University of Siena
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Three essays in innovation, competition and contracts

This dissertation is submitted in partial fulfillment for the degree of Doctor of Philosophy

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Acknowledgements

I wish to thank my supervisor, Luigi Luini, for his guidance, personal and professional support.
During my years at the University of Siena I benefited from the interaction with professor Ugo Pagano, Andrea Battinelli and Samuel Bowles, who helped me to expand my skills and improve my thinking
A relevant part of this project was developed and consolidated during my visiting periods at the economic departments of the Erasmus University of Rotterdam, and the Autonomous University of Barcelona. I am in debt with my hosts Robert Dur and David Pérez Castrillo for offering me the chance to be part of such challenging and stimulating environments. In particular, I am grateful to David for his precious insights and help which greatly influenced my work.
Writing this thesis implied to enter into a difficult learning path. Natalie Oprea gave me some of her strength, wisdom and cleverness, helping me to believe in my work and my purposes. She was determinant in the development of the ideas contained in the thesis, but her contribution goes far beyond it.
The main objective of a PhD thesis should be solving problems (at least partially!). I want to thank all those people who had an impact on my analytical thinking. In particular, Antonio Busciglio, who is a scientist, a very close friend and an outstanding 'problem solver'. He helped me countless times to clarify apparently tangled facts and set order in my thoughts. I thank Emanuele D'Osualdo, a brilliant mix of mathematical rigour and music talent. Thanks for all the times we played jazz together.
I owe a great debt of gratitude to Francesco Ricci. He has shown me a different approach to life, which was crucial to complete this work and will be necessary in the next years.
Finally, I wish to thank my family for constant support; and, in particular, my mother, who never doubted I would make it.

Contents

Introduction

The main aim of this work is to study market interactions and internal organization of firms, in an integrated framework. The issue is not new to economic inquiry [1]. However, it has been largely disregarded by further developments in industrial organization that attributed the origin of all distortions to market power. Therefore, the need of building and improving new theoretical approaches has recently re-emerged. In this regard, Legros and Newman (2014) explain the benefits of merging industrial economics with contract theory, creating a new set-up, which they call 'Organizational Industrial Organization':

> *«Nascent efforts at developing an OIO already suggest that market conditions or industrial structure matter for organizational design. At the same time, organizational design will affect the productivity of firms. Hence eventually the total industry output, the quality of products and information about this quality for consumers. Organizational design matters for consumers, hence for IO»* (p.4)

Put simply, competition plays a role in outlining the internal structure of firms. On the other way around, internal organization shapes firm's external outcomes, affecting market equilibrium.

The topic is not only of academic interest but has many practical consequences. In fact, a competition policy may have sometimes unexpected outcomes in terms of market equilibrium. This is due to the existing connection between the changes in internal firms' management and market consequences.

One classic example is innovation. While gaining market shares over competitors has an undoubted incentive effect on innovation, excessive competitive pressure may backfire, pushing down profits in such a way that negatively affects R&D investment. In order to gain a better understanding of the phenomenon, the scholarship moved

[1] See Williamson (1973), Williamson (1975) and Simon (1991)

from market interactions to an in-depth investigation of those internal processes that drive investment behaviour. The analysis focuses on the contractual relationships between firms' owners (shareholders) and individuals in charge (CEOs), showing that competitive pressure, and market characteristics in general, affect the structure and the power of incentives.

To see that the relation works in both directions (from organization to market, from market to organization) consider this further example. In general, both product and labour market competition induce firms to use high-powered incentives. This is made either to increase performance or attract talented employees. However, relying too much on performance-based incentives can increase short-termism, over-focus on measurable activities, or flatten intrinsic motivation. These drawbacks may finally decrease social welfare, as highlighted by some recent works (Benabou and Tirole, 2003; Bénabou and Tirole, 2016; Bowles and Polania-Reyes, 2012).

The present work tries to make further steps in this direction. The three chapters, although in different ways, disentangle the linkage between **competition**, organization **behaviour** and **structure**. In particular, we examine two cases when changes in the internal organization are *strategic* responses to different market conditions (chapters 1 and 3); and, one case in which, given a fixed competitive environment, heterogeneous organizations lead to different market outcomes (chapter 2).

In chapter 1 we analyse the effect of product market competition on the innovative behaviour of firms. Unlike previous IO models, we consider two types of R&D projects: (i) *exploitation* - the improvement of an existing technology; and (ii) *exploration* - the development of brand-new techniques. In competitive environments, firms design the project, other than deciding the investment amount. Moving further from the 'traditional' treatment, we consider firms as agency relationships (Jensen and Meckling, 1976), where information is released ex-post. Under this setup, the process of innovation involves agents who may, privately and ex-post, observe the relevant piece of information needed to make appropriate decisions, but whose preferences may not be aligned with those of the company they belong. As an example we explicitly consider corporate scientists, who prefer more experimentation, since it allows to publish results in scientific journals and keep links with the academic community. As a consequence, they have to be induced to make optimal choices (from firm's perspective) through an appropriate *incentive system*. Contract incompleteness plays an important role, as performance measures on exploration is imperfect and only dichotomous evaluations - *success* vs *failure* - can be made.

Our results show that as competitive pressure increases, firms shift from exploration to exploitation. Since firms' shareholders or general directors lack the relevant knowledge to figure out whether new scientific insights can be translated into profitable technology, decision authority is delegated to scientists. However, asymmetric information together with personal preferences raise incentive costs. Consequently, when competition is severe the use of incentives for truthful revelation becomes too costly, inducing firms to focus on exploitation. It is interesting to notice that in the analysed framework, intrinsic motivation is harmful for decentralized organizations. When failure puts firm's survival in danger, motivation emphasizes the costs of control. In these cases, a centralized authority is preferred as it overrides individual's motivation.

R&D behaviour is also the main subject of the second chapter. Here we analyse an investment game between state-owned and privately-owned firms. The R&D project can be more or less risky, depending whether it is basic or applied oriented. Under mild conditions, the Nash equilibrium of the game is one in which state firms always undertake a basic-oriented project. Private firms, instead, choose a risky project when competition is low, and shift to a safe one otherwise. Hence we document a direct effect of government enterprises on the market outcomes in terms of risky R&D, for different competition environment. Moreover, another interesting finding is the existence of a *negative* indirect effect on private firm's risk taking behaviour. The analysis of mixed strategies equilibrium reveals that, in highly competitive environments, private entrepreneurs are less likely to initiate risky projects when compared to fully-private markets.

In the last chapter, we investigate the effect of labour market competition on authority allocation between the board of directors and the manager. The latter is hired to design and run an innovative project. If, however, the project is of poor quality (from a financial point of view), a status-quo project should be undertaken instead. Organizations may decide between implementing a centralized (board's authority) or a decentralized (managers' authority) structure. In the last case, managers can use discretion to pursue their own interests, starting a large project to increase their reputation, even if it is financially unfavourable. However, we point out that, even when formal authority is retained, managers can still spend time and effort to *influence* members of the board to gain control over decisions. This activity is generally detrimental to organizations, since it distorts information and causes loss of efficiency due to an unproductive use of effort. Our results show that, when contracting occurs in isolation, centralization generally dominates delegation. Firms, by retaining authority and anticipating information distortion from influencing behaviour, make more profits even if they invest on average less. On the opposite side, when the comparison is extended to labour markets, results are reversed. In this case, decentralization emerges as an equilibrium, which is unique when competition is high. In fact, assuming that managers vary in their abilities, firms can strategically allocate authority to talented individuals and endow them with large amounts of capital on tap, as an attracting tool. This is unfeasible under centralization, where investment decisions are made ex-post and it is not possible to reach any ex-ante agreement.

Chapter 1

Competition and the exploration-exploitation trade-off

1.1 Introduction

Economic organizations face every day the necessity to innovate. Changes of internal practices, organizational structure, production technology or product quality are important to survive competition. As a consequence, firms invest a considerable amount of resources in purchasing expensive laboratory equipment, running tests and/or building prototypes. Perhaps more importantly, they also design appropriate mechanisms that make possible the creation of valuable innovation.

As pointed out by Chandler (1990), the link between internal structure (preferences, corporate culture and incentive systems) and external environment (market structure, competitive pressure, consumer preferences) plays a crucial role in shaping firm's competitive behaviour.

When it comes to innovation, a key element that organizations take into account is the *risk*. If riskier innovative paths can potentially lead to greater outcomes, higher levels of volatility can backfire in competitive environments. The organization theorist James March pointed out the existence of a similar trade-off within the firms' boundaries. According to him, organizations in general face a tension between *exploitation* of tested and well-known methods and the *exploration* of untested alternatives (March, 1991).

From a theoretical perspective, we can notice that the vast majority of Industrial Organization models consider firms as *black boxes*[1]. The trade-off between safe and risky activities can then be solved through a straightforward comparison of strategies with different mean-variance mix. However, while it is somehow reasonable to consider small firms as unitary blocks, it is not realistic when they are medium/large sized. In latter cases, delegation is ubiquitous and division managers have specific competencies and preferences.

This paper departs from the standard treatment by studying an oligopoly model where firms are considered as agency relations. Specifically, they involve contractual relationships between shareholders - who own the capital; and scientists - who own information. Our primary goal here is to examine optimal effort allocation between alternative research projects in a framework characterized by *ex-post* information asymmetry and moral hazard, where firms compete in the product market. To this aim, we construct a model of incentive provision under multi-tasking and market competition.

We consider the fact that in-house research is defined *in itinere*, constantly updat-

[1]This point is discussed in great detail in Legros and Newman (2014)

ing its plan according to new external solicitations which, if properly developed, can trigger innovative success and profits. The scientist's unique expertise makes him able to observe the relevant information and decide effort allocation consequently.

Once the scientist observes an external opportunity - for instance a scientific discovery with commercial potential - he decides whether to develop it or not. If no opportunity is profitably explored, then the effort is allocated to less innovative projects. Adopting James March's terminology, the former and latter project represent, respectively, exploration and exploitation.

We assume that scientists are intrinsically motivated. They derive non-material benefits from such activities leading to valuable scientific discoveries and receive recognition from the academic community (Merton, 1979; Dasgupta and David, 1994). The sources of such motivation can be *personal* - reputation, taste for challenges - or *social* - the willingness to contribute to science, or the advancement of society. Empirical evidence shows that intrinsic motivation drives scientist's career choices (Stern, 2004; Roach and Sauermann, 2010), and affects the organizational features of those industries where science can create value (Sauermann and Cohen, 2010).

In this regard, other scholars have already observed that corporate scientists often maintain links with the scientific community (Dasgupta and David, 1994; Lacetera and Zirulia, 2012). On the other hand, corporations are interested in transforming science in cutting-edge technology. However, they can do it by setting internal rules, mechanisms, and corporate culture to improve *absorptive capacity* (Cohen and Levinthal, 1990; Zahra and George, 2002; Markiewicz, 2004) [2].

The main question of this work is how organizational structure, incentives and market competition are connected in shaping R&D decisions. In other worlds, we ask whether competitive pressure plays any role in shaping the form of traded contracts and the *design* of research and development activities.

In our framework firms adopt a decentralized structure to take advantage of scientists' information. In this case they offer a compensation package in the form of task-based incentives. As we assume that effort is unobservable, incentives must be based on some output metrics. Such scheme is easily implementable for exploitation activities. Indeed, the assumption that all their possible outcomes are easily verifiable and contractible is plausible, since they involve the development of an existing technology. On the opposite side, the technological potential of exploration can be hardly

[2] The term was defined by Cohen and Levinthal (1990) for the first time as « [...] the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends is critical to its innovative capabilities. Its a function of the firms prior knowledge. »

specified in advance.

Imperfect observability and asymmetric information both increase the total provision of incentives. This makes, in expected terms, delegation more costly than centralization. This is in line with the research findings of Aghion and Tirole (1997), which point out that, in decentralized organizations, inducing focus on one project rather than another increases agency costs.

The second part of our analysis embed previous results in a market context, to study the role of competitive pressure.

In general, competition has a twofold effect (Raith, 2003; Schmutzler, 2010). First it decreases profits: an increase in firms number, products' degree of substitution raise the demand elasticity and reduces the margins (called *scale of wealth effect*). The second concurrent effect is rewarding the most efficient firm: competition shifts market shares from inefficient firms to the efficient ones (*business-stealing effect*).

We find that, assuming that in the equilibrium all firms delegate innovation decisions, competition monotonically spurs exploration. Devoting more time experimenting new ideas rises up the chance of discovering better technology or products, thus maximizing business-stealing. In addition, as profits fall with competition, firms have more incentives to rely on risky projects.

However, as wealth effect becomes severe, some firms have an incentive to shift to centralization, focusing on exploitative innovation. Deviating from the rival's strategy, firms increase the likelihood of monopoly, as duopoly profits are unappealing due to harsh competition and agency costs.

Therefore, delegation is not an equilibrium strategy in markets characterized by high levels of competition. It supports the conclusion that effort in exploration reaches its maximum for intermediate levels of competition.

The paper proposes a framework that can interpret and understand how different approaches to R&D (applied *versus* basic, risk *versus* safe) are mirrored in the internal structure of organizations. Often, in fact, the idea of profit maximizing firms investing in "ready to use" research on one side, and academic organizations or government labs pursuing scientific knowledge on the other side, has been pervasive. Yet, the history of scientific discovery tells us a different story: firms, other than institutional actors, had a central role in many cases[3]. In practice, there is no clear divide between science and technology (Nelson, 2004), since for a relevant part science is a valuable input to

[3] For instance, Bardeen, Brattain and Shockley, three scientists working at Bell Labs, the research unit of AT&T, won the Nobel Prize for the discovery of the *transistor* technology.

technological change and in some fields scientific research has a direct impact on commercialization of new products (as in biotechnology and pharmaceutical industries). For instance, few works (Cockburn et al., 1999; Henderson and Cockburn, 2006) have analysed how companies balance incentives for basic and applied research inside their laboratories.

The paper unfolds as follows. In the second section we present the relevant literature. Section three describes the model and discusses the main features. Optimal contracts are studied in the forth section. In the fifth section we underline the main results regarding the effect of competition on research choices. Next, we elaborate on further extensions based on brand-new experimental results. Finally we conclude.

1.2 Related Literature

Our work connects two strands of literature, both analysing incentives innovation. There is a long-standing tradition is Industrial Organization, which analyse the impact of market structure on innovation. However, we specifically refer to a subset of this literature that focuses on the issue within an agency framework.

Many of these studies (Hart, 1983; Scharfstein, 1988; Schmidt, 1997; Graziano and Parigi, 1998; Raith, 2003) focus on the link between competition and efficiency-enhancing effort under delegation and moral hazard. It is worth to mention the work of Schmidt (1997), which assumes that competitive pressure increases the probability of bankruptcy. The threat of liquidation, with the costs involved in losing the job, makes managers more prone to exert effort on efficiency. Raith (2003), like the previous paper, finds a positive relation between competition and effort. The work highlights the interplay between the *scale effect* (i.e. the negative impact on profits) and the *business stealing effect* (i.e. the shift of wealth from the least to the most efficient firm). Under the hypothesis of endogenous entry, the scale effect is negligible (as profits are zero), hence a decrease in product differentiation will raise business stealing. Firms will then avoid losing market shares increasing incentives for effort provision.

All the mentioned studies, however, neither make any behavioural assumption on agents (i.e. intrinsic motivation), nor differentiate among activities. From this perspective, Lacetera and Zirulia (2012) develop a more comprehensive approach. The authors analyse R&D investments in a differentiated Cournot model where corporate scientists carry out basic and applied research. Outcomes from basic research produce non-appropriable externalities since scientific results are shared with the community.

Assuming that corporate scientists have a preference for science, they find that incentives and competition have a U-shape relation. The authors introduce a framework close to the one we develop here. However, there are some relevant differences. We consider contract incompleteness and risk, to explain the tension between the two activities. Moreover, our model underlines the important of agency costs on organization and innovation decisions, since we include moral hazard and task substitutability together with asymmetric (ex-post) information. The cited paper, instead, departs from these issues, distinguishing the different types of research on the capacity of motivating scientists effort and create knowledge spillovers.

On a parallel ground, we refer to a relatively new strand of literature that takes an in-depth look at contracts for scientists (Lazear, 1997; Gambardella and Panico, 2009; Banal-Estañol and Macho-Stadler, 2010; Manso, 2011; Hellmann and Thiele, 2011; Gambardella et al., 2015). This literature applies contract theory to the management of knowledge workers, taking into account intrinsic motivation, contract imperfections, imperfect appropriability, uncertainty, and information. Banal-Estañol and Macho-Stadler (2010) study contract design for researchers, analysing the trade-off between research and development for further commercialization. According to their framework, scientists devote less time to research (i) when they are less (intrinsically) motivated, (ii) benefits from commercialization increase or (iii) commercialization costs decrease. Bearing in mind that basic research is riskier than applied, they find that the introduction of remuneration for commercial inventions induces researcher to act as a risk-lover with respect to the quality of results. Furthermore, it induces them to spend more time in research and be more reluctant in going to the market. On opposite, when basic projects are less likely to be commercialized, the introduction of remuneration causes a shift towards more applied projects. Our paper heavily builds on Hellmann and Thiele (2011). The authors study an agency model of effort allocation between standard and innovative tasks, where agents have superior information. In their framework, the innovative task is non-contractible, making bonus payments unfeasible. The moral hazard problem is, hence, solved by making knowledge-workers *residual claimants*, granting them a share of the surplus generated by innovation, together with a standard payment if the standard task is successfully accomplished.

The core result is that pay-for-performance incentives may not be appropriate for stimulating innovation. Manso (2011) shows that motivating innovation requires substantial tolerance for early failure and reward in the long run. It implies that bonus payments that are not appropriately designed can force scientists (or workers in general) to relate too much to standard tasks. Similarly, in our paper the principal has to balance incentives in order to maximize effort provision on applied research, while allowing agents to make some basic, scientific-driven research if profitable. On the contrary, in those cases where basic research cannot be fruitfully exploited for commercial purposes, incentives are needed to keep all the effort on applied research. Therefore, and differently from Manso (2011), we adopt a multitasking modelling for the choice between the two research approaches.

1.3 A bare-boned model

The competitive environment and firms' strategy We consider a Cournot model with a linear demand function and imperfect substitute goods:

$$p_i = z - q_i - \theta q_j$$

with $i, j \in \{1, 2\}$ and $i \neq j$. Parameter $z > 0$ measures market size, while $\theta \in [0, 1]$ represents the degree of substitutability, such that for $\theta = 0$ ($\theta = 1$) products have maximal (minimal) differentiation[4]. In this context θ is used as a proxy for competitive pressure (a detailed explanation of the features of a competition parameter can be found in the appendix)

Firm i's marginal costs of production are

$$k_i = k - e_i$$

where e_i represents the impact of innovation on technology.

The Cournot-Nash equilibrium of output and profit is equal to:

$$q_i^C = \frac{z-k}{2+\theta} + \frac{2e_i - \theta e_j}{4-\theta^2}$$
$$\pi_i^C(e_i, e_j) = (q_i^C)^2$$

[4]As pointed out by Zanchettin (2006), the demand function used here derives from a modified version of Singh and Vives (1984), where individuals have utility quadratic in quantity and linear in the numeraire M:

$$U = z(q_1 + q_2) - (1/2)(q_1^2 + q_2^2 + 2\theta q_1 q_2) + M$$

Solving the consumer's optimization problem leads to a system of linear equations:

$$q_i = \frac{(1-\theta)z - p_i + \theta p_j}{1-\theta^2}$$

whose solution returns the demand function in the model

R&D Strategies Before competing on the market, firms decide to enhance efficiency, hiring a corporate scientist (or a CTO) to start an R&D project. Project decisions are made ex-post, after the contracting stage, when relevant information is released. Following Hellmann and Thiele (2011), we model research as a multitasking activity *a la* Holmstrom and Milgrom (1991).

Consider two types of research projects, indexed by $\tau \in \{A, B\}$. Project A - exploitation - determines an efficiency level correspondent to the development effort $e_i \in \{0, 1\}$, with probability $\Pr(e_i) = e_i$. Development costs are certain and equal to $c > 0$.

Project B - exploration - determines an efficiency level equal to $x \geq 0$ if successfully developed. The variable x measures the potential values of **external knowledge** and it is common to the entire market (for instance a scientific discovery which can be suitable converted into a new technology). We assume that x is a random variable with CDF $F(x) = \int_{-\infty}^{z} f(x)dx$ within the support $[0, X]$ such that $f^{'}(x) \leq 0$ and $\mathbb{E}(x) \geq 1$. For the sake of reality, we assume in this case that knowledge is successfully converted into a technology that is worth x with probability $p \in (0, 1)$. Hence, exploration is ex-post riskier than exploitation.

