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R&D Investment Dynamics under Optimal Managerial Effort Allocation

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Supervised by  
**Paulo J. Pereira**

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Effort Allocation

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# Biographical Note

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After completing the bachelor degree, Nuno enrolled in the Master in Finance program of the School of Economics and Management of the University of Porto. The present dissertation is regarded as the last stage of the Master.

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To my friends João and Rui, I thank for all the moments which definitely also marked this period. We have come a long way together, and I will always be grateful to have such unique persons in my life.

To Nature, I thank for all the answers and inner-peace.

To my beloved and inspiring grandmother, Maria do Céu, full of the most profound feeling of humble gratitude, I dedicate my work.

# Abstract

We develop a dynamic model for an optimal compensation package that induces managers, who are assumed to actively impact the value of the projects they manage, to behave on the same wavelength of shareholders, mitigating existent agency issues. From our model we find that (i) the optimal compensation package is responsible for aligning the effort solutions of both players, as well as their investment timing decisions in R&D projects; (ii) we show that heterogeneous managerial skills imply different solutions for the players' optimal investment decision and effort allocation decisions, but the optimal compensation package is independent of the managerial skill set; (iii) in the presence of higher volatility, the firm's investment trigger for a R&D project is lower and firms invest sooner, going against standard Real Options literature; (iv) when the optimal compensation package is designed, the current state of the industry affects the investment decision (i.e., the trigger is shown to depend on the state variable) so that a firm in the early stages of its life-cycle tends to invest sooner than if in a mature stage; (v) finally, our model endogenously explains the competition dynamics of an industry where incumbent firms tend to be surpassed by outsiders while competing for innovation, i.e., we show why a firm has an increasing difficulty in maintaining its innovation-leading position throughout its life-cycle.

**Keywords:** Real options; Optimal contracting; Effort Allocation; Investment timing; Industry life-cycle; Agency.

**JEL codes:** D81; D82; G31.

# Sumário

Desenvolvemos um modelo dinâmico de otimização de um pacote de remuneração que é responsável por motivar os gestores, que são assumidos ter um impacto activo no valor dos projectos a cargo destes, a estarem no mesmo comprimento de onda dos accionistas. A partir do modelo descobrimos que (i) o pacote óptimo de remuneração é responsável por alinhar as soluções de esforço entre ambos os agentes, bem como as decisões relativas ao momento temporal do investimento em I&D; (ii) que heterogeneidade nas competências dos gestores implicam soluções óptimas de investimento e alocação de esforço diferentes, mas que o pacote óptimo de remuneração é independente desse mesmo quadro de competências dos gestores; (iii) na presença de maior volatilidade, o nível de fluxos de caixa limite a partir do qual é óptimo para a empresa investir em projectos de I&D é reduzido e a empresa investe mais cedo, indo em sentido contrário à literatura tradicional de Opções Reais; (iv) o estado atual da indústria influencia a decisão de investimento (i.e., o nível de fluxos de caixa limite que justifica a decisão de investimento é demonstrada depender da própria variável dos fluxos de caixa actuais da empresa) tal que a empresa nas primeiras fases do período de vida tem tendência a investir mais cedo do que se se encontrasse numa fase de maturidade; (v) finalmente, o nosso modelo explica endogenamente as dinâmicas de competição numa indústria onde empresas incumbentes tendem a ser ultrapassadas por empresas terceiras enquanto competem por inovação, i.e., o modelo demonstra que a empresa apresenta uma dificuldade crescente em manter a sua posição de líder em inovação durante todo o período de vida.

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# Chapter 1

## Introduction

“The future is open. It is not predetermined and thus cannot be predicted – except by accident. The possibilities that lie in the future are infinite.”

