Schmidt, K. M. (2003): "Convertible Securities and Venture Capital Finance," *Journal of Finance*, 58(3), 1139–1166.

Senge, P. (1994): *The Fifth Discipline.* Currency, New York.

Severinov, S. (2001): "On Information Sharing and Incentives in R&D," *RAND Journal of Economics*, 32(3), 542–564.

Silver, A. D. (1985): *Venture Capital: The Complete Guide for Investors.* John Wiley and Sons, New York.

Stein, J. C. (2002): "Information Production and Capital Allocation: Decentralised versus Hierarchical Firms," *Journal of Finance*, 57(5), 1891–1921.

UEDA, M. (2004): "Bank versus Venture Capital: Project Evaluation, Screening and Expropriation," *Journal of Finance*, 59(2), 601–21.

ULPH, D., AND Y. KATSOULACOS (1999): "Endogenous Knowledge Flows and the Welfare Evaluation of Research Joint Ventures," *mimeo*, University College London.