Information and incentives The realization of x is unobservable by the principal. In this context the concern is then inducing the optimal allocation of 1 unit of effort, into τ. We crucially assume that projects A and B are different from a contractual perspective. In particular:

Assumption 1 1. *project A's outcomes are ex-ante* contractible*, therefore a performance payment can be used to motivate effort;*

2. *project B's outcomes cannot be contracted in advance. Contract incompleteness limits the employers' capacity to drive agents' effort allocation through the use of power incentives.*

In particular, only an imperfect measure of success is feasible in case of exploration, given an ex-ante parameter fixed by the principal. Specifically, let $\hat{x} \subset x$ being a threshold level defined ex-ante, and $S \in \{0, 1\}$ a binary signal that informs the principal that the project has succeeded (failed) if $S = 1$ ($S = 0$) according to the following probability structure: $\Pr(S = 1|x > \hat{x}) = \Pr(S = 0|x \leq \hat{x}) = \sigma$ such that $\sigma \in (1/2, 1)$. Hence an *incentive menu* is used, providing monetary transfers w_i and β_i, respectively, for task A and B.

Moreover, we assume that scientists are driven by *intrinsic motivation* to work on exploration projects. Hence, when $\tau = B$ they obtain a personal benefit of $\gamma > 0$.

Timing The game unfolds as it follows:

- $t = 0$: each firm makes a take-it-or-leave-it offer to researchers;
- $t = 1$: $\tilde{x}$ is privately observed by researchers, and effort choices are made;
- $t = 2$: firms compete on the product market;
- $t = 3$: profits are realized and wages are paid.

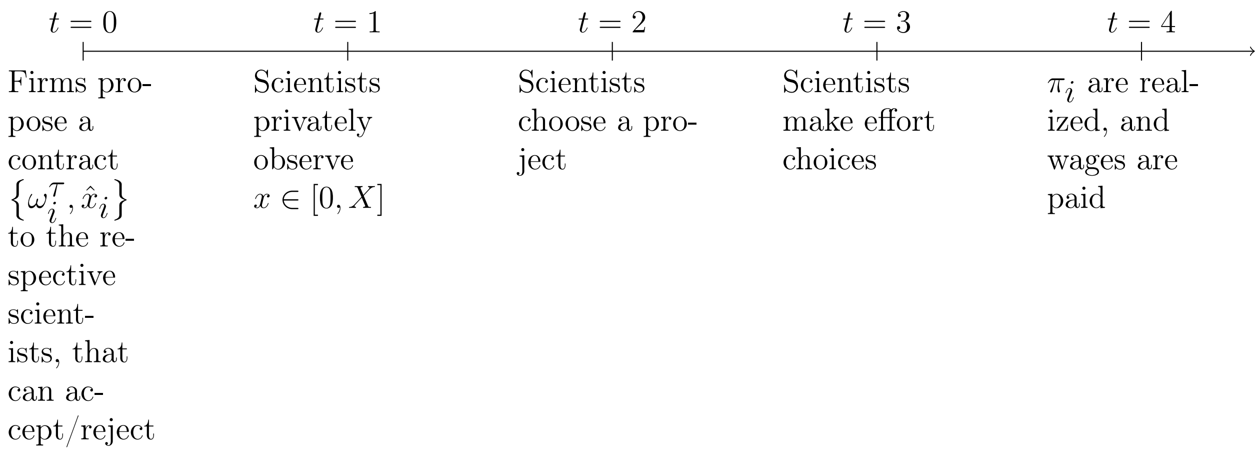


Figure 1.1: Timeline

1.4 Optimal incentives and firms' strategies

In this section we study the contractual characteristics of the market. Recall that information is privately observed by the scientist, hence it is not possible to write a contract which binds the prescription of a task to a specific value x. If firms want to exploit agents' superior knowledge they have to grant them all the decision authority over τ. Hence, firms take a decentralized structure. However, it can be the case that firms do not need to use subordinates knowledge. In this case, all the decisions are centralized and we assume that only exploitation is performed. In this vein, firm's i strategy space is described as $S_i \in \{D, C\}$, where D and C denote, respectively, *delegation* and *centralization*.

If firms do not want to use scientists' superior knowledge, we assume they can only focus on exploitation. Hence they do not need to induce truthful revelation, as the *exploit-or-explore* dilemma is ruled out[5]. To induce effort on exploitation the incentive compatibility constraint implies $w_i - c \geq 0$. Therefore, the following lemma holds:

Lemma 1 *Suppose firm i plays C. The incentive menu ω_i collapses into a singleton, where the unique incentive is $w_i = c$ and no exploration is performed.*

The optimization problem is more complex when $S_i = D$. In this case firm i offers a payment structure $\omega_i(\tau) = \{w_i, \text{if } \tau = A; \beta_i, \text{if } \tau = B\}$ and defines a threshold $\hat{x}_i$ in order to maximize:

$$\max_{\omega_i, \hat{x}_i} \mathbb{E}_x \left[\pi_i(e_i, e_j, \theta) - \omega_i \middle| \hat{x}_i \right]$$

subject to:

- the participation constraint

$$\mathbb{E}_x \left[U_i(e_i, \omega_i(\tau)) | \hat{x}_i \right] \geq 0 \tag{PC}$$

- incentive compatibility and truthful revelation constraints (in reduced form):

$$e_i, \tau \in \arg\max_{e_i', \tau'} U_i \left[e_i, \omega_i(\tau) | \hat{x}_i \right] \tag{ICC}$$

- the limited liability constraint:

$$\omega_i \geq 0 \tag{LL}$$

In our setting, diverging preferences over $\tilde{x}$ generate internal conflict. While corporate scientists would like in principle (in the absence of monetary incentives) to spend their time on exploration (getting the benefit γ), firms do it only when it is financially worthwhile. Since ex-post information is unverifiable, any ex-ante binding

[5]The possibility to manage authority, even when information is asymmetric, can be justified in many ways. Without modelling it explicitly, we assume that firms can keep authority by either providing or not, the complementary assets necessary to run the projects (these can be physical assets, like lab equipments, or time).

contract over effort allocation is unfeasible. For this reason, firms offer an incentive scheme in the form of a *menu* of choice-based payments. In particular, given the task $\tau \in \{A, B\}$, a menu is a function $\omega(\tau)$ such that $\omega(A) = w$ and $\omega(B) = \beta$.

The incentive compatibility constraint (ICC) serves the multiple purposes of inducing (i) maximal and (ii) optimal allocation of effort e_i, given $\hat{x} \subseteq x$. Regarding the first objective, given the menu, and according to the imperfect measure of success, the constraint is specified as:

$$U(e_i = 1|\omega_i, \tau) \geq U(e_i = 0|\omega_i, \tau)$$

that, for any $\tau \in \{A, B\}$, splits into:

$$w_i - c \geq 0$$
$$\beta_i(1 - \sigma + p(2\sigma - 1)) + \gamma - c \geq \beta(1 - \sigma_2) + \gamma$$

Optimal effort allocation is, instead, obtained, by balancing incentives in order to induce the choice of A when $x \leq \hat{x}$ and B when $x > \hat{x}$. In other words, given $\hat{x}_i$ and $x^{'}, x^{''} \subseteq x$, a menu of optimal incentives $\omega^*(\tau)$ satisfies the following set of $|\tau|$ inequalities[6]:

$$U(x^{'}, A|\omega^*(A)) \geq U(x^{'}, B|\omega^*(A))$$
$$U(x^{''}, A|\omega^*(B)) \leq U(x^{''}, B|\omega^*(B))$$

Once the contractual strategies are defined, we are now able to describe the optimal incentives in the following proposition:

Proposition 1 *Assume that firm i plays strategy D, then:*

(i) it offers the following strategy-contingent incentives:

$$w_i^* = c\frac{p(2\sigma - 1) + 1 - \sigma}{p(2\sigma - 1)}$$
$$\beta_i^* = c\frac{1}{p(2\sigma - 1)}$$

[6]We assume that, if indifferent, agents act according to firm's best interest.

(ii) it designs an optimal threshold $\hat{x}(S_j)$*, implicitly given by:*

$$p\pi_i(\hat{x}_i, e_j) + (1-p)\pi_i(0, e_j) = \pi_i(1, e_j) - \gamma \tag{1.1}$$

for any $e_j \in [0, x]$ *and* $S_j \in \{D, C\}$

Define the expected incentive costs under S_i as $\mathbb{C}(S_i)$, such that

$$\mathbb{C}(D) = F(\hat{x}_i)w_i^* + \left[1 - F(\hat{x}_i)\right]\Big(p\sigma + (1-p)(1-\sigma)\Big)\beta_i^*$$

and $\mathbb{C}(C)$ is defined as in lemma 1.

According to proposition 1 the following is true:

Lemma 2 *The strategy-dependent expected costs are*

$$\begin{aligned}\mathbb{C}(D) &= c + c\frac{1-\sigma}{p(2\sigma - 1)} + \gamma F(\hat{x}_i) \\ \mathbb{C}(C) &= c \end{aligned} \tag{1.2}$$

such that $\mathbb{C}(D) \geq \mathbb{C}(C)$

Notice that information precision plays an important role in shaping incentives. As a matter of fact, usually the more precise is information, the lower rent earn *high-type* agents (those who observe $x > \hat{x}$). In our framework, payments are one part of the contract. In addition, principals define, referring to some metrics, the cut-off value $\hat{x}_i$, according to which success is evaluated.

The above discussion is summarized in the following lemma:

Lemma 3 *For any* $e_j \in [0, X]$*, (i) optimal incentives are decreasing in information quality,* σ*, and development probability of success, p; (ii) threshold* $\hat{x}(S_j)$ *is decreasing in motivation* γ*.*

1.5 R&D choices and competition

In this section we analyse firms' R&D strategies, in a competitive environment. The determination of optimal incentives served to define innovation costs endogenously. We now examine the choice of project in a strategic context. Given the strategy space, described in previous section, $\mathcal{S}_i = \{D, E\}$, we look for Nash equilibrium $(s_i, s_j) \in$

$S \times S$, for $i, j \in (1, 2)$ and $i \neq j$, under a given competitive regime. In this regard, firms play a simultaneous game of organization structure, which we call *innovation game*, depicted in figure 1.2a .

The analysis below is carried under the following assumption:

Assumption 2 *z=k*

which states that the market size is not greater than marginal costs of production. The assumption implies that if firms do not update their technology they do not stay in the market. Hence, in our framework, firms are forced to innovate, while their choice is restricted to the type of innovation they want to pursue.

The results presented in this section assume that γ is normalized to zero. The normalization helped us to simplify calculations, without influencing the conclusions regarding competition and exploration behaviour. The impact of motivation on delegation costs are additional to incentive costs.

Lemma 4 *(i) If both firms play $S_i = S_j = D$, the threshold value is given by:*

$$\hat{x}_i(D, D) = \sqrt{\frac{1}{p^2 4 + p(1-p)(2+\theta)^2}}$$

(ii) If firms play asymmetrically, $S_i = D$ and $S_j = C$, the threshold has shape:

$$\hat{x}_i(D, C) = \frac{\theta}{2} + \frac{2-\theta}{2\sqrt{p}}$$

(iii) for each $\theta \in \Theta$ and $p \in (1/2, 2)$, $\hat{x}(D, D)$ is greater than $\hat{x}(D, C)$, both are decreasing in θ but the impact is smoother on $\hat{x}(D, D)$.

When the decentralized structure is widespread in the market, the cut-off value, based on which firms reward exploration, is lower than the alternative. In the second case ($S_i \neq S_j$), in fact, exploration is undertaken to the extent it brings the technological leadership of the enterprise to the market. For instance, when goods are perfect substitutes, $\hat{x}(D, C)$ is greater than 1 - which corresponds to the efficiency gain from exploitative innovation -; while the same condition does not need to be satisfied from $\hat{x}(D, D)$. This can be easily proved by evaluating the threshold for $\theta = 1$ and verifying that the inequalities

$$\frac{1}{2} + \frac{1}{\sqrt{p}} > 1 > \frac{1}{\sqrt{4p^2 + 9(1-p)p}} \tag{1.3}$$

hold whenever $p \in (1/2, 1)$. As a consequence, exploration is more likely to be observed in markets characterized by decentralization.

Part (iii) of lemma states that competitive pressure (in the form of product substitutability) rise up the time devoted to exploitation, pushing down the threshold. The explanation is the following. Managers fix a lower threshold $\hat{x}$ as an incentive for scientists to perform more often exploration. This is mainly due to maximise the *business-stealing* effect, that is the marginal increase of profits given by the shift of demand from the least to the most efficient firm. In our framework it has shape:

$$\frac{\partial}{\partial \theta} \mathbb{E}_x \left[\pi(x, 0) | \hat{x}\right] > 0$$

The effect can be easily observed. If $S_i = D$ is played, exploration is undertaken whenever $x > \hat{x}$. The effect occurs for a successful firm, provided that the rival has failed. Computing the partial derivative with respect to θ:

$$\frac{\partial}{\partial \theta} \int_{\hat{x}}^{X} p(1-p)\pi(x,0) f(x) dx = -p(1-p)\pi(\hat{x},0) f(\hat{x}) \frac{\partial \hat{x}}{\partial \theta} + \int_{\hat{x}}^{X} p(1-p) \frac{\partial \pi(x,0)}{\partial \theta} f(x) dx \tag{1.4}$$

Since the $\pi(x, 0)$ represents the monopoly profit, it follows that $\frac{\partial \pi(x,0)}{\partial \theta} = 0$. Hence the second element in the l.h.s. of equation (1.4) is equal to zero. As a result, the business-stealing effect is positive if and only if $\frac{\partial \hat{x}}{\partial \theta} < 0$. Therefore:

$$\frac{\partial \hat{x}}{\partial \theta} < 0 \implies \frac{\partial}{\partial \theta} \left[1 - F(\hat{x})\right] = -f(\hat{x}) \frac{\partial \hat{x}}{\partial \theta} > 0$$

The result, however, is partial, since there is no guarantee that (D, D) is an equilibrium of the game. A sufficient condition for such an equilibrium to exist is that *net* profits under (D, D) are greater than under (C, D). This may not be the case, provided that:

1. delegation involves additional agency costs;

2. the impact of competition on expected profits depends on S_i for all $i \in \{1, 2\}$

Point 1 underlines that using incentives to induce ex-post choice of project involves some further costs, given by moral hazard and preferences misalignment. Specifically, if $\mathbb{C}(S_i)$ represents the incentive costs when firm i undertakes the strategy S_i, the cost differential $\mathbb{C}(D) - \mathbb{C}(C)$ are given by:

$$\underbrace{\left[\frac{1-\sigma}{p(2\sigma-1)}\right]c}_{\text{Moral hazard}} + \underbrace{F(\hat{x})\gamma}_{\text{Diverging preferences}}$$

The analysis is performed evaluating the function $\Psi(\theta) = \Pi(D, D) - \Pi(C, D)$, where $\Pi(\cdot)$ represents the net profit. In other words, $\Psi(\theta)$ is the individual incentive to play $\{D\}$ as an equilibrium. The formal analysis, conducted in the appendix, reveals that:

Proposition 2 *a threshold level* θ^{th} *exists, such that* $\Psi(\theta)$ *is positive for* $\theta \leq \theta^{th}$*, and negative otherwise.*

The strategy-choice vector $(S_i, S_j) = (D, D)$ arises as an equilibrium for θ not greater of a certain threshold, provided that c is sufficiently small and X is sufficiently large. The main point here is that competition weakens the individual incentives of playing (D, D) is it if too high.

Why? We have already seen that when one firm chooses D, a marginal increase in competitive pressure moves down the threshold. Moreover, by lemma 8, we know that the latter is more reactive under (D, C) than (D, D):

$$|\frac{d\hat{x}(C, D)}{d\theta}| > |\frac{d\hat{x}(D, D)}{d\theta}|$$

This means that "D-players" adapt faster to raise of competition when the other play C. Interestingly, this has a positive indirect effect on rivals' payoff. In fact, as $\hat{x}(D, C)$ goes down the probability of getting positive profits goes up. As a consequence, profits under (C, D) decrease slower than (D, D), such that $\pi(C, D) > \pi(D, D)$ for some $\theta' > \theta^{th}$. Firms have an incentive to deviate from D, hence (D, D) is not an equilibrium any more.

The proposition also establishes that the equilibrium threshold $\hat{x}^E$ is a piecewise-defined function, such that:

$$\hat{x}^E = \begin{cases} \hat{x}(D, D) & \text{for } \theta < \theta^{th} \\ 0 & \text{otherwise} \end{cases}$$

Therefore, since $\hat{x}(\cdot)$ is decreasing and concave, it reaches a minimum at θ^{th-}. As $\hat{x}$

is inversely related to $1 - F(\hat{x})$, we can conclude that the probability of undertaking exploration is maximized when competition is lower than θ^{th} (see figure 1.2 below).

1.6 Internal organization, intrinsic motivation and X-efficiency

One important point of our analysis is that individuals derive intrinsic motivation from being involved in exploration activities. For a scientist, running a lab and having the possibility get involved in large research projects, keeping links with the scientific community, seems to be a powerful incentive. We take it into account by simply letting the agent to get a non-material benefit γ if he works on exploration.

The interaction between intrinsic motives and material as well as non-material rewards, is at the core of modern analysis of knowledge-workers' productivity[7]. Gambardella et al. (2015), for instance, discuss the use of *autonomy* within firms as a non-monetary incentive. They argue that when employers have no interest in the project (what they call *low employee-project fit*), their motivation will be low and so their effort. Granting a certain degree of autonomy enhances intrinsic motivation, although it may lead to a project design not perfectly suited for commercial purposes. In order to account for both individual motivation and organization's outcomes, firms offer a mix of intrinsic and extrinsic incentives (respectively, autonomy and wages).

However, such intrinsic benefit is by no means related to effort in development (it is activated when $\tau = B$, effort does no need to be positive). In our interpretation, motivation mainly derives from the creation of scientific outputs or working on a personal project. Hence we neglect the possibility that scientists may get any immaterial reward from developing new products or production techniques[8].

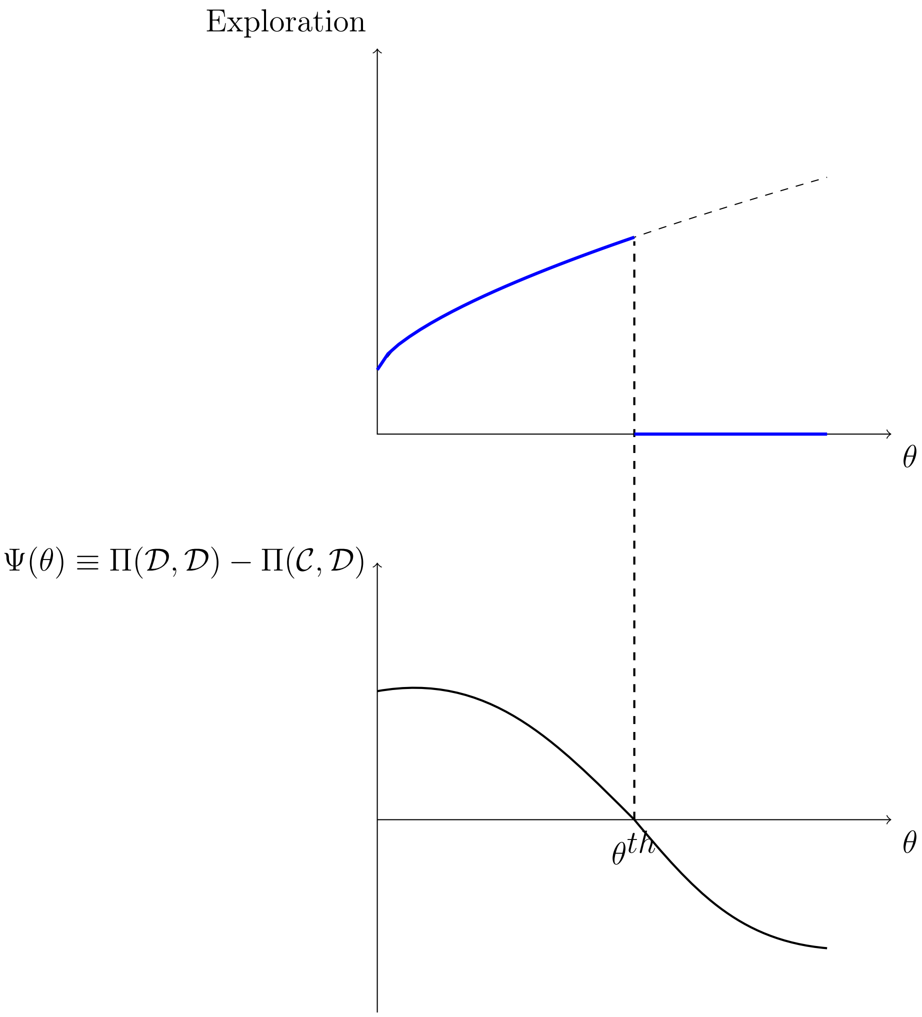
We study project design and motivation in a similar fashion. However, in our framework scientists pick one project from a bundle. In Gambardella et al.'s article emerges that motivation is fundamentally beneficial at the individual, as well as, organization level. In fact, in *single-task* settings, it decreases moral hazard costs. On the contrary, in our case, it raises the costs of indirect control. Contrasting results from multitasking, which characterize innovative processes in our framework. Whenever firms, need to induce optimal allocation of resources among multiple activities, incentives must be

[7]See Drucker (1999) for a detailed discussion on the subject

[8]This is very similar to the distinction between *pure* and *impure* altruism (see Andreoni, 1990; Francois, 2000)

Firm i \ Firm j	Delegation ($\mathcal{D}$)	Centralization ($\mathcal{C}$)
Delegation ($\mathcal{D}$)	$\Pi(\mathcal{D},\mathcal{D})$	$\Pi(\mathcal{D},\mathcal{C})$
Centralization ($\mathcal{C}$)	$\Pi(\mathcal{C},\mathcal{D})$	$\Pi(\mathcal{C},\mathcal{C})$

(a) The innovation game



(b) Competition and ex-ante probability of exploration.