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Karl Popper

Managers running an innovation-oriented firm are in charge of two important decisions regarding the firm’s R&D policy. First, the manager is the ultimate responsible for allocating effort to the actual process of discovery of an innovative technology. Effort (or attention) represents all the tasks associated with directing investment projects (Holmstrom and Milgrom 1991, Manso 2011). Managers are responsible for choosing how they want to distribute effort (attention) through the set of the firm’s projects. Second, managers decide when it becomes optimal to allocate capital and exercise the option to invest in the correspondent R&D project, whose success is contingent on the arrival of a technological shock. Thus, departing from the classic approach in which managers are assumed to only hold a trigger button to decide a firm’s R&D investment timing policy, the model herein developed assumes that the manager additionally has to *ex-ante* strategically decide how much effort to store to a potential long-term innovative project.

When ownership and control are separated, managerial and shareholders interests may go at loggerheads. R&D-heavy firms face a governance problem while trying to align both players interests with structural differences, as firm performance depends on having the right managers at the helm and incentivizing them properly. In particular, the rate of innovation developed in-doors is affected by frictions embed in such relationship, potentially dampening the optimality of their decisions. All in all, firm value for innovation-seeking companies is expected to be affected by the link between agency conflicts between managers and shareholders and the side-effects of such frictions in the way managers ultimately direct the firm’s assets portfolio, comprising the short-term projects- which can be viewed as the value of the company that derives from existing assets-in-place-, and the long-term innovative projects.

The efforts made by a manager can be viewed through the type of actions that she/he commits to taking on. A short-sighted manager is the one that invests too much effort in decisions that aim to accomplish short-term goals, even if it is not optimal from a shareholder standpoint of view. A manager biased towards the long-term, conversely, is the one that overly devotes attention to long-term projects that promise to only pay off in the long-run (projects that have distant cash-flows), to a level that exceeds the optimal level for the shareholder<sup>1</sup>. A manager's decision on her/his allocation of effort is considered to be, thus, a vector of two mutually-exclusive choices. Long-term projects are assumed to be riskier than short-term ones since the probability of success of discovering some innovative application within a firm is considered to be lower than the probability of a manager succeed by choosing to keep focusing on short-term goals, even if in with different payoffs. In fact, a trade-off is created when, notwithstanding the risk profile differences, one acknowledges that the potential impact on the value of the firm of an innovation success is greater than the impact of the current "status quo" approach.

Following Manso (2011), the dissertation will focus on how to structure an incentive package when the shareholder needs to induce the manager to seek her/his optimal effort allocation strategy. Importantly, we choose to follow a multi-dimensional modeling approach that acknowledges the type of environment in which managers operate and, ultimately, decide on their allocation of effort between short-term and long-term projects (Holmstrom and Milgrom 1991). By doing so, we model agent behavior when there are multiple tasks at her/his duty, and the compensation package serves to direct the allocation of manager's effort among different tasks. In other words, when the shareholder motivates managers to do some task  $x$ , they will reallocate effort in favor of such task in exchange for a detrimental behavior in terms of a substitute task  $y$ . This dynamic works in a framework where the decision of allocation of effort between different tasks is naturally constrained by the mutually-exclusivity assumption of the model. In our model, tasks  $x$  and  $y$  would generally represent the effort allocated by managers to short and long-term projects.

The model we propose herein differs from a large body of work that looks at agency issues in the context of a firm's investment policy in two main points. First, we model the principal-agent framework in a continuous fashion using real options methodology, rather than a static set. Second, our approach explicitly aims at modeling and aligning interests between conflicting agents through the effort allocation variable, rather than the investment trigger.

The model starts by assuming a non-competitive setting, where the innovative project is exclusively presented to one firm only. The lack of *ex-ante* competition allows studying the model dynamics under a monopolistic setting. Under this framework, our model renders that the optimal compensation package responsible for aligning the effort solutions of both agents is the same that aligns the investment timing strategy. Regarding the R&D

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<sup>1</sup>The following dissertation will, henceforth, use the denomination long-term projects as a *proxy* for innovative projects, and short-term projects as a *proxy* for those projects who seek to satisfy short-term goals, without any regard to technology creation issues and, accordingly, the long-run value of the firm.