Figure 1.2: Equilibrium (D, D) exists only for $\theta < \theta^{th}$. Therefore, time of exploration is maximized at θ^{th-}.

provided to compensate any *motivational loss.* [9].

To see this in formally, notice that to induce $\tau = A$ whenever $x < \hat{x}$, the principal set the compensation $w \geq \beta(1-\sigma) + \gamma$. The reward has to be proportional to γ and such that the agent would not be better off by picking $\tau = B$ and staying idle (which in our model simply means choosing exploration and deciding not to provide high effort in development).

Moreover, firms can stem scientists' discretion through $\hat{x}$, other than incentives. As previously explained, it identifies, with some noise, a contractible measure of success in exploration. By setting a low threshold the agent undertake type-B projects more often, as the probability of getting the bonus increased.

We already noticed in section 1.4 that $\hat{x}$ is inversely related to γ: more motivation induces the principal to optimally diminishing the threshold in order to reduce incentive costs. Hence the global effect of a marginal increase of intrinsic motivation on expected costs depends whether it gets compensated by a reduction in the exploration cut-off value. Formally:

$$\frac{d\mathbb{C}(D)}{d\gamma} = f(\hat{x})\frac{d\hat{x}}{d\gamma}\gamma + F(\hat{x}) > 0 \iff \left| f(\hat{x})\frac{d\hat{x}}{d\gamma}\gamma \right| < |F(\hat{x})|$$

Therefore, incentive costs are increasing in motivation whenever scientists have no interest in the development of the project.

On the contrary, in all those cases in which intrinsic motivation depends on effort, incentives are low. This situation is common in sectors where research produces intermediate goods. Firms can apply a flat incentive system, appropriating part of the scientists' motivational rents. This is consistent with the empirical results in Stern (2004). Analysing a dataset of job offers to postdoctoral biologists, the author finds that scientists working for science-oriented firms receive inferior wages. The analysis is conducted controlling for perceived ability, hence the wage differential can be interpreted as the amount scientists "pay" for working in an academic-like settings.

[9]This contrasts with Osterloh and Frey (2000) claiming that intrinsic motivation helps to solve the multiple-task problem. However their argument relates to those tasks which cannot be included inside a contract. On an opposite side, other papers have studied cases where high level of intrinsic motivation backfires. For instance, it increases adverse selection costs (Barigozzi and Burani, 2016), or worsen disagreement in organizations (Van den Steen, 2005).

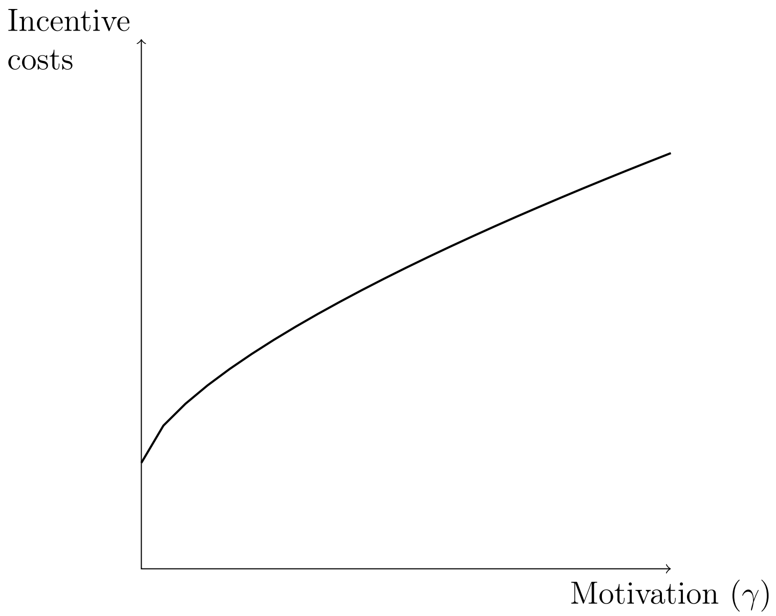


Figure 1.3: The figure depicts the effect of intrinsic motivation on incentive costs.

1.7 Competition, monetary incentives and creativity: a discussion

The main question of the paper, is backed by a long-standing discussion among scholars and policy experts. Originally, the debate was conducted in order to discriminate between the *Arrowian* hypothesis, which maintained that a competitive environment is more appropriate to stimulate the development of new products or technologies (Arrow, 1962); and the *Schumpeterian* hypothesis which claims the opposite (Schumpeter, 1942). As a sort of reconciliation of both views, Aghion et al. (2005) find that between competition and innovation elapses a U-inverted relation. Therefore, it finds a non-monotonic view of competitive pressure as a stimulus for firm-driven technological innovation.

However, previous empirical and theoretical works have mainly concentrated on the "quantitative" aspects of firms' innovation. Our work , instead, is interested in the "qualitative" characteristics of corporate research.

Proposition 9 establishes the conditions under which of competition has a positive impact on exploration. According to our analysis competition enhances exploration, but may not provide the right incentives to choose it in equilibrium. We conclude that exploration effort reaches a peak for an intermediate degree of competitive pressure.

Only in this case, in fact, firms can profitably bear the costs of delegation. A recent paper by Gross (2016), which has questioned whether competition boosts creativity, supports our finding. The author analysed a sample of 122 logo design contests, where participants were asked to create a logo for a sponsor, taking part into a winner-take-it-all competition. The paper measures the creativity level of participants through an automated system, which analyses the level of (dis)similarity of the newly created logos from already existent ones. When participants make the first submission they also receive an interim evaluation on a 1 to 5 scale. Based on it participants decide whether to continue the competition, making further modifications to logos, or abandon. Competition is then measured in terms of probability of winning the tournament inferred from ratings (for instance a 5 stars logo is ten times more likely to win than a 4 stars). Results show that participants' experimentation reaches its peak at moderate levels of competition, in particular when only two 5 stars participants race. Conversely, for low (no competitors) or very high (many competitors) levels, tweaking the former image is observed more likely.

The mentioned study is an example on how much experimental methods contribute to the theoretical method in the field. For instance, our work poses no interaction between the bonus β and worker's creativity. Nonetheless, recent behavioural approaches have questioned whether traditional incentives affect somehow human innovativeness. Can monetary rewards be used to increase creativity? Unfortunately this question has no definite answer, but a series of recent experiments have made important steps towards a better comprehension of the phenomenon.

Erat and Gneezy (2016) study the effect of piece-rate and competitive bonus on performances in creative tasks[10]. The experiment finds that providing piece-rate has a general positive effect, when compared to the baseline (no-incentive). However, competitive incentives have, instead, a *negative* impact on creativity. According to their interpretation, results depend from the fact that, after the introduction of competitive incentives, individuals spend on average less time on the task (if compared to both baseline and piece-rate groups). This seems to confirm the findings of a previous study by Ariely et al. (2009), which documents a detrimental psychological effect caused by competitive pressure.

A closely related issue is whether a *carrot and stick* approach succeeds in motivating individual's creativity. Ederer and Manso (2013) verify in an experimental setting that tolerance for early failures and reward for later success, outperform traditional power incentives in inducing innovative behaviour. When innovation involves a multi-step,

[10] They measured it by submitting a rebus to participants and evaluating the solutions

trial-and-error process, piece-rate incentives induce individuals to favour tested, hence safer, methods. If, instead, they get a fixed wage in the early stages and a premium in case of final success, they tend to explore more.

These empirical evidences motivate further developments of our framework. For instance, we can investigate how equilibrium incentives change if we drop the limited liability assumption. In other words, if we let firms to punish unsuccessful exploration, how would competition condition the punishment/reward ratio, and how would it affect innovative behaviour?

Moreover, when outcomes are not easily measurable (as it is for innovative tasks), firms may want to use *relative* incentives. In a competitive context, like our oligopoly model, experimental findings suggest that it may endanger firms' innovativeness, given the mentioned psychological effect.

1.8 Conclusion

Our model is an attempt to explain how competition affects the management of innovation inside firms. In this respect we bring together a recent strand of literature that explores the organizational features, incentives and motivation enabling creativity and innovation (in this paper referred as exploration), and the more traditional industrial organization modelling.

Our main finding is that investment in exploration are enhanced for intermediate levels of competition. When the competition is stiff they prefer to focus on exploitation. However, if competitive pressure is moderate, firms delegate the choice to scientists who own the relevant subjective knowledge. On one hand, delegation causes some efficiency losses, given by moral hazard and hidden information costs. On the other, competition's scale effect reduces profits, thus making delegation unfeasible. But even, in this case, incentives and effort may fall down rapidly with competition, because of the negative impact of firms' and scientists' incongruence of preferences.

1.9 Appendix

1.9.1 The theoretical construction of competition parameter

We study a general oligopoly market, with two risk-neutral firms. Each firm $i \in \{1,2\}$ is associated with an efficiency level e_i, while the market is characterized by a certain level of competition [11] $\theta \in \Theta \equiv [\underline{\theta}, \overline{\theta}]$, such that $0 \leq \underline{\theta} < \overline{\theta} < \infty$.

A profit function $\pi_i(e_i, e_j, \theta)$ is then defined as $\pi : [0, e]^2 \times \Theta \rightarrow \mathbb{R}$ which satisfies the following properties:

(p1) $\pi(\cdot)$ is non-decreasing (non-increasing) in its' first (second) argument: $\pi_1 \geq 0$ and $\pi_2 \leq 0$

(p2) $\pi(e_H, e_H, \theta) > \pi(e_L, e_L, \theta)$, if $e_H > e_L$.

The effect of competition on profits is summarized by the following conditions:

(c1) profits $\pi(\cdot)$ are decreasing in θ;

(c2) $\frac{\partial^2 \pi_i(\cdot)}{\partial e_i \partial \theta} > 0$ and $\frac{\partial^2 \pi_i(\cdot)}{\partial e_j \partial \theta} < 0$;

(c3) profit differentials $\pi(e_H, e_j, \theta) - \pi(e_L, e_j, \theta)$ are increasing in θ.

Assumption **c1** states a common tenet in market analysis: competition decreases margins and individual demand, so that it decreases profits. The importance of a cost reduction is stated in assumption **c2**: increasing efficiency has a positive direct effect on own profit, and a negative indirect effect on competitor's profit. Assumption **c3**, finally, postulates a **redistribution effect** boosted by competition: as θ increases greater portions of wealth move from the least to the most efficient firm. Schmutzler (2013) shows that the listed characteristics make our treatment quite general, as they apply to the majority of industrial organization models (differentiated Cournot, Bertrand, spatial models, etc.)

[11] For instance, assuming a linear inverse demand function $p_i = \mathcal{A} - q_i - \theta q_j$, where $\mathcal{A}$ represents the demand size while θ the degree of product differentiation, the latter is also often assumed as a competition measure

1.9.2 Proof of proposition 1

According to the model specifications, we split the constraints described in section 1.4 into the following set of inequalities:

$$\int_0^{\hat{x}} w_i f(x)dx + \int_{\hat{x}}^{X} \left[\beta_i \left(1-\sigma+p(2\sigma-1)\right)+\gamma\right] f(x)dx - c \geq 0 \tag{PC}$$

$$w_i - c \geq 0 \tag{IC$_1$}$$

$$\beta_i \left(1-\sigma+p(2\sigma-1)\right)+\gamma-c \geq \beta_i(1-\sigma)+\gamma-c \tag{IC$_2$}$$

$$\beta_i \left(1-\sigma+p(2\sigma-1)\right)+\gamma-c \geq w_i - c \tag{Tr$_1$}$$

$$w_i - c \geq \beta_i(1-\sigma)+\gamma-c \tag{Tr$_2$}$$

$$w_i \geq 0 \tag{LL$_1$}$$

$$\beta_i \geq 0 \tag{LL$_2$}$$

where: (i) (PC) ensures participation, assuming zero outside option; (ii) constraints (IC_1) and (IC_2) imply that at the optimum agents always exert maximal effort in development; (iii) inequalities (TR_1) and (TR_2) satisfy optimal project choice - ensuring an effort allocation equilibrium $(0,1)$ if $x \geq \hat{x}$ and $(1,0)$ otherwise; (iv) (LL_1) and (LL_2) protect the agent from being charged any fee in case of failure.

Instead of taking a Lagrangian approach, we study binding constraints by inspection. First notice that the (TR_1) and (TR_2) can never be both binding. This would, in fact, imply $\beta_i \left(1-\sigma+p(2\sigma-1)\right) = \beta_i \left(1-\sigma\right)$, which is impossible. Moreover, as w_i and β_i are used together for inducing optimal choice of task given $\hat{x}_i$, it follows that they can never be zero. Thus, the limited liability constraints do not bind.

By the standard argument (TR_2) is not binding, such that:

$$w_i = \beta(1-\sigma)+\gamma \tag{1.5}$$

Moreover, solving (IC_2) as an equality, makes shirking non-optimal for the agent, leading to the bonus:

$$\beta_i^* = c\frac{1}{p(2\sigma-1)} \tag{1.6}$$

Substituting equation (1.6) into (1.5), leads to optimal transfers as stated in proposition 1. Finally, it is possible to check that at (w_i^*, β_i^*) both (IC) and (TR_1) are both redundant.

Under the condition stated above, the expected profit can be written as:

$$\Pi_i = \int_0^{\hat{x}} \left[\pi_i(1,1) - w\right] f(x)dx +$$
$$+ \int_{\hat{x}}^{X} \left[p\pi_i(x, e_j) + (1-p)\pi_i(0, e_j) - \beta_i\left(1 - \sigma + p(2\sigma - 1)\right)\right] f(x)dx$$

Assuming that $\tilde{x}$ is uniformly distributed and computing the first order condition

$$\frac{\partial \Pi_i}{\partial \hat{x}_i} = \pi(1,1)f(\hat{x}) - p\pi(\hat{x},1)f(\hat{x}) - (1-p)\pi(0,1)f(\hat{x}) - \gamma = 0 \qquad (1.7)$$

1.9.3 Proof of lemma 8

The optimal threshold $\hat{x}$ depends on the rival's strategy. If $S_j = D$ then $\hat{x}(D,D)$ is the solution of:

$$p^2\left(\frac{\hat{x}}{2+\theta}\right)^2 + p(1-p)\left(\frac{\hat{x}}{2}\right)^2 = \frac{1}{(2-\theta)^2} - \gamma$$

that it:

$$\hat{x}(D,D) = \sqrt{\frac{1-\gamma(2+\theta)^2}{4p^2 + p(1-p)(2+\theta)^2}} \qquad (1.8)$$

Instead, whenever $S_j = C$ the optimal threshold solves:

$$p\left(\frac{2\hat{x}-\theta}{4-\theta^2}\right)^2 = \frac{1}{(2+\theta)^2} - \gamma$$

which leads to:

$$\hat{x}(D,C) = \frac{2-\theta}{2}\sqrt{\frac{1-\gamma(2+\theta)^2}{p}} + \frac{\theta}{2} \qquad (1.9)$$

Lemma 5 *(1) $\hat{x}(D,D)$ and $\hat{x}(D,C)$ are decreasing in θ; (2) $\hat{x}(D,D) < \hat{x}(D,C)$, $\forall\theta \in \Theta$*

Proof. Part (1) is proved by simply computing the partial derivatives with respect to θ:

$$\frac{\partial \hat{x}(D,D)}{\partial \theta} = -\frac{1}{2}\sqrt{\frac{1-\gamma(2+\theta)^2}{4p^2+p(1-p)(2+\theta)^2}}\frac{\gamma(2+\theta)4p^2+p(1-p)(2+\theta)^2}{\left(p^2+p(1-p)(2+\theta)^2\right)^2} < 0$$

$$\frac{\partial \hat{x}(D,C)}{\partial \theta} = -\frac{1}{2}\sqrt{\frac{1-\gamma(2+\theta)^2}{p}} - \frac{2-\theta}{2}\left(\frac{1-\gamma(2+\theta)^2}{p}\right)^{-1/2}\gamma(2+\theta)+\frac{1}{2} < 0$$

Part (2) is proved by contradiction:

$$\hat{x}(D,D) \geq \hat{x}(D,C)$$

Assuming $\theta = 0$, the former inequality implies:

$$\sqrt{\frac{1}{4p}} > \frac{1}{\sqrt{p}} \tag{1.10}$$

which is impossible.

Moreover, by further inspection we can check[12] that $|\frac{\partial \hat{x}(D,D)}{\partial \theta}| > |\frac{\partial \hat{x}(D,C)}{\partial \theta}|$. As a result $\hat{x}(D,D)$ decreases faster than $\hat{x}(D,C)$, such that $\hat{x}(D,D) < \hat{x}(D,C)$ for all $\theta \in [0,1]$.

[12]Since the calculations are somewhat cumbersome they were omitted here but can be provided upon request.

1.9.4 Proof of proposition 2

Substituting $\hat{x} \in \{\hat{x}_L, \hat{x}_H\}$ into the profit function and considering all the possible combinations of strategies, we obtain the following list of pay-off:

$$\begin{aligned}
\Pi(D,D) =& \int_0^{\hat{x}_L} \left(\frac{1}{2+\theta}\right)^2 f(x)dx + \int_{\hat{x}_L}^{X} \left\{p^2\left(\frac{x}{2+\theta}\right)^2 + p(1-p)\left(\frac{x}{2}\right)^2\right\} f(x)dx \\
& - c - \left[\frac{1-\sigma}{p(2\sigma-1)} - F(\hat{x}_L)\right] c - F(\hat{x}_L)\gamma \\
\Pi(C,D) =& \int_0^{\hat{x}_H} \left(\frac{1}{2+\theta}\right)^2 f(x)dx + \int_{\hat{x}_H}^{X} \left\{p\left(\frac{2-\theta x}{4-\theta^2}\right)^2 + (1-p)\left(\frac{1}{2}\right)^2\right\} f(x)dx \\
& - c \\
\Pi(D,C) =& \int_0^{\hat{x}_H} \left(\frac{1}{2+\theta}\right)^2 f(x)dx + \int_{\hat{x}_H}^{X} p\left(\frac{2x-\theta}{4-\theta^2}\right)^2 f(x)dx \\
& - c - \left[\frac{1-\sigma}{p(2\sigma-1)} - F(\hat{x}_L)\right] c - F(\hat{x}_L)\gamma \\
\Pi(C,C) =& \left(\frac{1}{2+\theta}\right)^2 - c
\end{aligned}$$

Given the symmetry of the game a sufficient condition for an equilibrium in (D,D) is

$$\Pi(D,D) > \Pi(C,D) \tag{1.11}$$

The statement is proved in two steps.

Step 1 In step 1 we check that $\pi(D,D) - \mathbb{C}(D) > \pi(C,D) - \mathbb{C}(C)$ for $\theta = 0$. Substituting $\theta = 0$ into expected profits defined above, and equations (1.9) and (1.8) we obtain:

$$\begin{aligned}
\mathbb{E}_x\left[\pi(C,D)|\theta=0\right] &= \int_0^{\hat{x}_H} \frac{1}{4} f(x)dx + \int_{x_H}^{X} (1-p)\frac{1}{4} f(x)dx \\
\mathbb{E}_x\left[\pi(D,D)|\theta=0\right] &= \int_0^{\hat{x}_L} \frac{1}{4} f(x)dx + \int_{\hat{x}_L}^{X} p\frac{x^2}{4} f(x)dx
\end{aligned}$$

We prove that $\mathbb{E}_x[\pi(C,D)|\theta=0] < \mathbb{E}_x[\pi(D,D)|\theta=0]$ by contradiction. Assume that

$$\int_0^{\hat{x}_H} \frac{1}{4} f(x)dx + \int_{x_H}^{X} \frac{1}{4} f(x)dx > \int_0^{\hat{x}_L} \frac{1}{4} f(x)dx + \int_{\hat{x}_L}^{X} p\frac{x^2}{4} f(x)dx \tag{1.12}$$

Given that $\hat{x}_L < \hat{x}_H$, the above inequality can be re-arranged as follows:

$$\int_0^{\hat{x}_L} \frac{1}{4} f(x)dx + \int_{x_L}^{x_H} \frac{1}{4} f(x)dx + \int_{x_H}^{X} \frac{1}{4} f(x)dx > \int_0^{\hat{x}_L} \frac{1}{4} f(x)dx + \int_{\hat{x}_L}^{X} p\frac{x^2}{4} f(x)dx$$

$$\int_{\hat{x}_L}^{X} \frac{1}{4} f(x)dx - p\int_{\hat{x}_H}^{X} \frac{1}{4} f(x)dx > \int_{\hat{x}_L}^{X} p\frac{x^2}{4} f(x)dx$$

which implies that:

$$\int_{\hat{x}_L}^{X} \frac{1}{4} f(x)dx \gg \int_{\hat{x}_L}^{X} p\frac{x^2}{4} f(x)dx \tag{1.13}$$

As we assumed that $p\mathbb{E}(x) \geq 1$; and $\pi(\cdot)$ is a monotonically increasing and convex function of x, then by the Jensen's inequality $E(\pi(x)) > \pi(E(x))$. These relations imply that:

$$\int_0^{X} p\frac{x^2}{4} f(x)dx \geq \int_0^{X} \frac{1}{4} f(x)dx \tag{1.14}$$

The above inequality holds for every left truncation $\hat{x}$. However this is this leads to a contradiction, given (1.13).

Therefore, $\Pi(D,D)|_{\theta=0} > \Pi(C,D)|_{\theta=0}$ provided that:

$$c < \hat{c} = \left.\frac{\pi(D,D) - \pi(C,D)}{\left[\frac{1-\sigma}{p(2\sigma-1)}\right]}\right|_{\theta=0}$$

Step 2 In step 2 we prove that $\frac{d\pi(D,D)}{d\theta} < \frac{d\pi(C,D)}{d\theta}$. Computing the partial derivatives with respect to θ:

$$\begin{aligned}
\frac{\partial}{\partial\theta}\pi(D,D) = &-\frac{2}{(2+\theta)^3}F(\hat{x}_L) + \frac{1}{(2+\theta)^2}f(\hat{x}_L)\frac{d\hat{x}_L}{d\theta} \\
&-\left[p^2\left(\frac{\hat{x}_L}{2+\theta}\right)^2 + p(1-p)\left(\frac{\hat{x}_L}{2}\right)^2\right]f(\hat{x}_L)\frac{d\hat{x}_L}{d\theta} - \int_{\hat{x}_L}^{X} 2p^2\frac{\hat{x}^2}{(2+\theta)^3}f(x)dx \\
\frac{\partial}{\partial\theta}\pi(C,D) = &-\frac{2}{(2+\theta)^3}F(\hat{x}_H) + \frac{1}{(2+\theta)^2}f(\hat{x}_H)\frac{d\hat{x}_H}{d\theta} \\
&-\left[p\left(\frac{2-\theta\hat{x}_H}{4-\theta^2}\right)^2 + (1-p)\left(\frac{1}{2}\right)^2\right]f(\hat{x}_H)\frac{d\hat{x}_H}{d\theta} + \int_{\hat{x}_H}^{X} p\frac{d}{d\theta}\left(\frac{2-\theta x}{4-\theta^2}\right)^2 f(x)dx
\end{aligned}$$

where $\frac{d}{d\theta}\left(\frac{2-\theta x}{4-\theta^2}\right)^2 = -2p\frac{x^2(\theta^3+4\theta)-x(6\theta^2+8)+8\theta}{(2-\theta)^3(2+\theta)^3}$. Notice that $\frac{d}{d\theta}\left(\frac{x}{2+\theta}\right)^2 > \frac{d}{d\theta}\left(\frac{2-\theta x}{4-\theta^2}\right)^2$ for every $\theta \in [0,1]$. Simple calculations leads to the condition $px^2 > \frac{x^2(\theta^3+4\theta)-x(6\theta^2+8)+8\theta}{(2-\theta)^3}$ which holds for $\theta = 0$ and $\theta = 1$. Since profit functions are monotonically decreasing in θ, it follows that the condition is always satisfied within the interval $[0,1]$.

Since $\hat{x}_H > \hat{x}_L$ we can write $\int_{\hat{x}_L}^{X} 2p^2\frac{\hat{x}^2}{(2+\theta)^3}f(x)dx - \int_{\hat{x}_H}^{X} p\frac{d}{d\theta}\left(\frac{2-\theta x}{4-\theta^2}\right)^2 f(x)dx$ as:

$$\begin{aligned}
\mathcal{K} = &\int_{\hat{x}_L}^{x_H} 2p^2\frac{\hat{x}^2}{(2+\theta)^3}f(x)dx + \int_{\hat{x}_H}^{2/\theta}\left[\frac{d}{d\theta}\left(\frac{x}{2+\theta}\right)^2 - \frac{d}{d\theta}\left(\frac{2-\theta x}{4-\theta^2}\right)^2\right]f(x)dx \\
&+ \int_{2/\theta}^{X} 2p^2\frac{\hat{x}^2}{(2+\theta)^3}f(x)dx
\end{aligned}$$

Moreover, let:

$$\mathcal{M} = \frac{2}{(2+\theta)^3}\left(F(\hat{x}_L) - F(\hat{x}_H)\right) - \frac{1}{(2+\theta)^2}\left(f(\hat{x}_L)\frac{d\hat{x}_L}{d\theta} - f(\hat{x}_H)\frac{d\hat{x}_H}{d\theta}\right) \quad (1.15)$$

$$\mathcal{H} = p(1-p)\left(\frac{\hat{x}_L}{2}\right)^2 f(\hat{x}_L)\frac{d\hat{x}_L}{d\theta} - (1-p)\left(\frac{1}{2}\right)^2 f(\hat{x}_H)\frac{d\hat{x}_H}{d\theta}$$

$$\mathcal{N} = p^2\left(\frac{\hat{x}_L}{2+\theta}\right)^2 f(\hat{x}_L)\frac{d\hat{x}_L}{d\theta} - p\left(\frac{2-\theta\hat{x}_H}{4-\theta^2}\right)^2 f(\hat{x}_H)\frac{d\hat{x}_H}{d\theta}$$

Thus we can write:

$$\frac{\partial}{\partial \theta}\pi(D, D) - \frac{\partial}{\partial \theta}\pi(C, D) = -(\mathcal{M} + \mathcal{N} + \mathcal{H} + \mathcal{K}) \tag{1.16}$$

where $\mathcal{M}, \mathcal{N} < 0$ and $\mathcal{H}, \mathcal{K} > 0$.

Finally, for $\hat{x}_L, \hat{x}_H$ defined as in (1.8) and (1.9) (for $\gamma = 0$), and given the assumptions over $f(\cdot)$ and $\pi(\cdot)$, it is easy to check that $\mathcal{M} + \mathcal{N} + \mathcal{H} + \mathcal{K} > 0$. This implies that $\frac{\partial}{\partial \theta}\pi(D, D) < \frac{\partial}{\partial \theta}\pi(C, D)$.

Results from part 1 and 2, together with monotonicity of $\pi(\cdot)$, prove that expected profits cross almost once at a given θ^{th}, and that $\Pi(D, D) > \Pi(C, D)$ if and only if $\theta < \theta^{th}$.

Chapter 2

Risky R&D in mixed oligopoly

2.1 Introduction

The main concern around the presence of State-owned enterprises (SOEs) in markets is inefficiency. Empirical works have shown that the public entrepreneurs make worse performances if compared to their private counterparts (see for instance Megginson and Netter (2001) which reviews the literature on changes in performances after privatization). Lack of efficiency and market distortions are then the main supporting arguments of those invoking state ownership withdrawal from product market.

However, what makes privately owned firms (POEs) effective in product design and commercialization, may cause some downside effects on R&D behaviour. Profit maximization leads to focus on projects characterized by low risk and short-term outcomes [1]. The economic consequences can be significant. In the pharmaceutical industry, for instance, small changes in ancillary aspects of drugs are preferred over more drastic, and risky, quality improvements (Antoñanzas et al., 2011; Mestre-Ferrandiz et al., 2012; González et al., 2016).

Government agencies are managed under a regime of soft budget constraint and make choices that, at least in principle, are not aimed at increasing profits. As a result, SOEs are more likely to invest in long-term projects and react less negatively to risk.

We examine the economic consequences of the presence of state-owned firms in research and development decisions. In other words, we ask whether innovation choices are different in mixed markets compared to pure private.

To explore the issue, we build a mixed oligopoly model where firms invest in vertical differentiation. In general, products sold on the market differ in two aspects, quality and variety, usually represented as, respectively, the vertical and horizontal dimension. Theoretical work has shown that competition may lead firms to over-differentiate along the horizontal dimension (Hotelling, 1929)[2]. Economides (1989) extends the previous framework, considering that firms may costly invest in quality, other than variety. In his framework the market equilibrium is characterized by *maximal* horizontal and *minimal* vertical differentiation.

Our formulation takes variety as exogenously fixed, while quality depends on innovation. It is assumed that research projects can be very focused on product features and concerned with immediate commercialization, or, alternatively, can have a more *scientific* orientation. In the latter case, outcomes contribute to the stock of existing

[1] Which, however, can vary depending on competitiveness, firms' size and regulation system.

[2] Although Hotelling's model specifications were technically incorrect, as d'Aspremont et al. (1979) proved that no Nash equilibria exist under the assumption of linear transportation costs.

knowledge, alongside firm's commercial success. In this context we explicitly consider the scientific community concerns about the advancement of science. However, pursuing science increases the risk relative to the commercial aspects of the project (Nelson, 1971, 2004): when a science-oriented project is carried out successful delivery of product features is not *immediate*, but suffers from additional variability.

Moreover, we posit that an innovation failure will cause the automatic withdrawal from the market, provided that the other firm has successfully updated quality. Under this condition, project's volatility becomes a crucial strategic element, since firms' survival depends on it.

Our first finding is that, when competition is severe state-owned firms undertake risky research strategies. On the contrary, private firms focus their investments on safe projects. The result has a simple interpretation. Profit maximization leads firms to choose those strategies with the higher expected value. Welfare maximization, instead, takes into account scientists' preferences. This brings state-owned enterprises to choose, to some extent, the riskier strategy. As increase in competition flattens duopoly profits, the private firms will 'play safe' in order to increase the chance of being monopolist, given the non-zero probability of a government failure at the commercialization phase.

Our second result establishes that private firms bear less risk as compared to the purely private case. The presence of state firms in the market discourages risk-taking behaviour of the private counterpart. In other words, we show that the frequency of risky R&D is higher in private markets than in mixed ones.

Our analysis is complementary to the one in Ishibashi and Matsumura (2006), who show, in a patent race model, that the state enterprises invest less than the social optimum. Instead, we underline that government entrepreneurs correct risk avoidance by their counterparts, undertaking risky R&D when competition is harsh.

Our model can be useful to interpret the persistent presence of state-owned firms (or, broadly speaking, the participation of the State in semi-private firms) in a remarkable number of markets [3] . Economic scholars, albeit from different perspectives, attribute to the public the merit of having helped the growth of these markets, in the early stages, when it was more risky to start also due to technological constraints (Armstrong, 2005; Mazzucato, 2013).

This paper, then, complements the literature that studies the economic consequences

[3] For instance in *broadcasting*, health care, biotechnology and others, public sector plays an important role in many countries

of public sector in oligopolistic markets (Cremer et al., 1989; Fraja and Delbono, 1990; Poyago-Theotoky, 1998; Ishibashi and Matsumura, 2006). Our contribution is in analysing the role of government enterprises in risky R&D decisions.

At the best of our knowledge, this is the first study that analyses risky decisions in mixed oligopoly. Few other works have studied the effect of risky innovation in a purely private setting. In a product differentiation model, for instance, Gerlach et al. (2005) finds that when the probability of success in innovation is low, agglomeration occurs in equilibrium. Within a similar framework, Christou and Vettas (2005) finds that if the ratio between the expected quality improvement and strength of horizontal differentiation is large, agglomeration is again the unique equilibrium of the market. In both cases agglomeration is above the socially optimal level, hence increasing risk determines welfare losses.

On a parallel ground, Cabral (2003) and Anderson and Cabral (2007) focus on the strategic determinants of playing risky. Considering firms with different efficiency levels, they find that technological laggards bear more risk, compared to competitors, if it raises the outcomes' upper bound. As a connection to their work, we also take into account asymmetry between firms, but it concerns their objective function (profit *versus* welfare), rather than technology.

The paper unfolds as follows. Section 2 describes the model. In section 3 we compute the equilibrium of prices and profits. Section 4 analyses the endogenous choice of risk in R&D. Section 5, finally, concludes.

2.2 Model

Consider a duopoly model *a la* Hotelling (1929) with one pure private and one publicly owned firm, respectively identified by A and B. Each firm is located at l_i, and sells a good of *quality* q_i at price p_i, with $i \in \{A, B\}$. Since our primary focus is around investment in product quality, it is assumed, for simplicity, that $l_A = 0$ and $l_B = 1$.

R&D strategies Firm i invests in research and development in order to improve product's quality q_i, whose start-up value is normalized to zero.

We model the *research process* such that a quality level q_i is obtained with probability ρ_i, and zero otherwise. According to our premises, a commercial-oriented project directs all the effort towards product development, minimizing all risk. On the contrary, a science-oriented project tries to achieve multiple goals. Other than improving product features, it wants to create valuable knowledge that *eventually* conduct to new technology and/or products. As an effect, this adds a certain degree of volatility at the development stage.

We model previous considerations introducing parameters (i) e_i, that measures the amount of resources invested in R&D; (ii) ϵ_i which represents the project's type. With respect to the latter, it takes values in $\{0, \epsilon\}$, with $\epsilon \in (0, 1)$, such that $\epsilon_i = 0$ if the project is commercial-oriented, and $\epsilon_i = \epsilon$ otherwise. Therefore, product's quality and success probability can be defined as follows:

$$q_i \equiv q(\epsilon_i) = q(1 + \epsilon_i)$$

and success probability as:

$$\rho_i(e_i, \epsilon_i) = e_i(1 - \epsilon_i/2) + (1 - e_i)\epsilon_i/2 \tag{2.1}$$

Notice that, given $\mathbb{E}(q_i) = q\rho_i(e_i, \epsilon_i)$, for $\epsilon_i \to 0$ (no volatility), expected quality fully depends on e_i; while for $\epsilon_i \to 1$, $\mathbb{E}(\tilde{q}) = 1/2$, regardless e_i

Individual preferences We consider that research is carried by a corporate scientist with intrinsic preferences $\gamma > 0$ for science: γ is the marginal benefit from effort spent in scientific projects. Normalizing w.l.o.g. effort cost to zero, his utility function has shape:

$$V_i = \gamma \epsilon_i e_i$$

Moreover, we assume hereafter that $e_i = 1$.

Market demand Consumers locate along a segment of unit length, such that the individual placed at $x \in [0, 1]$ that buys a good from firm i gets utility:

$$U_{i,x} = q_i - p_i - t|x - l_i| \tag{2.2}$$

where t measures the degree of product differentiation [4].

Defining the indifferent consumer according to:

$$q_A - p_A - t(z) = q_B - p_B - t(1 - z) \tag{2.3}$$

[4] It represents the marginal cost that a consumer with taste $x \in (0, 1)$ bears in purchasing 1 unit of good which does not fit perfectly his preferences.

and solving equation (2.3) for z, we obtain the firms' demand functions:

$$
\begin{aligned}
D_A(\mathbf{p},\mathbf{q}) &\equiv z = \frac{1}{2} + \frac{q_A - q_B + p_B - p_A}{2t} \\
D_B(\mathbf{p}.\mathbf{q}) &\equiv 1 - z = \frac{1}{2} + \frac{q_B - q_A + p_A - p_B}{2t}
\end{aligned} \tag{2.4}
$$

for $\mathbf{p} = (p_A, p_B)$ and $\mathbf{q} = (q_A, q_B)$.

Profit function The profit function, assuming zero marginal costs of production, is given by:

$$\Pi_i = p_i D_i(\mathbf{p},\mathbf{q}) \tag{2.5}$$

with $i = \{A, B\}$

Welfare Social welfare is the sum of profits, consumer surplus (CS) and agents' utilities:

$$
\begin{aligned}
W &= \pi_A + \pi_B + CS + V_A + V_B \\
&= s + zq_A + (1-z)q_B - t\left(\int_0^z (x)\,dx + \int_z^1 (1-x)\,dx\right) + \gamma(\epsilon_A + \epsilon_B)
\end{aligned}
$$

Timing The game unfolds as follows:

1. in the first stage firms choose the research project volatility ϵ_i ;
2. in the last stage firms engage in Bertrand competition.

In the next sections we analyse price and project choice equilibria, comparing results of mixed market with a benchmark set-up, where all firms are private.

The analysis is based on two main assumptions:

Assumption 3 $t < 3q(\epsilon)$

Assumption 4 $\gamma \in [1, q)$

The first assumption ensures that the market is fully covered; the second one discards the trivial case in which γ is high and the state firm always invest in risky R&D.

2.3 Bertrand Equilibrium in Mixed oligopoly

The equilibrium concept used is the subgame Nash equilibrium, derived by backward induction.

Price stage At the second stage firms fix prices. The quality differentials, determined at the previous stage, cause the exclusion of, at least, one firm from the market. Therefore, given $q_i - q_j$, with $i \neq j \in \{A, B\}$, the following conditions hold:

1. for $q_i - q_j > p_i - p_j + t$, firm i remains uniquely active in the market.

2. for $q_i - q_j = p_i - p_j + t$, both firms compete in the product market.

In the remaining part of this section we must consider that the market may settle into (i) a private or public monopoly; or (ii) a duopoly.

Assume that firm A has successfully updated quality product, while firm B does not. Hence the private enterprise gets all the market share. As a result:

$$z = \frac{1}{2} + \frac{q_A - p_A}{2t} = 1$$

This implies the following monopoly prices:

$$p_A^M = q_A - t$$
$$p_B^M = 0$$

If the opposite holds, the state-owned firm remains in the market as a monopolist. Therefore, $1 - z = 1$ implies:

$$p_A^M = 0$$
$$p_B^M = q_B - t$$

Finally, consider the case in which both firms stay in the market, having successfully innovated. Computing the first order conditions,leads to:

$$\begin{aligned}
\frac{\partial \pi_A}{\partial p_A} =& z + p_A \frac{\partial z}{\partial p_A} = 0 \\
=& \frac{q_A - q_B - p_A + p_B}{2t} + \frac{1}{2} - \frac{p_A}{2t} = 0 \\
\frac{\partial w_B}{\partial p_B} =& - \frac{\partial z}{\partial p_B} p_B + z p_B - t \left(2z \frac{\partial z}{\partial p_B} - \frac{\partial z}{\partial p_B} \right) = 0
\end{aligned}$$

Prices are determined as the solutions of the above system of equations, such that:

$$p_A = \frac{q_A - q_B - p_B + t}{2t} \tag{2.6}$$

$$p_A = p_B \tag{2.7}$$

Substituting (2.7) into (2.6), we obtain the price equilibrium under duopoly:

$$p_i^D = q_i - q_j + t$$

$\forall i, j \in \{A, B\}$, with $i \neq j$.

Profits and welfare Once we determined the equilibrium prices, profits and welfare are defined accordingly. Conditional on success in innovation, our analysis uses the following set-up:

1. Private firm's monopoly.It is characterized by government firm's withdrawal caused by failure in quality development. In this case, firms' pay-offs are given by:

$$\begin{aligned}
\pi_A^M &= q_A - t \\
w_B^M &= q_A + \gamma \epsilon_A - \frac{t}{2}
\end{aligned}$$

2. State firm's monopoly, which occurs when the opposite holds. Thus:

$$\begin{aligned}
\pi_A^M &= 0 \\
w_B^M &= q_B + \gamma \epsilon_B - \frac{t}{2}
\end{aligned}$$

3. Duopoly, when both firms coexist:

$$\pi^D = \left(\frac{1}{2} + \frac{q_A - q_B}{2t}\right)\left(q_A - q_B + t\right)$$
$$w^D = \frac{\left(q_A - q_B\right)}{2} - \frac{\left(q_A - q_B\right)^2}{2t} + q_B + \gamma(\epsilon_A + \epsilon_B) - \frac{t}{4}$$

At this point, a further elucidation about the measure of *competitiveness* used in this setup is worthwhile. The transportation cost t, is usually interpreted as an inverse measure of market competition. When t is high, firms can charge higher prices, as customers are less likely to purchase from the competitor. In our framework , as t increases duopoly profits grow, while monopoly profits get diminished. This may seem, at first look, contradictory. However, the connection between the competition parameter and profits becomes obvious once we carefully distinguish ex-ante and ex-post competition. The former is negatively related to t, and represents market power *before* any innovation is carried out. The latter regards profit levels *after* innovation. In our case, severe ex-ante competition (low t) awards more the ex-post successful innovator; and vice versa

The ex-post expected profit and welfare are given by:

$$\Pi^E = \rho_A \rho_B \pi^D + \rho_A(1 - \rho_B)\pi^M$$
$$W^E = \rho_A \rho_B w^D + \rho_A(1 - \rho_B) w^M + \rho_B(1 - \rho_A) w^M + \gamma(\epsilon_A + \epsilon_B)$$

setting up, with little abuse of notation, $\rho_A(e_A, \epsilon_A) \equiv \rho_A$ and $\rho_B(e_B, \epsilon_B) \equiv \rho_B$.