investment dynamics of innovation-oriented firms, our model shows that firms tend to invest sooner in a context of high-volatility. This finding sets us apart from traditional Real Options literature which predicts less (delayed) investment in the context of higher volatility (e.g. McDonald and Siegel 1986). This result comes as a consequence of the way we model managerial decision-making, assuming an optimal two-step sequential decision-making approach and assuming an active role of manager's skills in the project's value. Moreover, we study the link between the firm's life-cycle and the firm's engagement in innovative investments. We find that, in the moment when the optimal compensation package is applied, the investment decision is affected by the current state of the industry so that a firm in the early stages of its life-cycle tends to invest sooner than if in a mature stage. This finding is also endogenous to our model and offers an additional explanation for the life-cycle pattern in R&D investment.

Then, we make a step further and we generalize for a setting in which two firms, an incumbent and an outsider, compete for a R&D project. Our model retrieves that higher market uncertainty ultimately leads incumbent firms to be willing to invest sooner than outsider idle competing firms, justifying the preemptive behavior of firms operating in highly volatile industries. Additionally, we find that as firms evolve throughout the life-cycle, the probability of being preempted by an outsider while disputing R&D projects increases. Competition is responsible for governing the industry dynamics that yield an explanation for the life-cycle pattern in R&D investing. Our work allows us to contribute to various fields of literature, ranging from agency theory and corporate governance, to the literature on strategic investment policy.

This dissertation is organized as follows. Chapter 2 presents the basic model derivation and the main results under a monopolist setting. Chapter 3 showcases the model with a numerical example. Section 4 extends the basic model and considers heterogeneous managerial skills. In this section we cover the investment dynamics inherent to the model. Chapter 5 sheds light on industry dynamics and the R&D preemptive game under a competitive setting. In addition, Chapter 5 sums up the policy implications. Chapter 6 presents the final remarks.

## Chapter 2

# Literature Review

### 2.1 The role of R&D in firm growth

The relevance of innovation has its roots in macro and micro arguments. Since the development of economic growth theory, ranging from the seminal studies of Schumpeter, Solow to Romer, innovation, in broad, has been the center of an enriching debate. No matter the conceptual differences that set apart all the models, innovation has risen to a degree where its impact on the economic landscape is no more a mere theoretical mirage, but rather a tangible footprint on western economies.

At the economy level, the undergoing rise of the new-economy firms<sup>1</sup>, defined as smaller (workforce-wise), fast-growing, and R&D intensive companies are shaping the traditional industrial vision of an economy's structure (Ittner et al. 2003). What is a novelty about current innovation is no longer its concept or even its surge, but rather the level of emphasis that firms are putting in it. Increasing competition at the worldwide level has pushed firms towards more dynamic innovation processes, as success has shifted from the traditional sources, such as economies of scale and other tangible-asset-based factors (Chandler 1990), to intangible ones, such as human capital and R&D efforts (Zingales 2000). In line with this argument, Lev and Gu (2016) concluded that only 25 percent of the variation in market capitalization of public companies that are listed since 2000 can be explained by fixed assets on their balance sheet. For companies listing 50 years ago, the figure was between 70 and 80 percent. Intangible assets—encompassing branding, patents and information technology—make up much of this gap. Moreover, R&D expenditure as a percentage of Gross Domestic Product, a key indicator of government and private sector efforts to obtain a competitive advantage in science and technology, is continuously seeing new highs<sup>2</sup>. The economy has been re-shaped for the past decades, and so should the models be.

At the firm-level, financial markets have been the epitome of the rise of the new-economy firms, as the enterprises with a higher market capitalization have changed from the traditional value firms to the new-economy firms. Hall et al. (2005) and Lanjouw

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<sup>1</sup>Following Anderson et al. (2000), new economy firms are defined as the companies competing in the computer, software, internet, telecommunications, or networking fields.

<sup>2</sup><https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS>

and Schankerman (2001) highlighted the impact of innovation on firm's value by showing the positive linkage between firm's market value and the number of citations of a firm's patents. In particular, Hall et al. (2005) concluded that, on average, if a patent receives one additional citation, the firm's market value should increase by 3 %. Deng et al. (1999) also showed a positive relationship between citation intensity and market-to-book ratios and stock returns. Indeed, innovation has historically been, regardless of the timing of growth economists conceptualization, a significant driver of entrepreneurial success. The new-economy-firms-dominated ecosystem, however, had the virtue of empowering change through competition to all different level, as new product development has grown dramatically over the last few decades, and is now the dominant driver of competition in many industries. Product life-cycles shortening is a clear evidence of such phenomena, as Schumpeter's original creative destruction concept seems to be fostering rapid product obsolescence (Schilling and Hill 1998). Furthermore, due to the idea that the life-cycle of innovation in high-tech firms is shorter than in other low-tech industries, there is a constant pressure for quicker innovation, which amplifies the relevance of our study (Makri et al. 2006). For the purpose of our research, we will focus the spectrum of this dissertation model on the role of innovation at the firm-level.

## **2.2 The role of Managerial Effort in R&D policy**

The role of the manager in a standard firm facing growth opportunities has been laid out in early contributions to the management literature, going back to Penrose (1959). The managers are entitled to interacting with the firm's resources, subjectively perceiving and creating new uses for resources and ultimately driving the rate and direction of the firm's growth and strategic experimentation. Bertrand and Schoar (2003) document systematic behavioral differences in firm decision-making across manager styles as the answer for the observed unexplained variation in corporate practices, providing evidence that managerial heterogeneity does affect firm policies and performance. Bennedsen et al. (2011) find robust CEO effects for relatively young firms and highly educated CEOs, and for CEOs in rapidly changing growing environments as the one being studied in this dissertation. Additionally, Roberts (2007) studies a number of business cases in which managerial limitations to firm growth play a prominent role and a change in management is instrumental in unlocking the growth potential of a firm.

Our model attempts to capture the role of the CEO style in effort allocation in innovative projects by considering different managers with different skill sets. The base assumption is that different tasks, such as the one of focusing on innovation discovery, require particular skills in order to optimize a firm's approach towards R&D. Managers have the task of proper matching of resources and capabilities with opportunities, identifying and creating appropriate productive opportunities unique to a firm (Kor and Mahoney 2000). A skilled manager is considered to be the one who effectively allocates financial and human resources to seize these opportunities which can create entrepreneurial growth and



competitive advantage. The managers are assumed to have, therefore, a direct impact on the value of the projects they are responsible for managing through their own skill set.

The idea that firm productivity is determined by the quality of the match between the skill set of the manager and the current circumstances of the firm has been the subject of literature modeling efforts. For instance, Eisfeldt and Kuhnen (2013) develop a competitive assignment model in which CEOs are viewed as hedonic goods with multidimensional skill bundles. Likewise, firms' production functions have heterogeneous weights on CEOs' firm-specific knowledge and on general CEO skills such as the ability to grow sales, and the ability to cut costs, for example. Firm productivity is determined by the match between the firm's skill demands and the supply of the skills of its particular manager. Adapting from Eisfeldt and Kuhnen (2013), we assume that different skills are required to manage assets-in-place and R&D projects, as random growth opportunities via innovative discoveries shocks arrive, the quality of firm-CEO matches may change. Similarly, Jenter et al. (2014) extend the standard Bayesian learning model of CEO turnover by allowing the possibility of shocks to the quality of the firm-CEO match to vary over time. Also, Anderson et al. (2012) study managerial incentive provision under moral hazard when growth opportunities arrive stochastically and pursuing them requires a change in management, as a particular set of skills is required to lead the firm in such circumstances vis-à-vis a more stable period.

We develop a framework slightly different from the studies above, as managers are induced to take a pro-active stance towards the development of growth opportunities— which we assume to arrive randomly— rather than passively waiting for a shock and adjusting their position. Thus, our work applies to the particular case of an already active firm, with existent cash-flows deriving from its assets-in-place, which aims to negotiate a compensation package so that the manager will optimally manage their effort allocation between existent projects and a R&D option. In this context, our model findings are in line with the literature, as different managers profiles regarding their skill set imply different solutions for their respective optimal investment decision and effort allocation. Nonetheless, the model also shows that the optimal compensation package that is responsible for aligning both managers and shareholders solutions are independent of managerial skills.