Substituting ρ_i and q_i according to their extended specifications we obtain:

$$\begin{aligned}
\Pi^E &= \left(-\frac{\epsilon_A}{2} + 1\right)\left(\epsilon_A q + q - t\right) + \\
&\quad - \left(-\frac{\epsilon_B}{2} + 1\right)\left(\epsilon_A q + q - t - \left(\frac{1}{2} + \frac{1}{2t}\left(\epsilon_A q - \epsilon_B q\right)\right)\left(\epsilon_A q - \epsilon_B q + t\right)\right) \\
W^E &= \frac{\epsilon_A}{2}\left(-\frac{\epsilon_B}{2} + 1\right)\left(\epsilon_B q + q - \frac{t}{2}\right) + \frac{\epsilon_B}{2}\left(-\frac{\epsilon_A}{2} + 1\right)\left(\epsilon_A q + q - \frac{t}{2}\right) \\
&\quad + \left(-\frac{\epsilon_A}{2} + 1\right)\left(-\frac{\epsilon_B}{2} + 1\right)\left(\epsilon_B q + \frac{1}{2} q\left(\epsilon_A - \epsilon_B\right) + q - \frac{t}{4} - \frac{1}{4t}\left(\epsilon_A q - \epsilon_B q\right)^2\right) \\
&\quad \gamma(\epsilon_A + \epsilon_B)
\end{aligned}$$

2.4 The Project Choice Equilibrium

In this section we look for Nash Equilibria in the strategy space $(0, \epsilon) \times (0, \epsilon)$. To underline the effect of Government enterprises on market Equilibria, we compare project choices both in mixed and pure private oligopoly.

All the action-contingent payoff characterizing the games, as well as proofs of lemmas and propositions, are gathered in the appendix.

Project Choice in Fully Private Oligopoly In this section we analyse R&D strategies of firms in purely private oligopoly. It is easy to show that the price vector in this case is identical to the one determined in the mixed market case. The same holds for profits. This case will serve as a comparison to measure the qualitative differences from mixed markets.

The game described in figure 2.1 is symmetric, since firms are identical. The complete specification of $\pi(\epsilon_i, \epsilon_j)$ is gathered in the appendix.

	ϵ	$\pi(\epsilon, \epsilon)$	$\pi(\epsilon, 0)$
Private Firm			
	0	$\pi(0, \epsilon)$	$\pi(0, 0)$

Figure 2.1: **Project choice in Pure Private Oligopoly**

Firms' preferences, for any given q and ϵ, vary according to t as described in the following lemma:

Lemma 6 *A threshold level $t^P \in (0, \bar{t})$ exists such that:*

1. *for $t > t^P$, $\pi(\epsilon, \epsilon) > \pi(0, \epsilon)$ and $\pi(\epsilon, 0) > \pi(0, 0)$*
2. *For $t < t^P$, $\pi(\epsilon, \epsilon) < \pi(0, \epsilon)$ and $\pi(\epsilon, 0) > \pi(0, 0)$*

The next proposition characterize the equilibrium:

Proposition 3 *In a market characterized by only private firms:*

1. *for low levels of competition ($t > t^p$), firms' investment in risky project arises as an equilibrium:*

$$(\epsilon_i^E, \epsilon_j^E) = (\epsilon, \epsilon), \ \forall t \in (t^p, \bar{t})$$

2. *for high competition levels ($t < t^P$), no equilibrium exists in pure strategies; a symmetric equilibrium exists in mixed strategies (σ_A^P, σ_B^P) such that:*

$$\sigma_A^P = \sigma_B^P = \frac{-\epsilon^2 q^2 + 2\epsilon q^2 - 2\epsilon qt + 4qt - t^2}{\epsilon\left(-2\epsilon q^2 + \epsilon qt + 4q^2 - qt - 1.5t^2\right)} \tag{2.8}$$

where σ_i^j is the probability that player i plays ϵ in equilibrium j.

Project Choice in Mixed Oligopoly In mixed markets the game structure is described as in figure, where the extensive form of $w(\epsilon_i, \epsilon_j)$ is in the appendix 2.2.

		State Firm	
Private Firm	ϵ	$\pi(\epsilon, \epsilon), w(\epsilon, \epsilon)$	$\pi(\epsilon, 0), w(\epsilon, 0)$
	0	$\pi(0, \epsilon), w(0, \epsilon)$	$\pi(0, 0), w(0, 0)$

Figure 2.2: **Project choice in Mixed Oligopoly**

Likewise the previous analysis, the relation between pay-off and competitive pressure is highlighted in the following lemma. The analysis of risk behaviour of private firms corresponds to the one summarized in lemma 6. The following, then, focuses only on government enterprises.

Lemma 7 *A threshold level of transportation cost $t^S \in (0, \bar{t})$ exists such that:*

1. *for $t > t^S$, $w(\epsilon, \epsilon) > w(0, \epsilon)$ and $w(\epsilon, 0) > w(0, 0)$;*

2. *for $t < t^S$, $w(\epsilon, \epsilon) > w(\epsilon, 0)$ and $w(0, \epsilon) < w(0, 0)$;*

The relationship between t^P and t^S is expressed in the following lemma:

Lemma 8 $t^P > t^S$ *whenever $\gamma \in [1, q)$*

Therefore, Nash Equilibria depend on t in the way described into the following proposition:

Proposition 4 *Equilibrium strategies in mixed markets, with one private and one state-owned firms, are given by:*

1. *for* $t > t^P$ *an unique equilibrium exists in which both firms undertake the risky strategy:*
$$(\epsilon_A, \epsilon_B) = (\epsilon, \epsilon)$$
2. *for* $t^S < t < t^P$ *an unique equilibrium exists in which the state-owned firm undertakes the riskier investment, while the rival plays the safer one:*
$$(\epsilon_A, \epsilon_B) = (0, \epsilon)$$
3. *for* $t < t^S$*, no equilibrium exists in pure strategies; a mixed strategy equilibrium* (σ_A^M, σ_B^M) *exists such that:*

$$\sigma_A^M = \frac{-2\epsilon^2 q^2 + 4\epsilon q^2 + 4\epsilon qt - 16\gamma t - 8qt + 2t^2}{\epsilon\left(4\epsilon q^2 + 4\epsilon qt - 8q^2 - 4qt - 3t^2\right)}$$
$$\sigma_B^M = \frac{-\epsilon^2 q^2 + 2\epsilon q^2 - 2\epsilon qt + 4qt - t^2}{\epsilon\left(-2\epsilon q^2 + \epsilon qt + 4q^2 - qt - 1.5t^2\right)}$$

As stated below, competition has a countervailing effect. On one side it increases monopoly profits, and,at the same time, decreases duopoly profits. When t is high, playing $\epsilon_i = \epsilon$ is dominant, for every strategy played by the rival. A marginal increase of t has a stronger effect on duopoly profits than on monopoly profits, raising the expected benefits of playing the risky strategy.

When t goes below a certain threshold each firm individually prefers to become monopolist. As a consequence, given the choice of the rival, each firm has an incentive to choose asymmetrically. If, in fact, the rival plays risky, then the other wants to play the safe project, thus enjoying *a quite life* in case of rival's failure. This hampers the possibility for an equilibrium to exist. Notice that the same dynamics occur both in mixed and in pure private markets. However, state enterprises maximize the sum of profits, consumers surplus and scientists' utility. Then they react less fiercely to increase in competition, since, differently from private firms, they maximize individual motivation. As a result, SOEs keep investing on science-oriented projects for higher levels of competition ($t^S < t < t^P$).

A second effect ot the presence of State firms in markets, emerges by comparing the mixed-strategy equilibria. We find that, in case of randomization, private firms undertake risky R&D strategies *more often* in pure-private than in mixed oligopoly. Thus an *indirect effect* occurs, in which the presence of government induces private entrepreneurs to bear less risk on average.

Previous considerations are summarized in the next final proposition:

Proposition 5 *The presence of SOE has two effects. A* **direct** *effect, given by the fact that* $\epsilon_B = \epsilon$ *for* $t < t^P$*. An* **indirect** *effect, given by* $\sigma_A^M < \sigma_A^P$.

The direct effect is a consequence of the second part of proposition (4). The government undertakes risky innovation, for higher competition, if compared to the pure private case. As we stated above, this is consistent with the welfare maximization goal. On the other side, comparing mixed strategies under the two regimes, underlines that private firms are less likely to invest in risky projects when competing with state firms. Thus, the *indirect effect* takes place when the presence of state firms induces private ones to bear less risk *on average.*

2.5 Discussion and Conclusions

Many economic sectors are still characterized by the presence of public owned enterprises (SOEs) competing with private firms. Economics, generally, does not favour these situations. First, because the presence of the State in markets may cause distortions that compromise its efficiency. Second, because state firms are assumed to be less efficient. Nevertheless, government intervention is, in some cases, effective in correcting market failures.

Our study focuses on firm's risk-taking behaviour in R&D. Research creates scientific knowledge - other than higher quality products - which may not have an immediate application. Moreover, scientific advancements are riskier if compared to technological innovation (Nelson, 1971). As a result, organizations appropriately design research projects to serve different purposes.

It is commonly accepted that private firms do not incur risk unless it is justified by higher profits. In this respect, industrial research aims at commercial success, while everything else is left in the second place.

Public enterprises, instead, obey to a different logic. Very often they work in close collaboration with university labs and research centres, which inevitably reflects the approach. The likelihood of commercial success is penalized by a less applied approach taken in favour of a more scientific-oriented one (Etzkowitz, 2003; Lacetera, 2009; Fini and Lacetera, 2010). Still this approach has a consistent spillover effect that cannot be commercially appropriated (for instance a discovery whose application is unclear or needs further development). Since they are not profit-seekers,we show, in a parsimonious model, that SOEs act as risk-lovers in designing R&D projects, if compared to their private counterpart. The basic results of our analysis is that the presence of state enterprises has two main effects:

- **direct** effect: if a riskier path is positively associated with the production of scientific outcomes, there might be non-commercially appropriable benefits accruing to the scientific community;
- **indirect** effect: the presence of a public entrepreneur has a non-straightforward negative effect on private firms' R&D choices. In general, firm's investment best response is related to the competitor's strategy: for high levels of competition, profit maximization leads firms to prefer asymmetric choice of ϵ_i. In this way firms maximize the chance to end-up in a monopoly. Therefore, by undertaking risky research programs, the government entrepreneur induces safer investments in the private sector.

Our paper introduces new insight about the effect of competition and the role of the public sector. Although it is acknowledged that the market mechanism can be effective in pushing firms toward improving their efficiency and/or product quality (Aghion and Schankerman, 2004; Aghion et al., 2005), there is no consensus around the influence of extreme competition on investment in risky research. In our duopoly framework, market competition has a negative effect on the expected investment levels. Our analysis finds that in mixed markets, this effect is mitigated. In conclusion, our paper presents an oversimplified model of real-world markets. Nonetheless, it introduces important issues related to risk and economic behaviour (specially in the context of research). The trade-off between exploration of new methods and exploitation of previous knowledge (March, 1991), producing disruptive or incremental innovation, needs further effort to be properly understood. We still lack the comprehension of individual and organizational motives and determinants of innovative behaviour. As a matter of fact this implies, in some cases, the lack of effective solutions to solve market failures, such as organizational inertia and industry under development. Our paper tries to make a step in this direction, but it should be extended in many ways. For instance, instead of being active in the market, one can consider the State as a *patient* investor (Mazzucato, 2015). This can be justified in cases where private investors, who are mostly concerned with fast and secure profit-shares, hinder exploration. In this context, Balsmeier et al. (2015) find empirically that the presence of outside directors on the board is associated with greater focus of innovation around the core business of the organization. This opens new interesting questions to be explored both on empirical and theoretical grounds.

2.6 Appendix

List of Pay-off

To check the equilibrium we list the whole set of profit for every combination of (ϵ_A, ϵ_B):

$$\begin{aligned}
\Pi(0,0) =& \frac{t}{2} \\
\Pi(0,\epsilon) =& q - t - \left(-\frac{\epsilon}{2} + 1\right)\left(q - t - (-\epsilon + t)\left(-\frac{\epsilon}{2t} + \frac{1}{2}\right)\right) \\
\Pi(\epsilon,0) =& \left(-\frac{\epsilon}{2} + 1\right)(\epsilon + t)\left(\frac{\epsilon}{2t} + \frac{1}{2}\right) \\
\Pi(\epsilon,\epsilon) =& \left(-\frac{\epsilon}{2} + 1\right)\left(\epsilon q + q - t - \left(-\frac{\epsilon}{2} + 1\right)(\epsilon q + q - 1.5t)\right)
\end{aligned}$$

and the set of welfare functions:

$$\begin{aligned}
W(0,0) =& q - \frac{t}{4} \\
W(\epsilon,0) =& \frac{\epsilon}{2}\left(q - \frac{t}{2}\right) + \left(-\frac{\epsilon}{2} + 1\right)\left(-\frac{\epsilon^2 q^2}{4t} + 0.5\epsilon q + q - \frac{t}{4}\right) \\
W(0,\epsilon) =& \frac{\epsilon}{2}\left(q - \frac{t}{2}\right) + \left(-\frac{\epsilon}{2} + 1\right)\left(-\frac{\epsilon^2 q^2}{4t} + 0.5\epsilon q + q - \frac{t}{4}\right) \\
W(\epsilon,\epsilon) =& \epsilon\left(-\frac{\epsilon}{2} + 1\right)\left(\epsilon q + q - \frac{t}{2}\right) + \left(-\frac{\epsilon}{2} + 1\right)^2\left(\epsilon q + q - \frac{t}{4}\right)
\end{aligned}$$

Proof of lemma 6

The first part of the lemma claims that $\Pi(0,0) < \Pi(\epsilon,0)$,for every $t \in [0, \underline{t}]$.

To prove it notice that $\lim_{t \to 0} \Pi(\epsilon,0) = +\infty$. Moreover, $\frac{\partial}{\partial t}\Pi(\epsilon,0) = -\frac{\epsilon}{2t^2}\left(-\frac{\epsilon}{2} + 1\right)(\epsilon + t) + \left(-\frac{\epsilon}{2} + 1\right)\left(\frac{\epsilon}{2t} + 0.5\right) = 0$ which brings us to $t^* = \epsilon$. This is a global minimum, given that $\frac{\partial^2}{\partial^2 t}\Pi(\epsilon,0) = \frac{\epsilon^2}{2t^3}|_{t=t^*} > 0$.

Substituting t^* into $\Pi(0,0)$ and $\Pi(\epsilon,0)$, we find that $2\epsilon\left(-\frac{\epsilon}{2} + 1\right) > \epsilon/2, \forall \epsilon \in (0,1)$. Therefore, the above inequality always holds.

The second part of the lemma introduces t^P, which divides the transportation costs range in two regions such that for $t > t^P$ the following inequality holds $\Pi(0,\epsilon) < \Pi(\epsilon,\epsilon)$.

The value of t^P is derived as a solution of $\pi(0,\epsilon) = \pi(\epsilon,\epsilon)$. Straightforward algebraic calculations leads to:

$$t^P = q\frac{\epsilon^2 + \epsilon + \sqrt{\epsilon^4 - 4\epsilon^3 + 9\epsilon^2 - 16\epsilon + 16} - 4}{3\epsilon - 2}$$

Proof of lemma 2

We first show that $w(\epsilon, 0) < w(\epsilon, \epsilon)$ for every $t \in \left[0, \bar{t}\right]$.

The solution of $w(\epsilon, \epsilon) - w(\epsilon, 0)$ is:

$$t' = \frac{2\epsilon^2 q - 8\gamma - 4q + \sqrt{4\epsilon^4 q^2 + 6\epsilon^3 q^2 - 32\epsilon^2 \gamma q - 32\epsilon^2 q^2 + 8\epsilon q^2 + 64\gamma^2 + 64\gamma q + 16q^2}}{3\epsilon - 2}$$

We can see that the numerator is always *negative* in the relevant range of parameters. First, notice that is increasing in ϵ. Hence, by substituting $\epsilon = 1$:

$$-8.0\gamma - 2.0q + \sqrt{64.0\gamma^2 + 32.0\gamma q + 2.0q^2}$$

which is always *negative*.

Similarly to the private firm's case, we study the region of t in which the inequality holds:

$$t^S = -\epsilon q + 4\gamma + 2q - \sqrt{2\epsilon^2 q^2 - 8\epsilon\gamma q - 6\epsilon q^2 + 16\gamma^2 + 16\gamma q + 4q^2}$$

Proof of lemma 8

Computing the partial derivative $\partial t^S / \partial\gamma$, we find

$$-\frac{16\gamma + 9.6}{\sqrt{16\gamma^2 + 19.2\gamma + 1.92}} + 4 < 0$$

for $\gamma > 0$. Moreover, for $\gamma = 1$ the following inequality holds: $t^S < t^P$. Since we proved that t^S is decreasing in γ, previous inequality holds within the whole interval $[1, q)$.

Proof of propositions 3 and 4

Pure strategy equilibrium Point 1 of proposition 3, and points 1 and 2 of proposition 4 determine pure strategy Nash equilibria by a straightforward application of lemma 1, 2 and 3. In what follows we prove the existence of mixed strategies for the considered market games.

Mixed strategy equilibrium In pure-private oligopoly, a mixed strategy profile is $(\sigma_A^P(S), \sigma_B^P(S))$ with $S \in \{0, \epsilon\}$ and $\sigma_i^P(\epsilon) = \sigma_i$, for all $i \in \{A, B\}$. Exploiting symmetry, the equilibrium is given by:

$$\sigma_A^P = \sigma_B^P = \sigma^P = \frac{\pi(\epsilon, 0) - \pi(0, 0)}{\pi(0, \epsilon) + \pi(\epsilon, 0) - \pi(0, 0) - \pi(\epsilon, \epsilon)} \tag{2.9}$$

In mixed-market oligopoly, a mixed strategy profile is $(\sigma_A^M(S), \sigma_B^M(S))$ with $S \in \{0, \epsilon\}$ and $\sigma_i^M(\epsilon) = \sigma_i$, for all $i \in \{A, B\}$.

An equilibrium profile is given by:

$$\sigma^M = \frac{\pi(\epsilon, 0) - \pi(0, 0)}{\pi(0, \epsilon) + \pi(\epsilon, 0) - \pi(0, 0) - \pi(\epsilon, \epsilon)} \tag{2.10}$$

$$\sigma_B^M = \frac{w(\epsilon, 0) - w(0, 0)}{w(0, \epsilon) + w(\epsilon, 0) - w(0, 0) - w(\epsilon, \epsilon)} \tag{2.11}$$

Given the list of pay-off at the beginning of this paragraph, we obtain the explicit formulation of (2.9), (2.10) and (2.11) as in propositions 3 and 4

2.6.1 Proof of proposition 5

Putting $\alpha = -2\epsilon^2 q^2 + 4\epsilon q^2 + 4\epsilon qt - 16\gamma t - 8qt + 2t^2$ and $\beta = \epsilon \left(4\epsilon q^2 + 4\epsilon qt - 8q^2 - 4qt - 3t^2\right)$ and re-arranging terms, mixed strategies can be rewritten as:

$$\sigma_A^P = \frac{\alpha - 4\epsilon qt + 8\gamma t - 2t^2 + 8qt}{\beta - 4\epsilon^2 q^2 + \epsilon qt(1 - \epsilon)}$$

$$\sigma_A^M = \frac{\alpha}{\beta}$$

For $t < t^S$, $q > 3t$ and $\gamma > 0$ the following inequalities always hold:

$$-4\epsilon qt + 8\gamma t - 2t^2 + 8qt > 0$$
$$-4\epsilon^2 q^2 + \epsilon qt(1 - \epsilon) < 0$$

which implies that $\sigma_A^P > \sigma_A^M$

Chapter 3

Influence activities and Authority in two-sided matching markets

3.1 Introduction

The exercise of control is an important concern of organizations. For instance, division managers supervise subordinates and exercise control over their decisions. In large corporations, at higher hierarchical levels, a board of directors is appointed to oversee the CEO, by evaluating his choices and providing advice. However, in all cases where subjective knowledge and specific competencies are necessary for the effectiveness of organizations, the delegation of decision-authority to lower tiers is inevitable. As an example, in the research and development divisions, it is usually the corporate scientist, not the investor or the shareholders, that decides how to organize work in the lab, sets the agenda, or how many tests to run before launching a product.

We compare the two decision models in the context of investment choices. In some cases, in fact, large discretionary power is given to managers, while in others the use of corporate resources is subject to strict control and evaluation by the board of control. Typically in the internal capital allocation the firm's headquarters decide the amount of resources to allocate among divisions. Likewise, in many cases, the board of control evaluates a CEO's proposal, and then allows investments.

The allocation of decision powers arises as an issue because hierarchical social structures are internally plagued by conflicting interests (Berle and Means, 1991). This represents a crucial reason why firms use incentive schemes extensively. Firms provide pay-for-performance incentives to induce optimal behaviour. In other words, principals use monetary incentives to get *indirect* control over the agent's actions (Jensen and Meckling, 1976). However, this approach is by no means devoid of inefficiency, due to the additional costs it involves[1]. Moreover, in many situations incentives are not even feasible due to *contract incompleteness* (Hart and Moore, 1999). Such are the downsides of decentralized decisions that bring organizations far from their first best.

Alternatively, firms can adopt centralization. It's main and obvious drawback is imperfect information. As underlined by Jensen et al. (1995), if the knowledgeable person is not in charge, organizations bear communication costs and are characterised by stiffness to change. From a different perspective, however, this structure prevents opportunistic behaviour and ensures better coordination and higher commitment of lower tiers towards the organization objectives.

[1] As standard information theory has pointed out (Laffont and Martimort, 2009), providing monetary incentives is a source of additional costs, given (i) agents wealth constraint, which limits the possibility to apply fines in case of bad outcomes; and (ii) risk-aversion, which makes more costly the use of bonus payments to induce optimal choices when outcomes are uncertain.

Moreover, centralized control discourages resource diversion for private use and ensures that members act in the organization's interest. However, a non-negligible aspect is the fact that managers can try to obtain larger capital allocations, using part of their time/effort in lobbying activities (building a network of relations, strengthening leadership). Practitioners acknowledge that lower tiers try to bypass direct control and weaken effective monitoring by influencing individuals in charge. Milgrom (1988) and Milgrom and Roberts (1988), have been the first to embed this issue into an economic framework, underlining the importance of **costs** involved in lobbying activities.

We claim that influence activities exist in any organization where the decision-maker does not coincide with the person in charge of the implementation phase. The purpose of this paper is then to clarify the relationship between the existence of such activities and corporate governance. In particular, we try to understand how they are linked to optimal decisions and authority allocation. Thus the basic question we try to answer can be formulated as follows: is it more efficient to appoint an independent board with monitoring duties and decision power on resources allocation, or would it be better to give managers decision rights over investment choice providing a certain amount of capital?

We build a principal-agent model where agents contribute to the development of innovative projects, but successful implementation depends on investment decisions. [2] Unlike much of the literature in the field, we endogenize the sources of imperfect information. While the agent has a crucial role in generating project's quality, the latter can be (at least in principle) perfectly observed by directors, that consequently decide the appropriate amount of resources to invest. Crucially agents have the possibility to exert some unproductive effort (influence) aimed at distorting information and getting more favourable decisions (Milgrom, 1988). Such an effort is by assumption non-verifiable, hence there is no contractual arrangement which can explicitly prevent from doing it.

On the other hand, firm's board is characterized by a certain degree of *independence*, defined as the proportion of influence that produces no distortions.
It is furthermore assumed that agents derive private benefits from implementation of innovative projects and that such benefits are proportional to the amount of in-

[2]Subordinates are often a source of valuable innovation (Aghion and Tirole, 1997; Rantakari, 2012). Nevertheless, to successfully realize a project it is crucial to actively involve in its development the upper and lower tiers. The reason lies in the fact that when the head of an organization or business-unit is able to recognize the value of a new project, more effort will be exerted for its completion. This is even more important for innovative projects, whose market success is uncertain and require extra funding, expensive and time-consuming tests before being implemented.

vestment. This creates a rationale for conflict between principals and agents, given that the latter have a specific interest in implementing innovation even when they are financially not convenient.

Empirical and theoretical works have shown that the firm's internal capital market is generally plagued by inefficiency. This is mainly due to the fact that shareholders and division managers do not share the same amount of information about the profitability of certain markets on one side, and, on the other, that managers are more concerned with *empire-building* than the wealth of organizations they work for (Stein, 2003). The bias becomes larger when it come to consider investment allocation between core divisions - pursuing well established activities- versus new ones, which causes organizational conservatism and inertia. As a result, lobbying is an ubiquitous activity within divisional firms (Wulf, 2009).

A recent paper by Acharya et al. (2015) analyse the relationship among corporate governance, compensation packages and competition for high-ability managers. Using a composite database - which aggregates balance-sheet data and corporate governance information of US firms together with executive's compensation and turnover - they find, first, that there is a positive association between *duality* -a governance setting where CEOs are appointed also as chairman of the board- and their ability level. In particular they find that hiring a higher-ability CEO causes a 9.6% increase of the probability of duality, suggesting that the latter is used as part of compensation schemes to attract higher-ability executives. This intuition gets further support by the second finding of the paper, which claims that in those industries characterized by higher within-industry turnover (a proxy inversely related to the degree of competition) the correlation between ability and duality is weak.

We find that if investment choices are not ex-post contractible, centralized organizations end up in an inferior equilibrium where managers spend effort in influence activities and boards under-invest. If, instead, managers did not spend such an effort, both part would strictly increase their expected outcomes. Board will in fact invest more in high quality project, as they could rely on first-rate information; and managers will benefit from more capital invested, when the project is undertaken. However, the other hand, delegation also fails in reaching optimality. In this setting managers make the investment decisions, but the board fixes a ceiling ex-ante, to limit managerial discretion. However, the upper-bound is set considering the expected quality of the project and the manager's preferences for capital consumption. This in practice results in investing less than the optimum in equilibrium.

Our main findings regard the conditions under which one authority structure dominates over the other. For any exogenous board-manager pair, centralization, generally, produces higher profits, provided that manager's outside option and influence costs are not too high. Also centralized control is more likely adopted when the manager has high ability.

These results, however, no longer hold when matching between firms and managers is endogenous. If firms compete for managers, delegation is used to attract talented managers. In fact, delegation does not involve any additional cost related to influence, it grants higher utility levels. Therefore, it allows firms to win competition for talent in the labour market for managers. As a result, despite conclusions, delegation dominates centralization when market interactions are taken into account.

The paper unfolds as follows. Section 2 presents the relevant literature. Section 3 introduces the model, with the description of variables and the main assumptions. In section 4 we state the characteristics of optimal contracts under the two authority regimes. Sections 5 analyses competition for manager in a two-sided matching model. In section 6 we extend the base model encompassing the possibility of providing high powered incentives. Finally we conclude summarizing our main results and briefly discussing some future developments.

3.2 Related Literature

Different strands of literature conflate into the present work. Below we provide a synthetic account on extant research regarding: (i) the allocation of authority inside organizations, and (ii) the effect of influence activities on efficiency. Even if we claim the existence of a link between influence and authority, generally they have been studied separately. Finally (iii) we introduce some recent works that study optimal contracts in competitive environments. We strongly relate to this stream of studies and the theoretical framework it developed.

Authority allocation Our general treatment of authority is based on Aghion and Tirole (1997) and Rantakari (2012). We share with the these authors a bottom-up view of idea generation within organizations. Both works assume that lower tiers are sources of new innovative opportunities. However, while they focus on optimal effort in creation, our interest lies on th effects of their rent-seeking behaviour under different control rights allocation.

One of the basic assumption of the present work is that ex-post decisions are not verifiable. Such assumption, which describes the realm of many economic settings, is shared, among many others, by Rajan et al. (2000), Dessein (2002), Prendergast (2002), Hart and Moore (2005, 2008), Friebel and Raith (2010) and Hart and Holmstrom (2010).

Influence activities in organizations The contributions of Milgrom (1988); Milgrom and Roberts (1990, 1988) represent the milestones in formalizing the phenomenon of lobbying in bureaucracies. They focus on the time-wasting effect of influence activities, underlining the efficiency loss it causes. We adopt a similar approach, however differing from several aspects. First, we assume that influence occurs at the project's evaluation phase Second, while they consider such activities to justify long-lasting bureaucratic procedures, in our approach they are functional to the difference between centralization and delegation.

Our paper is close to Powell (2015). The author compares the costs and benefits, respectively, embedded in rigid and flexible practices inside organizations. The paper proposes an influence cost model of organization, focusing on the effect of authority on the quality of managerial practices. However the author departs from market interactions, taking a more standard one-principal-one-agent approach.

Other works analyse influence activities as a managerial behaviour, although with different connotations. Laux (2008), for instance, associates *influence* to the extra-effort made by managers, to find and produce useful information about projects.

Finally we refer to the substantial literature on influence and the capital allocation mechanism in multi-divisional firms (Schaefer, 1998; Scharfstein and Stein, 2000; Wulf, 2009, among others)

Matching Markets The novel results of this paper are obtained comparing the two authority settings in a labour market for managers. In this respects we heavily build on the works of Alonso-Paulí and Pérez-Castrillo (2012) and Macho-Stadler et al. (2014). Besides the specific topics investigated, these papers show that well established results in traditional principal-agent models, may no longer hold when the analysis is embedded into a market framework. In particular, like Alonso-Paulí and Pérez-Castrillo (2012), we focus on the use of discretion in contracts as a competitive device, since the former analyses the adoption of "code of best practices" in organizations aimed at limiting the boundaries of managerial discretion.

Finally, it is worth to mention Besley and Ghatak (2005) and Dam and Perez-

Castrillo (2006). The former, in particular, studies stable matching when principals and agents can be both intrinsically motivated. Akin to these works, we focus on how personal motivation influences internal organization of firms. Nevertheless, in our framework individuals' heterogeneity derives from efficiency, while motivation is constant. Barros and Macho-Stadler (1998) and Terviö (2008) analyse the impact of power incentives on attracting talent. Departing from their approach we, instead, focus on authority and optimal investments in labour market.

3.3 Model

Set-up Consider a market constituted by one set of *risk-neutral* firms (principals)

$$F = \{f_1, \cdots, f_i, \cdots, f_P\}$$

and one set *wealth constrained* managers (agents)

$$M = \{m_1, \cdots, m_j, \cdots, m_A\}$$

Each f_i offers a contract to m_j. If the latter accepts the contract he joins the firm with the duty of carrying out a project which will contribute to the financial success of the firm. If implemented, the project generates s flow of returns whose present value is R_i with probability $p(x, \delta_{ij}) = x\sqrt{\delta_{ij}}$, and zero otherwise. Parameters are such that: (i) the financial outcomes R_i are firm specific (for this reason we use the index i); (ii) x takes values $\{x_L, x_H\}$, such that $x_L < x_H$, and represents the project *quality*; (iii) δ_{ij} is a non-negative continuous variable corresponding to the amount of capital firm i is willing to invest in the project, if the manager j joins the firm. Without loss of generality it is simply assumed that $x_L = 0$ and $x_H = 1$, while the cost of investment is borne by the firm and is equal to $r\delta_{ij}$.

Information and Influence activities Information over projects is not ex-ante available to the contracting parts. Instead the actual realization of x is observed *after* the parts sign the contract. Before it, they only know the ex-ante probability $\Pr(x = x_H) = \nu_j$ of producing an high quality project [3]. Afterwards, a public signal $s \in \left\{s_L, s_H\right\}$ is observed, in principle with full precision, by both principal and agent which conveys the relevant information over x. The signal turns then to be crucial

[3]Probability ν_j proxies for m_j's ability level, which can be interpreted as managers reputation for past performances.

in deciding what is the appropriate amount of capital to implement a given project. However, managers have the possibility of distorting such information by exerting some unverifiable effort on signal-jamming activities. These can span from producing over-optimistic reports to lobbying the board or building a network of favourable people. We model these, so-called, *influence* activities by means of a discrete variable $b_{ij} \in \{0, \mu\}$, with $\mu < 1$, such that:

$$\Pr\left(s = s_H | x \in \{x_L, x_H\}\right) = \begin{cases} 1 \text{ if } x = x_H \\ b_{ij} \text{ if } x = x_L \end{cases} \tag{3.1}$$

Therefore, even a bad quality project still has a chance to get funded since b_{ij} increases the probability of getting a positive signal; and, at the same time, it decreases the probability of observing an unfavourable one. In common with the relevant literature on the subject , it is assumed that b_{ij} is **unproductive** and **costly**, as it does not contribute to the success of the project and causes a personal cost $c(b_{ij})$, such that $c(0) = 0$ and $c(\mu) = c$.

Contract A contract is summarized by the tuple $\mathcal{C} = \left\langle w_{ij}, \mathcal{D} \right\rangle$, where w_{ij} represents the monetary transfers from f_i to m_j, and $\mathcal{D} \in \left\{ f_i, m_j \right\}$ is the identity of the decision-maker. To save on notation we pose $\mathcal{C}_{ij}^c = \left\langle w_{ij}^c, f_i \right\rangle$ and $\mathcal{C}_{ij}^d = \left\langle w_{ij}^d, m_j \right\rangle$ denoting, respectively, centralization and delegation contracts signed by f_i and m_j. Under $\mathcal{C}^d$ the amount of capital available is part of the contractual agreement on which m_j gets the right to take any spending decision. Under $\mathcal{C}^c$, instead, f_i decides δ_{ij} after observing s. Hence, decisions over b_{ij} are taken considering the *induced* distribution of signals, which in turn affects the investment δ_{ij} and the costs $c(b_{ij})$.

Pay-off functions From firms perspective, the financial value of implementing an innovative project is summarized by its net present value:

$$\sqrt{\delta_{ij}} x R_i - r\delta_{ij}$$

Once m_j joins the firms, he adds a fixed value F irrespective of the undertaken project. For any $\mathcal{C}$-contract profits are then given by:

$$\pi_{ij} = F + \sqrt{\delta_{ij}} x R_i - r\delta_{ij} - w_{ij} \tag{3.2}$$

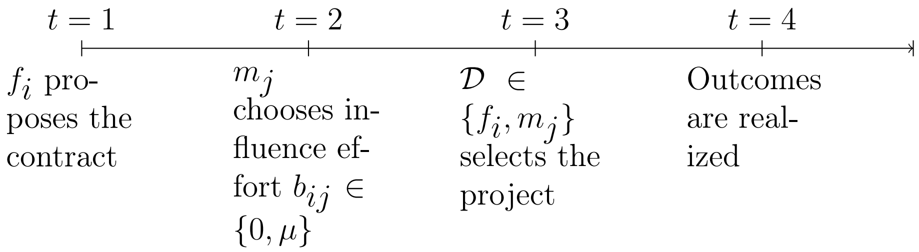


Figure 3.1: Timeline

On the other side of the market, managers enjoy monetary rewards *plus* the benefits of managing capital. Our model allows for elastic interpretations of the sources of this intrinsic motivation, accounting for either reputation or capital hunger. Therefore, for any (w_{ij}, δ_{ij}):

$$u_{ij} = w_{ij} + \gamma \delta_{ij}$$

where γ is the marginal benefit from capital consumption.

It is finally assumed that the agent accepts the contract only if it gives him a utility level not less than $\underline{U}_j$ and that he is wealth constrained, such that $w_{ij}(\mathcal{C}) \geq 0$ for any $\mathcal{C}$.

Timing The game is played according to the following sequence of events (see figure 3.1):

- $t = 1$) f_i proposes the contract establishing: monetary transfers and identity of the decision maker, $\mathcal{C} \in \left\{\mathcal{C}^c, \mathcal{C}^d\right\}$, plus a capital allocation δ_{ij} in case of delegation;
- $t = 2$) m_j chooses influence effort $b_{ij} \in \{0, \mu\}$;
- $t = 3$) signal s is observed and $\mathcal{D} \in \{f_i, m_j\}$ takes decisions over projects;
- $t = 4$) payoffs are realized and wages are paid.

3.4 Optimal contracts

In this section we outline the characteristics of optimal contracts under the two authority models. We then compare them in a non-competitive environment, providing the conditions under which one *dominates* the other.

3.4.1 Preliminaries

In section 3.3 we have already introduced the distinguished features of centralization and delegation from the point of view of information.
As stated, we make the extreme assumption that under centralization information is in principle perfect. Without any external interference the joint forces of principal and agent make possible to detect the project's future returns with the highest degree of precision. Hence, the unconditional probability of implementing a new project exclusively reflects managerial ability: $\Pr(s = s_H) = \nu_j$, when $b_{ij} = 0$.
However, influence b_{ij} drastically changes things. In fact, managers' effort in signal-jamming prevents the discovery of unfavourable states. In other words, under the hypothesis of perfect observation $\Pr(s_H|x_H) = 1$, while $\Pr(s_L|x_L) = 1 - b_{ij}$: the probability of catching-up a *low*-quality project is decreasing in b_{ij}. Then, for any $b_{ij} > 0$, the information conveyed by signal s is not reliable any more. If $s = s_H$ is observed, firm's headquarters - internalizing the manager's choice of b_{ij} - updates her beliefs according to:

$$\Pr(x = x_H|s = s_H) = \frac{\nu_j}{\nu_{ij} + (1 - \nu_j)b_{ij}}$$

For future reference it is convenient to write down the unconditional distribution of signals on $x \in \{0, 1\}$:

$$\begin{aligned} \Pr(s = s_H) \equiv & \xi_{ij} = \nu_j + (1 - \nu_j)b_{ij} \\ \Pr(s = s_L) \equiv & 1 - \xi_{ij} = (1 - \nu_j)(1 - b_{ij}) \equiv 1 - \xi_{ij} \end{aligned} \quad (3.3)$$

In the remaining parts we solve the firm's optimization problem under the authority regimes for *any* level of reservation utility $\underline{U}_j$. In fact, due to the existence of an entire market of multiple firms, manager's outside-option is influenced by the possibility to sign a contract with other firms.

3.4.2 Centralization

Under this setting boards keep the authority over funding decisions. These are made ex-post, based on the available information.

The distribution of signals $s \in \{s_L, s_H\}$ depends on influence $b_{ij} \in \{0, \mu\}$, such

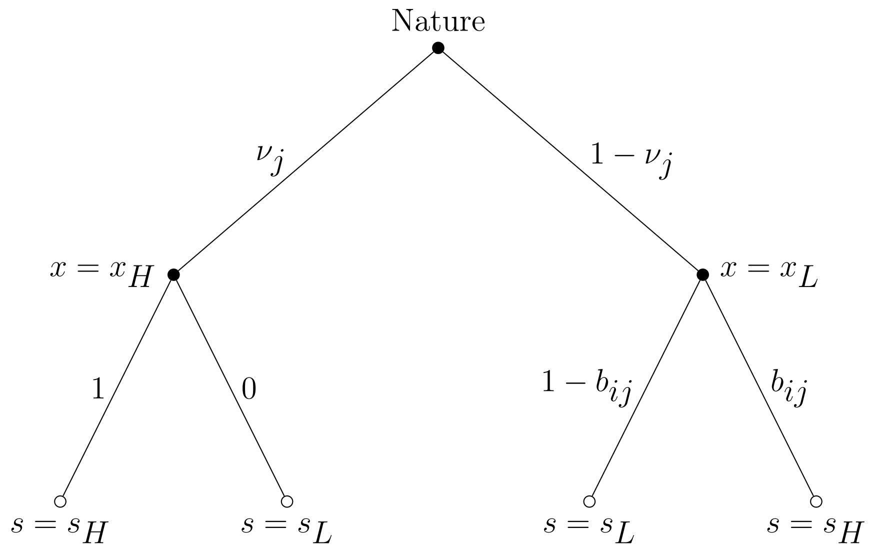


Figure 3.2: Information tree under centralization and influence

that optimal investment is determined ex-post (after observing s) according to:

$$\delta_{ij}^{c}(s) \equiv \arg\max_{\tilde{\delta}_{ij}} \left\{ \mathbb{E}_{x|s} \left[\pi_{ij} \left(\tilde{\delta}_{ij}, \mathcal{W}_{ij}^{c} \right) |s \right] \right\}$$

On the other hand, managers make decisions over b_{ij} are made considering (i) the expected benefits from capital consumption and (ii) personal costs $c(b_{ij})$.

Therefore, after signing the contract, f_i and m_j play a sequential game of imperfect information where: (i) the manager moves first taking an unobservable action from the set $\{0, \mu\}$; (ii) the board moves after observing s, according to the best response function $\delta_{ij}(s|b_{ij})$. As b_{ij} is discrete, f_i's strategy space reduces to $\left\{ \sqrt{\underline{\delta}_{ij}}, \sqrt{\bar{\delta}_{ij}} \right\}$ for $s = s_H$, where

$$\sqrt{\underline{\delta}_{ij}} = \frac{\nu_i}{\nu_i + (1-\nu_i)\mu} \left(\frac{R_i}{2r} \right)$$
$$\sqrt{\bar{\delta}_{ij}} = \frac{R_i}{2r}$$

and $\delta_{ij}(b_{ij}|s_L) = 0$, whatever b_{ij} in its range.

Proposition 6 (Nash Equilibrium) *The investment game has a unique Nash Equilibrium for* $\left(b_{ij}^{NE}, \delta_{ij}^{NE} \right) = \left(\mu, \underline{\delta}_{ij} \right)$, *if influence costs are below the threshold* $c < \hat{c} \equiv \frac{R_i}{2\nu_j} \left(1 - \nu_j/\xi_j \right)$.

Proof see the Appendix

The results stated in proposition 6, support the claim that in centralized organizations, influence is always undertaken provided that it is not too costly for the agent. Notice that if the possibility of making influence was denied (because of high c or small μ), f_i and m_j would both end-up with better outcomes, given that $\overline{\delta}_{ij}$ would now be optimal, increasing the expected benefits of managers and profits.

Corollary 1 *The Nash Equilibrium of the investment game is not Pareto-optimal*

The next proposition summarizes the main characteristics of centralization contracts $\mathcal{C}^c$. The agent's limit liability is active only for levels of outside utility under

$$U_{ij}^{t,c} = \gamma\nu_j \frac{R_i}{2r} - c$$

Below this threshold f_i does not need to give extra-money in order to induce participation.