We start by assuming that the manager of a monopolistic firm shows equal skills in directing short and long-term projects (Chapter 3). Then, we produce a model development assuming the existence of heterogeneous skills (Chapter 4). For the Chapter 5, where we now operate under a competitive setting, we start by assuming that both firm's management teams show equal levels of management expertise. Again, we relax this assumption and then study the impact of heterogeneous innovative skills between the incumbent firm's management team and the outsider's.

## 2.3 The agency problem

Agency problems derive intuitively from (i) the notion that optimal investment decisions are taken under the ultimate goal of value maximization (Jensen 2001) and (ii) the del-

egation of tasks, such as the allocation of effort towards innovative and non-innovative investments, from the shareholder to the manager. Whenever there is a misalignment of targets between both, the probability of management actions being detrimental to the maximization goal increases (Jensen and Meckling 1976, Berle and Means 1932, Fama and Jensen 1983)<sup>3</sup>. The short and long-term debate represents one episode of the fundamental misalignment between managers and shareholders, specifically looking at the temporal dimension of the agency dilemma.

Managerial Myopia is the conceptual bedrock of the effort allocation debate, which translates the fundamental differences between managers and shareholders to the decision of managers overweight effort in tasks associated with short-term projects, and underweight effort in tasks associated with riskier innovative long-term projects. Stockholders pursuit of strategies consistent with maximizing the long-run profitability of a company collides with management pursuit of strategies that maximize their own utility (Hill and Snell 1988).

The agency problems are often related to the risk aversion differential between the principal and the agent to justify the misalignment between what is optimal for the shareholder and the manager (Sharpe 1964). Nonetheless, having in mind that this risk aversion gap may be different according to each situation<sup>4</sup>, and with the aim of developing a model as flexible as possible, the dissertation model aims to model agency conflicts without being constrained by any explicit risk aversion consideration. Importantly, the trade-off between managers and shareholders still holds in an environment where there is no strict risk aversion gap. To replicate such environment, we may assume a long-lived firm is run by a sequence of risk-neutral managers where we consider the existence of information asymmetries between these and shareholders, as the latter group is unable of properly observe key value drivers. Another alternative would be to build the model in a framework where managers are protected by a limited-liability condition (Grenadier and Wang 2005). In a nutshell, the agency conflict between managers and shareholders is the product of any investment inefficiency, which can be treated assuming different risk-aversion levels or adding some feature, such as information asymmetries, to a risk-neutral setting. The latter will be the approach used in our model.

The reasoning behind the existence of an agency conflict has been widely covered in literature and is largely related to short-termism literature. Managers are biased towards short-term projects, whether because innovation requires making long-term investments in projects that may have a negative short-term impact on firm's financial statements and conditions (Hoskisson et al. 1993, Graham et al. 2005); due to career concerns (Narayanan 1985); stock market myopia (Laverty 1996); institutional investors preference for near-

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<sup>3</sup>In fact, we can trace the first academic observation of the agency dilemma back to Smith (1776), who has first raised the issue of negligence and profusion in such relationship.

<sup>4</sup>In fact, managerial myopia may be greater or smaller according to the specificity of the environment in which the decision is made. By the same token, shareholders being always well-diversified, as the marginal investor concept preaches, might be at loggerheads with reality, as some of the shareholders of innovative firms may be betting a significant amount of their wealth into an innovative firm, leading the shareholder to have a higher level of exposure to the idiosyncrasies of such bet (e.g., the founder and, simultaneously, shareholder of a start-up firm). Thus, the risk aversion gap can fluctuate accordingly.

term earnings over long-run value (Bushee 1998, 2001); the impact of takeover threats that leads managers to sacrifice long-term interests in order to boost current profits (Stein 1988); manager's work overburden that leads her/him to focus on what is tangible in her/his work (Mintzberg 1973); information asymmetries regarding the investment level (Bebchuk and Stole 1993); or the presence of noise traders (Shleifer and Vishny 1990).