Proposition 7 (Optimal incentives contract under centralization) *Under centralization firm and manager sign a contract such that:*

1. *the board keeps the authority over decisions:* $\mathcal{D} = f_i$
2. *monetary transfers are given by:*

$$w_{ij}^c = \begin{cases} U_j + c - \gamma \frac{\nu_j R_i}{2r} \; \textit{if} \; U_j > U_{ij}^{t,c} \\ 0 \; \textit{otherwise} \end{cases}$$

   where $U_j \equiv \max\left\{U_{ij}^{t,c}, \underline{U}_j\right\}$ *with* $\underline{U}_j < U_{ij}^{0,c}$

3. *firms profit:*

$$\pi_{ij}^c = \frac{\nu_j^2}{\xi_j}(R_i^2/4r) - w_{ij}^c \tag{3.4}$$

3.4.3 Delegation

Under delegation managers have full authority over project choices. This has two major implications. First, lobbying is not an issue any more: managers have no reason for influencing the board to get more funds. Second, to limit managerial discretion, the board can commit to an upper bound of possible investment by offering a 'wallet' which m_i can use.

Optimal contracts under delegation then are represented by the tuple $\mathcal{C}^d = \left\langle \mathcal{W}_{ij}^d, m_j \right\rangle$, where $\mathcal{W}_{ij}^d = (w_{ij}, \delta_{ij})$. Firms make choices over δ_{ij} ex-ante, according to:

$$\delta_{ij}^d \in \arg\max\{\nu_j \sqrt{\delta_{ij}} R_i - r\delta_{ij} - w_{ij}^d\} \tag{3.5}$$

We demonstrate in the appendix that equation (3.5) has no unique solution. Firms, in fact, allocate capital taking into account the managerial ability, which affects expected results, and the possibility to attract talented managers by offering generous capital endowments. The optimal amount is given by

$$\sqrt{\delta_{ij}^d} = \begin{cases} \frac{\nu_j R_i}{2r} \text{ for } U_i < U_i^{t,d} \\ \frac{\nu_j R_i + \gamma}{2r} \text{ otherwise} \end{cases}$$

Hence, when managers have high reservation utility ($U_j > U^{t,d}$, see above), boards offer more capital, proportional to the manager's personal benefits γ.

As in the previous case, limited liability is active only when U_j is lower than:

$$U_{ij}^{t,d} = \gamma \frac{\nu_j R_i + \gamma}{2r} - c$$

such that for any $\underline{U}_{ij} \leq U_{ij}^{t,d}$, compensation is set at zero.

Below the characteristics of delegation contracts are summarized.

Proposition 8 (optimal payment under delegation) *Under delegation firm and manager sign a contract*

1. *managers get the authority over project's choice:* $\mathcal{D} = m_j$
2. *monetary transfers are given:*

$$w_{ij}^d = \begin{cases} U_j - \gamma \frac{\nu_j R_i + \gamma}{2r} \textit{ if } U_j > U_{ij}^{t,d} \\ 0 \textit{ otherwise} \end{cases} \tag{3.6}$$

3. $U_j \equiv \max\left\{U_{ij}^{t,d}, \underline{U}_j\right\}$ *with* $\underline{U}_j < U_{ij}^{0,d}$

4. firms profit:

$$\pi_{ij}^{d} = \begin{cases} \frac{\nu_j^2 (R_i+\gamma)^2}{4r} - U_j + \gamma \frac{\nu_i^2 R+\gamma}{2r} - c \text{ if } U_j > U_{ij}^{t,d} \\ \nu_j^2 \frac{R_i^2}{4r} \text{ otherwise} \end{cases} \tag{3.7}$$

Notice that when capital allocation is made ex-ante, choices are only based on managerial ability

3.4.4 The trade-off between the two organizational modes

Lemma 9 *The expected value of investment under centralization is always lower than delegation, for every level of managerial outside option.*

Proof It is easy to check that the expected investment under centralization $\mathbb{E}(\delta^c)_{ij}$ is given by:

$$\Pr(s = s_h) \cdot \delta_{ij}^c = \frac{\nu_j^2}{\xi_{ij}} \frac{R_i^2}{4r^2}$$

Hence, given (3.6), $\delta_{ij}^c < \delta_{ij}^d = \frac{\nu_j^2 R_i^2}{4r^2}$ for $U < U^{d,t}$; and $\delta_{ij}^c < \delta_{ij}^d = \frac{\nu_j^2 R_i^2 + \gamma}{4r^2}$ for $U \geq U^{d,t}$.

Under a centralization model the decision making occurs ex-post. Hence, the information provided by managers and not their outside options will matter in this setup. Managerial distortion of information (through influence) is anticipated by principals' beliefs, which lead to under-investment. On the contrary, under decentralization, investments are established ex-ante, and designed to attract potential agents. If their outside options are high the proposals will also be higher.

Proposition 9 (Delegation vs Centralization) *f_i's profit under $\mathcal{C}^c$-contract is higher than under $\mathcal{C}^d$-contract provided that* $U_j < \tilde{U}_{ij} = \frac{(\nu_j R_i)^2}{4r} \left(\frac{1}{\xi_j} - 1 \right) + \gamma \frac{\nu_j R_i}{4r} - c$

Proof see the appendix.

Since the principal can only pay a fixed salary, she has no means to dissuade effort on influence. However, the personal costs associated with b_{ij} are in the end borne by firms (if they want to induce manager's participation). As we previously observed,

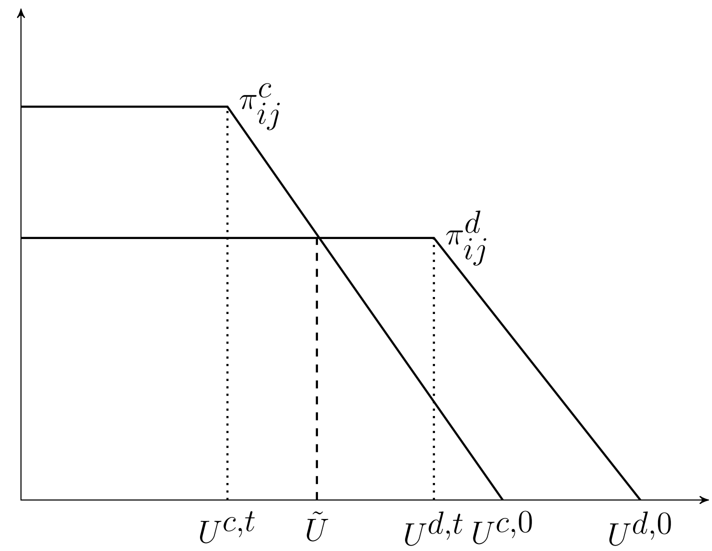


Figure 3.3: Profits under $\mathcal{C}^c$ and $\mathcal{C}^d$ at any level of $\underline{U}_{ij}$ for $c \leq \hat{c}$

influence costs have to be lower than a certain threshold $\hat{c}$ to make centralization feasible. On the other side, the informative advantage that features centralization is such that if those costs are negligible, delegation will never be adopted. For low utility levels we have that $\pi^c_{ij} > \pi^d_{ij}$. Two facts are worth to be mentioned. First, for U_{ij} within the interval $\left(U^{th,c}_{ij}, U^{th,d}_{ij}\right)$ profit functions exhibit different slopes: $\dfrac{\partial \pi^c_{ij}}{\partial U_{ij}} = -1 < 0$ and $\dfrac{\partial \pi^d_{ij}}{\partial U_{ij}} = 0$. Second, it is easy to check that $U^{0,c}_{ij} < U^{0,d}_{ij}$: under centralization, profits get to zero faster than delegation as manager's utility increases. Therefore, as stated in the proposition, there is a threshold utility level $\tilde{U}_{ij}$ such that for $U_{ij} > \tilde{U}_{ij}$ delegation dominates centralization and vice versa.

Further inspections brings us to the conclusion that, if considered in isolation (meaning abstracting from market interaction), $\mathcal{C}^c$-contracts are more likely to be adopted if managers are highly skilled.

To see this we just check that $\dfrac{\partial \tilde{U}_j}{\partial \nu_j} > 0$:

$$\frac{\partial \tilde{U}_j}{\partial \nu_j} = \frac{2\nu_j R_i^2}{4r}\left(\frac{1}{\xi_j} - 1\right) + \frac{(\nu_j R_i)^2}{4r}\left(\frac{\mu}{\xi_j^2}\right) + \gamma\frac{R_i}{2r} > 0 \tag{3.8}$$

which always holds, for all the parameters in their range.

3.5 Equilibrium contracts in markets

So far we considered optimal contracts in isolation. We now expand our analysis considering a market where firms and managers match through contracts.
The analysis is conduced with the twofold objective of underlining how market interactions drive contractual decisions, and the characteristics of contracting parts.

It is required that traded contracts let the partners with an amount of utility non less than their respective alternatives. Then a contract is **acceptable** for (f_i, m_i) if $\pi_{f_i}(\phi(f_i), \mathcal{C}) \geq 0$ and $U_{m_j}(f_i, \mathrm{C}) \geq 0$

We assumed that agents are protected by limited liability, hence contracts cannot contain monetary punishments. A contract that satisfies acceptability and limited liability is **feasible**.

Definition 1 (One-to-One Matching) *A one-to-one matching is a mapping* $\phi : \mathcal{F} \cup \mathcal{S} \rightarrow \mathcal{F} \cup \mathcal{S}$ *such that: (i)* $\phi(f_i) \in \mathcal{S} \cup \{f_i\}$ *for all* $f_i \in \mathcal{F}$*, (ii)* $\phi(s_j) \in \mathcal{F} \cup \{a_i\}$ *for all* $s_j \in \mathcal{S}$ *and (iii)* $\phi(f_i) = s_j \iff \phi(s_j) = f_i$ *for all* $f_i \in \mathcal{F}$ *and* $s_j \in \mathcal{S}$

A matching function is a ϕ that associates (i) f_i to each m_j, if a pairing is successfully formed, and (ii) f_i *or* m_j to themselves, if it is not.

An **outcome** for the market is a pair $(\phi, \mathcal{C})$ for a given couple (f_i, m_j), which then specifies the identity of the matching partners under a given contract $\mathcal{C}$.

Now we are able to go through the main purpose of our analysis: finding the equilibrium pairs of firms and managers in the market. To be an equilibrium, any outcome has to be *stable*. Stability establishes that any pairing of firms and managers has to be immune from *blocking*: if matching is stable then there is no other pair of firm and manager where both would be better off by signing a contract which does not belong to $(\phi, \mathcal{C})$. Analytically:

Definition 2 (Stability) $(\phi, \mathcal{C})$ *is stable if there is no other pair* (f_i, s_j) *such that* $\pi_i(m_j, C') > \pi_i(m_j, C')$ *and* $U_j(f_j, C') > U_j(f_j, C)$ *such that* C' *is feasible and* $C' \neq C \in \mathcal{C}$

3.5.1 Homogeneous firms and heterogeneous managers

Consider here the case when firms exhibit the same project' return, $R_i = R$, while managers differ in efficiency, $\nu_1 > \nu_2 > \cdots > \nu_M$, such that $\nu_1 > 0$ and $\nu_M < 1$ for every $i \in \{1, \cdots, P\}$ and $j \in \{1, \cdots, M\}$.

Proposition 10 (Homogeneous firms; heterogeneous managers) *When managers are heterogeneous in ability, then market outcome* (ϕ, W) *for this market is characterized by:*

a $\pi_{f_i}(\phi(f_i), W_j)$ *is constant for each* $f_i \in \mathcal{F}$

b *if* $P \leq M$, *whatever* $\mathcal{C}$ *we have* $\pi_{f_i} \in \left[\pi_{f_i}(m_{P+1}, \mathcal{C}), \pi_{f_i}(m_P, \mathcal{C})\right]$, *where in case* $P = M$ *we have that* $\pi_{f_i}(0, \mathcal{C}) = 0$. *In particular, contract used are such that:*

- **b.1** *if* $\pi_{f_i}(m_1, \mathcal{C}) \leq \tilde{\pi}_{f_i}$ *then* $\mathcal{C} = \mathcal{C}^d$;
- **b.2** *if* $\pi_{f_i}(m_P, \mathcal{C}) \geq \tilde{\pi}_{f_i}$ *then* $\mathcal{C} = \mathcal{C}^c$;
- **b.3** *if exists* j *such that* $\pi_{f_i}(m_{j+1}, \mathcal{C}) \leq \tilde{\pi}_{f_i}$ *and* $\pi_{f_i}(m_j, \mathcal{C}) \geq \tilde{\pi}_{f_i}$ *then the two matching outcomes* $(\phi(m_{j+1}), m_{j+1})$ *and* $(\phi(m_j), m_j)$ *rise out under* $\mathcal{C} = \mathcal{C}^c$ *and* $\mathcal{C} = \mathcal{C}^d$;

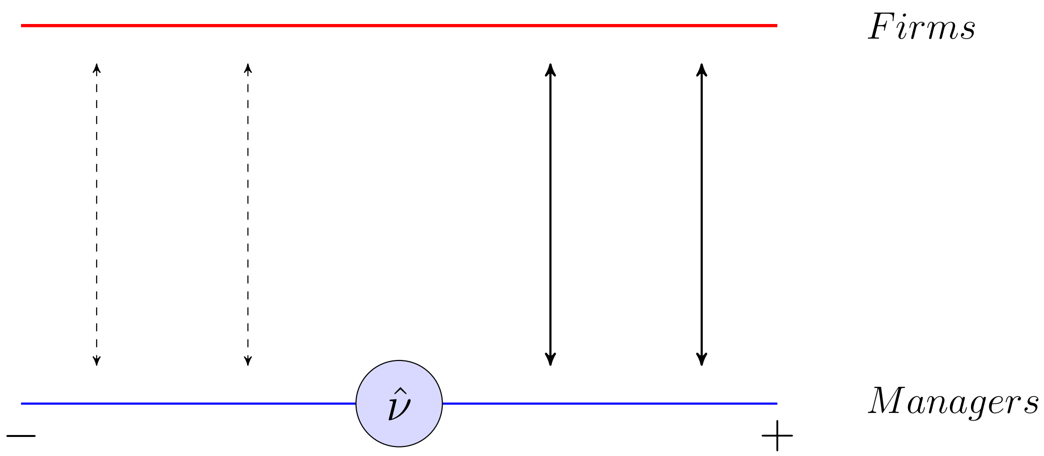
c *if P>M then* $\pi_{f_i}(m_j, \mathcal{C}) = 0$ *and all contracts are* $\mathcal{C}^d$

Part (a) follows directly from **stability**. If f_i and m_j sign a stable contract, all f_i obtain the same profit, regardless the ability of managers. When firms are on the short side of the market they get a positive profit, otherwise it is equal to zero.

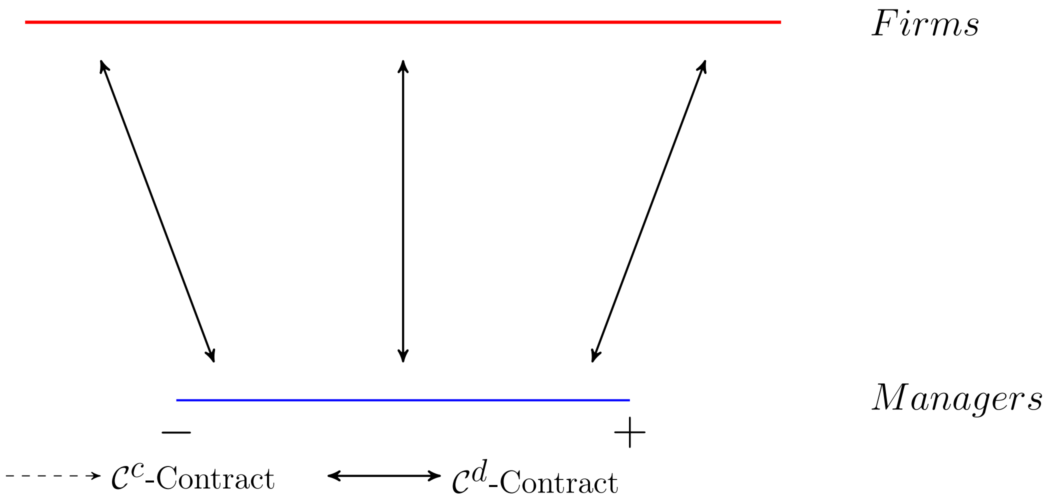
Part (b) of the proposition has important implications. It considers, in part b1 and b2, two polarized situations. The first (b1), where profits are low, as $\pi_{f_i}^{\mathcal{C}} < \tilde{\pi}_{f_i}$ for whatever $\mathcal{C}$, may be associated with a market where managers have low levels of competences. In this case, we find that contracts involve only delegated authority. Otherwise, part (b2), when $\pi_{f_i}^{\mathcal{C}} > \tilde{\pi}_{f_i}$ all contracts entail centralization. Therefore, (b1) and (b2) are consistent with proposition 9: centralization is more likely to be adopted for higher ability levels. However, if we introduce competition in the model, results are drastically different. In fact, part (b3) states that, if firms want to attract talented managers, then delegation contracts are signed. In this case, centralization is used instead with low skilled managers, and therefore the results from proposition 9 are reversed (findings are depicted in figure 3.4).

3.5.2 Heterogeneous principals and agents

Heterogeneous efficiency We now consider when the two sides of the market are both heterogeneous. Firms, differing in terms of investment returns R_i, are ordered



(a) Matching when $M \leq N$ (low competition): firms form a pair with low-ability managers ($\nu < \hat{\nu}$) through centralization contracts ($\mathcal{C}^c$); otherwise matching occurs through delegation contracts ($\mathcal{C}^d$)



(b) Matching when $M > N$ (high competition): all contracts are $\mathcal{C}^d$

Figure 3.4: Matching through contracts

$R_1 > R_2 > \cdots > R_P$. Managers instead differ in their ability, whose proxy here is the probability of observing a high quality project, such that $\nu_1 > \nu_2 > \cdots > \nu_A$. The main theoretical question here is whether firms with high returns R_i end up hiring high or low ability managers, using either $\mathcal{C}^C$ or $\mathcal{C}^D$. In this respect we distinguish between positive assortative matching (PAM), when the sorting parts have similar traits - matching of likes- and negative assortative matching (NAM) which refers to a negative correspondence of traits - matching of unlike.

Definition 3 *Given a market $\{\mathcal{F}, \mathcal{M}, \mathbf{R}, \nu\}$, a matching function ϕ such that $\phi(f_i) = m_j$ and $\phi(f_{i'}) = m_{j'}$ is a* ***PAM*** *for this market is and only if $R_i > R_{i'}$ implies $\nu_j > \nu_{j'}$*

In the next propositions we state the type of matching when only one contract is available in the economy (either centralization or delegation).

Proposition 11 (Conditions for PAM) *If the matching $(\phi, \mathcal{C})$ is stable , then ϕ is PAM and $\mathcal{C} = \{\mathcal{C}^c\}$ or $\mathcal{C} = \{\mathcal{C}^d\}$.*

Heterogeneous independence Let us now distinguish firms on the base of board's independence. This is the inverse of μ, that is the extent to which influence is effective in distorting information. Firms can then be listed in ascending order (from the last independence level) according to:

$$\frac{1}{\mu_1} > \cdots > \frac{1}{\mu_P}$$

A matching ϕ, for this market is **PAM** if the most independent signs a contract with the most efficient manager, that is $\phi(f_i) = \mu_j$ and $\phi(f_{i'}) = \mu_{j'}$ if $\frac{1}{\mu_i} > \frac{1}{\mu_{i'}}$ and $\nu_j > \nu_{j'}$.

Proposition 12 *Given the market $\{\mathcal{F}, \mathcal{M}, \vec{\mu}, \vec{\nu}\}$, an outcome $(\phi, \mathcal{C})$ for this market when all contracts are $\mathcal{C} = \mathcal{C}^c$ is stable if and only if ϕ is PAM*

Proposition 12 states that boards independence is crucial in attracting high skilled managers. The reason is that expected levels of investment are positively related to the degree of independence, thus increasing the probability of project's success. As a result, m_j with higher ν_i maximize their expected utility matching with more independent boards.

3.6 Discussion

In this section we want to underline two important points from the analysis above, which can explain some related empirical findings. The first point regards the role of board independence in shaping firm's performances in R&D. An important feature of our model is to stress the role of independence in limiting the interpersonal power of managers on board's members. This role becomes crucial, as we find , when firms compete in the labour market for managers. The second point elaborates on the link between corporate governance and matching markets.

3.6.1 Board's independence and innovation

The importance of corporate governance on the innovative behaviour of firms has been investigated by some recent works. Aghion et al. (2013), for instance, find a positive correlation between the presence of institutional ownership and number of patents. The authors explain this result in terms of *pressure* the external investors make on the management to exert more effort in innovation. More related with the present work, Balsmeier et al. (2014, 2015) find that independent boards have an increasing effect on innovative outcomes[4].

Proposition 12 states that firms with greater degree of board independence are more likely to match with highly talented managers. This has a strongly positive effect on investments, thus on the overall probability of success of the project. Our approach highlights that the effect of independence in these cases may not be direct on managerial behaviour, but, instead, on hiring procedures.

3.6.2 Corporate Governance

Two opposite fronts in the literature grapple with explaining the source of managerial power in organizations. One part of the literature (Jensen and Meckling, 1976; Raith, 2008) assumes that high pay is justified by the fact that managers own the skills, not available elsewhere, which bring value to firms. According to this point, centralization would then suffer from the losses given by asymmetric information. Moreover, payments have increased as a consequence of competition among firms trying to attract talented managers (see, for instance, Adams et al., 2010). Besides, some authors have

[4]Balsmeier et al. (2015) find also that independence encourages the undertaking of less risky, more standard, projects.

stressed the relevance of the rent-seeking behaviour of managers, who exploit their position to extract resources from shareholders when director's control is weak (Jensen and Murphy, 1990; Bertrand and Mullainathan, 2001).

Proposition 10 proposes an interpretation somehow different from both views. Influence works mainly as a **threat**. Centralization is intrinsically plagued by the loss of efficiency given by information distortion and managerial lack on focus on productive activities. On the contrary, delegation has the double pray of attracting the most efficient manager and save on such costs, but has to grant him more power over firm's assets.

3.7 Conclusion

Authority might be allocated to the most knowledgeable person. According to this basic principle shareholders allocate decision rights to managers because they own subjective knowledge needed to run complex operations inside a firm. However, managers may be willing to develop certain projects for the sake of their own interests - which do not always correspond with enterprises' - hence is necessary to bound in some ways their discretion. Some scholars have stressed the importance of designing an appropriate incentive system that drives managerial choices (Prendergast, 2002; Athey and Roberts, 2001; Bester and Krähmer, 2008). This view gives a marginal, if any, role to *other* structures that assist the manager in governing the firm, as the board of control.

At the same time, the corporate governance literature has focused on the relationship between boards, which should act as shareholders' watchdog, and executives. For instance, research in the field of contract theory has considered the crucial role of boards in hiring and dismissing CEOs, as well as, screening and selecting projects (Weisbach, 1988; Graziano and Luporini, 2003; Dominguez-Martinez et al., 2008; Adams et al., 2010).

However, a less explored issue is that division managers lobby the headquarters to obtain larger budgets as well as CEOs lobby board of directors to get financial support for big and potentially risky market operations. We point out that hierarchical control may induce managers to undertake activities aimed at gaining (interpersonal) power over the board's members (Simon, 1965). Our model embodied these *influence* activities in a comparative analysis of alternative authority structures. The main novelty of our approach is to embed the comparison within a labour market framework, where firms compete for managers. In dealing with the dilemma of improving control or giving up allocation decision authority to CEOs, firms acknowledge that contracts are, in fact, strategic competitive devices. Therefore, we conclude that the joint effect of external forces (labour market competition) and internal mechanisms (information, contracts and incentives) determines the mode of governance. In particular, we find that delegated authority can emerge as a market equilibrium, where the impact of influence activities is zero and managers have large amounts of resources at their disposal.

3.8 Appendix

3.8.1 List of parameters

Symbol	Meaning	Range
ν_j	Manager j's probability of developing a successful idea	$(0, 1)$
r	Firm i's cost of capital	> 0
μ	Inverse measure countof firm's degree of independence	$(0, 1)$
γ	Manager's private benefit from capital	> 0
c	Influence cost	$(\underline{c}, \overline{c})$
R_i	Firm's revenue	> 0

3.8.2 Proofs of proposition 6 and 7

Under centralization f_i takes all the investment decisions according to the received signal s. Therefore she offers w_{ij} to m_j and ex-post set δ_{ij} in order to maximize her ex-ante expected profit:

$$\mathbb{E}_S\left(\nu_j\sqrt{\delta_{ij}}R_i - r\delta_{ij}\right) - w_{ij} \tag{3.9}$$

subject to the following set of constraints:

1. manager participation constraint (PC) that ensures that the contract will be accepted since it gives an expected utility not less than the outside option:

$$\mathbb{E}_S\left(\gamma\delta_{ij} + w_{ij}\right) - c(b_{ij}) \geq \underline{U}_j$$

2. wealth constraint that excludes the possibility of punishing the manager with negative payments:

$$w_{ij} \geq 0$$

3. principal incentive compatibility constraint (PCC): the board chooses δ_{ij} optimally after observing s according to the *posterior* distribution:

$$\delta_{ij} \equiv \arg\max\left\{\Pr\left(x|s\right)\sqrt{\delta_{ij}}R - r\delta_{ij}\right\} \tag{3.10}$$

The investment game The choice of b_{ij} is unobservable by assumption. Managers may decide to spend effort on influence, at cost of c, in order to increase the likelihood of obtaining project's acceptance.

On the other hand, boards decide the investment levels incorporating the manager's choice of b_{ij}, according to (3.10). Computing the first order condition we have:

$$\frac{\partial\pi_{ij}}{\partial\delta_{ij}} = 0 \implies \sqrt{\delta_{ij}(s)} = \Pr\left(x|s\right)\frac{R_i}{2r} \tag{3.11}$$

where, by a straightforward application of Bayes updating rule, and considering $x \in \{0,1\}$ and $s \in \{0,1\}$:

$$\Pr\left(x = s\right) = \frac{\nu_j}{\nu_j + (1-\nu_j)b_{ij}}s$$

Therefore, the optimal invested capital $\delta_{ij}(s, b_{ij})$ is a function of s and b_{ij}, such that:

(i) $\delta^c_{ij}(0,\mu) = 0$ whatever b_{ij}; and

$$\text{(ii) } \delta^c_{ij}(1, b_{ij}) \equiv \begin{cases} \left(\frac{\nu_j}{\nu_j+(1-\nu_j)\mu}\right)^2 \left(R_i/2r\right)^2 & \text{if } b_{ij} = \mu \\ \left(R_i/2r\right)^2 & \text{if } b_{ij} = 0 \end{cases} \tag{3.12}$$

hence $\delta_{ij}(s,0) \geq \delta_{ij}(s,\mu)$ for any $s \in \{0,1\}$.

Managers make decisions over b_{ij} ex-ante, according to the expected value of $\delta_{ij}(s, b_{ij})$:

$$U_{ij}\left(\mathcal{W}^C, \delta^C_{ij}, b_{ij}\right) = w_{ij} + \gamma \underbrace{\left[\nu_j + (1-\nu_j)b_{ij}\right]}_{\equiv \Pr(s=s_H)} \delta^c_{ij}(s = s_H) - c(b_{ij}) \tag{3.13}$$

In what follows we will show that $b_{ij} = \mu$ is always a *dominant strategy* for m_j.

Let $\delta_{ij}(b_{ij})$ be, with a little abuse of notation, the expected investment level, then the expected outcomes $U\left(b_{ij}, \delta(b_{ij})\right)$ of m_j conditional on b_{ij} are given by:

$$\begin{aligned} U\left(0, \delta(\mu)\right) &= w_{ij} + \gamma \frac{\nu_j^2}{\xi_j}(R_i/2r) \\ U\left(\mu, \delta(\mu)\right) &= w_{ij} + \gamma\nu_j(R_i/2r) - c \\ U\left(0, \delta(0)\right) &= w_{ij} + \gamma\nu_j(R_i/2r) \\ U\left(\mu, \delta(0)\right) &= w_{ij} + \gamma\xi_j(R_i/2r) - c; \end{aligned}$$

It is easy to check that:

$$\begin{aligned} U_{ij}(\mu, \delta(\mu)) > U_{ij}(0, \delta(\mu)) &\iff c < \hat{c} = \frac{R_i}{2r}\nu_j\left(1 - \frac{\nu_j}{\xi_j}\right) \\ U_{ij}(\mu, \delta(0)) > U_{ij}(0, \delta(0)) &\iff c < \hat{\hat{c}} = \frac{R_i}{2r}\left(\xi_j - \nu_j\right) \end{aligned}$$

where $\hat{c} < \hat{\hat{c}}$.

Hence, m_j has a dominant strategy for $b_{ij} = \mu$, and f_i for $\delta_{ij}(s,\mu)$, which proves proposition 6.

Given the equilibrium of the investment game, we can re-write the principal's optimization problem as follows:

$$\underset{w_{ij}}{\text{maximize}} \quad \mathbb{E}(x|s)\sqrt{\delta_{ij}(s)}R_i - \mathbb{E}_s\Big(r\delta_{ij}(s)\Big) - w_{ij} \tag{$\mathbb{C}$}$$

$$\text{subject to} \quad \mathbb{E}_s\Big(\gamma\delta_{ij}(s)\Big) + w_{ij} - c - \underline{U}_j \geq 0 \tag{PC}$$

$$w_{ij} \geq 0 \tag{LL}$$

$$\sqrt{\delta_{ij}(s)} = \frac{\nu_j}{\nu_j + (1-\nu_j)\mu}\big(R_i/2r\big)\, s \tag{PCC}$$

substituting (PCC) into (PC) and ($\mathbb{C}$), and computing the expectations we obtain:

$$\underset{w_{ij}}{\text{maximize}} \quad \nu_j^2 \frac{R_i^2}{4r\xi} - w_{ij} \tag{$\mathbb{C}$}$$

$$\text{subject to} \quad \gamma\nu_j \frac{R_i}{2r} + w_{ij} - c - \underline{U}_j \geq 0 \tag{PC}$$

$$w_{ij} \geq 0 \tag{LL}$$

The problem can be solved without using Lagrange. It is easy to check the following lemma

Lemma 10 *(PC) and (LL) can never be simultaneously binding*

Consider the case where (PC) is not binding (it is always positive). The case is satisfied when the outside utility is $\underline{U}_j < \gamma\nu_j(R_i/2r) - c \equiv U_j^{t,c}$. In this case there is no need to provide a positive wage to induce participation, hence monetary transfers are set at the liability level $w_{ij} = 0$. Thus (LL) is binding.

For $\underline{U}_j > U_j^{t,c}$, (PC) is binding. Therefore, inducing agent's participation implies $w_{ij}^* = \underline{U}_j + c - \gamma\nu_j(R_i/2r)$. Since $w_{ij}^* > 0$, (LL) is not binding.

Expected profits, as function of manager's utility, are given by:

1. $\frac{\nu_j^2}{\xi_j}\frac{R_i^2}{4r}$ for $U_j \in \Big[0, U_j^{t,c}\Big]$;

2. $\frac{\nu_j^2}{\xi_j}\frac{R_i^2}{2r} - U_j - c + \gamma\nu_j(R_i/2r)$ for $U_j \in \Big(U_j^{t,c}, U_j^{0,c}\Big]$;

with $U_j^{0,c} = \frac{\nu_j^2}{\xi_j}\frac{R_i^2}{2r} - c + \gamma\nu_j\frac{R_i}{2r}$

3.8.3 Proof of proposition 8

Under delegation, the board of directors decides ex-ante the investment upper-bound allowed to managers. Hence she maximizes the profit $\pi\left(w_{ij}, \delta_{ij}\right)$ over w_{ij} and δ_{ij}, in order to satisfy the manager's participation (PC) $\gamma\delta_{ij} + w_{ij} \geq \underline{U}_j$, and wealth constraint.

The problem is stated as follows:

$$\begin{aligned}
&\underset{w_{ij},\delta_{ij}}{\text{maximize}} && \nu_j\sqrt{\delta_{ij}}R_i - r\delta_{ij} - w_{ij} && (\mathbb{D})\\
&\text{subject to} && \gamma\nu_j\sqrt{\delta_{ij}} + w_{ij} \geq \underline{U}_j && (\text{PC})\\
& && w_{ij} \geq 0 && (\text{LL})
\end{aligned}$$

We solve the maximization problem through a Lagrangian approach, with λ and ρ being respectively the multiplier of (PC) and (LL):

$$\mathcal{L} = \nu_j\sqrt{\delta_{ij}}R_i - r\delta_{ij} - w_i + \lambda\left(\gamma\nu_j\sqrt{\delta_{ij}} + w_{ij} - \underline{U}_j\right) + \rho w_{ij}$$

Computing the first order conditions, we obtain:

$$\frac{\partial\mathcal{L}}{\partial w_{ij}} = -1 + \rho + \lambda = 0 \tag{3.14}$$

$$\frac{\partial\mathcal{L}}{\partial\delta_{ij}} = \frac{\nu_j R_i}{2\sqrt{\delta_{ij}}} - r + \lambda\frac{\gamma}{2\sqrt{\delta_{ij}}} = 0 \tag{3.15}$$

$$\frac{\partial\mathcal{L}}{\partial\lambda} = \gamma\nu_j\sqrt{\delta_{ij}} + w_{ij} - \underline{U}_j = 0 \tag{3.16}$$

$$\frac{\partial\mathcal{L}}{\partial\rho} = w_{ij} = 0 \tag{3.17}$$

In what follows we check the four cases:

Case 1 $\lambda > 0$ and $\rho > 0$.

Both constraints are binding, hence $w_{ij} = 0$, and can either be (1) $\sqrt{\delta_{ij}} = \underline{U}_j/\gamma$, from equation (3.16).

Case 2 $\lambda = 0$ and $\rho = 0$.

Impossible, as can be easily proved by substituting $\rho = \lambda = 0$ into (3.14).

Case 3 $\lambda > 0$ and $\rho = 0$.

For $\rho = 0$, we get $\lambda = 1$ from equation (3.14). Substituting into equation (3.15) and solving for δ_{ij} we obtain:

$$\sqrt{\delta_{ij}} = \frac{\nu_j R_i + \gamma}{2r}$$

Monetary transfer is then given by:

$$w_{ij} = \underline{U}_j + c - \sqrt{\delta_{ij}}\gamma$$

Case 4 $\lambda = 0$ and $\rho > 0$.

Constraint (LL) then $w_{ij} = 0$. Moreover, from equation (3.15) evaluated at $\lambda = 0$:

$$\sqrt{\delta_{ij}} = \frac{\nu_{ij} R_i}{2r}$$

In what follows we prove that case 1 never holds at the optimum. First, Case 4 profit is given by:

$$\pi^{(4)} = \frac{\nu^2 R^2}{4r}$$

which holds, whenever $U_j < \gamma \frac{\nu R}{4r}$

Case 1 profit is instead specified as follows:

$$\pi^{(1)} = \frac{U_j + c}{c} \nu R - r \left(\frac{U_j + c}{c} \right)^2$$

where the superscript (1) denotes the profit level in case 1.

Evaluating $\pi^{(1)}$ at $U_j = \gamma \frac{\nu R}{4r}$, we find that:

$$\pi^{(1)} = \gamma \frac{(\nu R)^2}{4r} - \left(\frac{c}{\gamma} \right)^2 < \gamma \frac{(\nu R)^2}{4r} = \pi^{(4)}$$

which proves that $\pi^{(1)} < \pi^{(4)}$ in the relevant range of U_j.

Moreover is easy to check that $\pi^{(1)}$ is concave in U_j, and holds a maximum at

$U^* = \gamma \frac{\nu R}{4r} - c$. Comparing $\pi^{(1)}$ evaluated at U^* with Case 3 profit:

$$\pi^{(3)} - \pi^{(1)} = \gamma \frac{(\nu R)^2}{4r\gamma}(\gamma - 1) + \frac{\gamma^2}{4r}$$

which is positive for every $\gamma \geq 0$.

This proves the proposition.

3.8.4 Proof of proposition 9

We compare equilibrium profits as stated in propositions (7) and (8). First assume that $\underline{U}_j = 0$, then:

$$\pi_{f_i}(\mathcal{C}^c(0)) \geq \pi_{f_i}(\mathcal{C}^d(0)) \iff \frac{\nu_j^2}{\xi_j}(R_i^2/4r) \geq \nu_j^2(R_i^2/4r) \iff \xi_j \leq 1$$

It is easy to check also that $U_{ij}^{d,t} \geq U_{ij}^{c,t}$ for $c \geq \underline{c} \equiv \left(\frac{1-\xi_j}{\xi_j}\right) \nu_j^2 (R_i/2r)^2$. Moreover

$$\frac{\partial \pi(\mathcal{C}^c(\underline{U}_j))}{\partial \underline{U}_j} = 0 \text{ for } \underline{U_j} < U_j^{c,t} \qquad \frac{\partial \pi(\mathcal{C}^c(\underline{U}_j))}{\partial \underline{U}_j} = -1 \text{ otherwise}$$

$$\frac{\partial \pi(\mathcal{C}^d(\underline{U}_j))}{\partial \underline{U}_j} = 0 \text{ for } \underline{U_j} < U_j^{c,d} \qquad \frac{\partial \pi(\mathcal{C}^d(\underline{U}_j))}{\partial \underline{U}_j} = -1 \text{ otherwise}$$

Therefore, in the interval $\left(U_{ij}^{t,c}, U_{ij}^{t,d}\right)$, profit functions cross at most once at point $\left(\tilde{\pi}_j, \tilde{U}_{ij}\right)$, such that

$$\tilde{\pi}_j = \pi_{f_i}(\mathcal{C}^d(0))$$
$$\tilde{U}_{ij} = \nu_j^2 \frac{R^2}{4r}\left(\frac{1+\gamma/r}{\xi_j} - 1\right) - c$$

Hence, we can finally check than if $\underline{U}_j < \tilde{U}_{ij}$, then $\pi_{f_i}\left(\mathcal{C}(\underline{U_j})\right) > \tilde{\pi}_{ij}$ implies that $\mathcal{C} = \mathcal{C}^c$; otherwise $\pi_{f_i}\left(\mathcal{C}^d(\underline{U_j})\right) > \pi_{f_i}\left(\mathcal{C}^c(\underline{U_j})\right)$ always holds.

This proves the proposition.

3.8.5 Proof of proposition 10

Part (a) follows from stability. Suppose for instance that, on the contrary, under any $\mathcal{C}$, $\pi_{f_i}(\phi(f_i), w) > \pi_{f_{i'}}(m_{j'}, w_{j'})$ such that $i \neq i'$ and $j > j'$. Then $f_{i'}$ can block $(f_i, \phi(f_i))$ by offering m_j a small improvement in wage $w' = w + \epsilon$ with $\epsilon \in \mathbb{R}_+$ small enough that $\pi_{f_{i'}}(m_j, w') = \pi_{f_i}(m_j, w) - \epsilon > \pi_{f_{i'}}(m_{j'}, w')$. Hence ϕ can not be part of a stable outcome.

If $\tilde{\pi} \equiv \pi_i(m_P, W_{ip}(\tilde{U}_P))$ then $\pi \in \left[\tilde{\pi}_{P+1}, \tilde{\pi}_P\right]$ under $\phi(f_i) \in M$. Since contracts are Pareto-constrained, $U_j > \tilde{U}_{j*=P}$, therefore from proposition 9 it is implied that $\mathcal{C} = \mathcal{C}^d$. This proves part b_1 of proposition, and similarly b_2. To prove part b_3 let us assume that exists a j' such that $\pi \leq \tilde{\pi}_{j'}$ for $j \geq j'$, hence $U_j \leq \tilde{U}_{j*}$. Therefore $\mathcal{C} = \mathcal{C}^d$ since contracts are pareto-constrained. Otherwise, for $j < j' + 1$ we have that $U_j > U_{j*}$ which implies $\mathcal{C} = \mathcal{C}^c$.

When $P > M$ there are $P - M$ unmatched firms, whose autarky payoff are zero. Then combining findings from part (a) and (b) proves the statement (c).

3.8.6 Proof of proposition 11 and 12

The assumption of limited liability, configure a case of non-transferable utility (NTU) between subjects. The conditions for PAM (NAM) have been already introduced in Legros and Newman (2007). If $\pi_{f_i}(m_j, \mathcal{C}(U_j))$ is non-decreasing in j and $U_{m_j}(f_i, \mathcal{C})$ is non-decreasing in i, then matching is PAM if

$$\text{(i)}\ \frac{\partial^2 \pi_{ij}}{\partial R_i \partial \nu_j} \geq 0$$
$$\text{(ii)} \frac{\partial^2 \pi_{ij}}{\partial R_i \partial U_j} \leq 0 \tag{3.18}$$

By simple inspection we find:

1. condition (i) implies $\frac{\partial^2 \pi_{ij}}{\partial R_i \partial \nu_j} = \frac{\nu_j}{\xi_j}(R_i/r)(1 + I_{U > U^{t,c}} \gamma / r) > 0$ and (ii) $\frac{\partial^2 \pi_{ij}}{\partial R_i \partial U_j} = -1 < 0$ implies that $\mathcal{C} = \mathcal{C}^c$, where $I_{U > U^{t,c}}$ is an indicator function that takes 1 if $U_j > U_{ij}^{t,c}$ and 0 otherwise

2. condition (i) implies $\frac{\partial^2 \pi_{ij}}{\partial R_i \partial \nu_j} = \nu_j (R_i/r)(1+I_{U>U^{t,d}}\gamma/r) > 0$ and (ii) $\frac{\partial^2 \pi_{ij}}{\partial R_i \partial U_j} = -1 < 0$ implies that $\mathcal{C} = \mathcal{C}^d$, where $I_{U>U^{t,d}}$ is an indicator function that takes 1 if $U_j > U_{ij}^{t,d}$ and 0 otherwise

which proves proposition 11.

By a very similar argument, we can check that a PAM occurs when firms are heterogeneous in the degree of independence, μ_i, and managers in ability, ν_j (calculations omitted):

$$\text{(i)} - \frac{\partial^2 \pi_{ij}}{\partial \mu_i \partial \nu_j} > 0$$
$$\text{(ii)} \frac{\partial^2 \pi_{ij}}{\partial \mu_j \partial U_j} = -1 < 0 \tag{3.19}$$

which proves proposition 12

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