There are also reasons specific to the innovative-heavy sector in which our dissertation focuses that backs the managerial myopia idea. The high-tech sector is usually considered to be one in which managers operate with a greater degree of freedom. Thus, the potential impact of a manager's decision on her/his success or failure is even more significant than in traditional industries, leading to an expansion of this agency cost (Balkin et al. 2000). Moreover, the fact that to perform an objective attribution analysis is difficult when assessing innovation efforts, due to the intrinsically subjective notion of such task, induces managers to take less risky decisions (Makri et al. 2006), i.e., in our model's language, to allocate a sub-optimal low level of effort to long-term projects, as it is so difficult for outsiders to separate unfortunate circumstances from poor decisions of managers regarding a given long-term project engagement (Wiseman and Gomez-Mejia 1998).

Empirical evidence documents that managers do tend to behave in a myopic way. In a survey-based study, Graham et al. (2005) showed that a staggering 78% of the inquired CFOs would give up economic value in exchange for smoother earnings. When firms are dominated by shareholders, innovation strategies are usually favored, as when managers dominate, diversification strategies are most common (Hill and Snell 1988). By the same token, Hoskisson et al. (1993) showed that incentives based on short-term divisional financial performance are negatively related to total R&D intensity. In fact, such contribution is one of the main arguments in favor of studying an optimal compensation package that motivates managers to allocate more effort to the long-term.

In spite of the risk profile differences between short and long-term projects that justify manager's natural myopia, the potential of successful innovation is considered to be such that it creates a trade-off whenever managers are able to participate on the upside created by a given innovation. The potential of innovation is responsible for the findings that show the positive link between innovation, through patent citation for example, and firm's value (Hall et al. 2005, Lanjouw and Schankerman 2001). Furthermore, there are even authors that argue that in high-tech industries not investing in innovation may be more risky from the point of view of managers because investing in innovations may be an institutional norm in those industries (Ahuja et al. 2008), highlighting the decisive role of innovation and, at the same time, the competitive dynamics in this hub. The role of an optimal incentive system is to provide an equilibrium between risk and return so that the manager's chosen optimal combination of weights between short and long-term is simultaneously the one that maximizes the value of the firm, hence, the shareholder's welfare. Managerial Myopia and the trade-off between risk and payoff of allocating effort to riskier innovative projects is the center of our research.

## 2.4 Mechanisms to reduce the agency problem

Internal and external mechanisms of correcting agency conflicts are widely known literature. The first category comprises incentive contracts (Jensen and Smith 1985), insider ownership (Jensen and Meckling 1976), existence of large investors (Shleifer and Vishny 1986), board of administration (Fama and Jensen 1983), the free-cash-flow hypothesis (Jensen 1986) or corporate governance arguments (Hart 1995). External mechanisms includes managers reputation (Shleifer and Vishny 1997), market for managers (Fama 1980), market competition for production factors and product (Hart 1983), takeover fears (Eastbrook and Fischel 1981), monitoring by investment professionals (Chung and Jo 1996) or legal framework (Shleifer and Vishny 1997), and market analysts (Moyer et al. 1989) .

In short, we can sum up all the relevant mechanisms for modeling purposes as two main alternatives to solve the agency problem being studied: monitoring manager's behavior and/or devising an incentive package. In our research, we opt only to study how to motivate managers through an optimal incentive package, rather than focusing on monitoring as a solution itself. The engagement of a manager in innovative efforts is particularly difficult to assess, due to the underlying subjective nature of innovation (Makri et al. 2006), which is even more important in high-tech firms, as R&D exacerbates shareholder-manager information asymmetries (Milkovich et al. 1991). Moreover, managers may incur in some sort of game-playing, as the ambiguity of the appraisal criteria and the monitor's own biases may lead executives to manipulate the relevant variable to which their behavior analysis is tied up to -the "impression-formation" idea- and, ultimately, reduce agent risk-taking, hence, not correcting the risk differential which is inherent to the agency dilemma (Wiseman and Gomez-Mejia 1998). In fact, generally, the full observation of manager actions is either impossible or prohibitively costly (Hölmstrom 1979), as R&D-intensive firms hold technical information that is not promptly available to principals with limited cognitive ability. Thus, in these cases, we will focus our analysis on the alternative way to solve the risk gap issue: through a compensation incentive plan, avoiding what could be an inefficient and potentially counterproductive approach.

The way of aligning managers and shareholders with different profiles in our model takes the form of allowing the manager to participate on the upside of the innovation potential, via a combination of fixed and variable pays which acknowledges the time dimension of innovation (Jensen and Murphy 1990, Tosi Jr and Gomez-Mejia 1989). Indeed, Milkovich et al. (1991) concluded that R&D intensive firms fundamentally differ from low-R&D companies as far as the compensation practices are concerned, as the former tends to have higher relative base pay vis-à-vis fixed base pay, higher relative bonus pay, and greater eligibility for long-term incentive contract, which is consistent with classic agency theory<sup>5</sup>. At the same time, the reasons presented in the paragraph above on why one dismisses behavior monitoring are the cornerstone argument in favor of an optimal compensation

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<sup>5</sup>Moreover, Gerhart and Milkovich (1990) showed a positive link between annual bonuses and firm's return on assets. Also, Leonard (1990) concluded that implementing bonus plans leads firms to a higher return on equity, when compared with bonus-less systems, *ceteris paribus*.

package linked with the financial potential of a given innovation, rather than tied up to some behavioral assessment. At the end of the day, the financial value added by innovation efforts are the key metric of success for any shareholder. Having this said, finding a commitment between a financial-oriented approach and acknowledging the behaviorists arguments shall help us model a far more comprehensive compensation package. We will discuss this next.

Tying the compensation of managers to the financial reward of the allocation of effort to long-term projects is inherently better (Balkin et al. 2000) as it controls for a situation where a high-tech firm may produce a significant amount of innovations but these do not translate into marketable and profitable technologies (Makri et al. 2006). In spite of the lagging link between a firm's innovation efforts and its firm value, the value of a R&D intensive firm eventually reflects the commercial value of its pipeline of innovation (Deng et al. 1999). Allowing the manager to benefit from the commercial value of innovation creates an incentive, *ceteris paribus*, to approximate its optimal weight combination between effort allocated to short-term projects and to more innovative long-term projects to the optimal shareholder combination that maximizes the value of the firm. This could be done, among many other ways, through a variable payment vis-à-vis relying solely on base pay. This variable component could be any instrument ranging from stock options, restricted stock, annual bonus plans, or other that conceptually allow managers to enjoy the upside of innovation applications (Murphy 1999).

Having this said, the optimal incentive package shall not be the same as the standard pay-for-performance used to motivate managers in other industries and rely only on a mix of base and variable pay, as highly-innovative firms fundamentally differ from low-tech ones. Indeed, standard pay-for-performance measures *per se* may even have an adverse impact on innovation in R&D intensive firms (Manso 2011). For instance, for managers whose salaries are tied to equity market value through stock payment or options grants, and in accordance with the contingency valuation theory, there may be, *ceteris paribus*, incentives for managers to act perversely, by intentionally increasing the volatility of a firm's cash flows by selecting too risky long-term projects, regardless of the optimality of such actions on shareholder's value maximization proposition. Additionally, managers may choose to allocate a suboptimal great weight of effort to long-term projects, by over-investing in innovation (Balkin et al. 2000). This may happen, for instance, when shareholders can observe the level of investment but have incomplete information regarding the returns to investment of long-term selected projects (Bebchuk and Stole 1993). In this case, managers have an incentive to deviate from the value-maximization proposition of shareholders because managers may benefit from a high level of investment in innovation without the knowledge of the monitors (the outside investors) about the level of productivity of those investments. To some extent, the signaling effect of investing in innovation can spur, without the correct incentive system, a sub-optimal managerial decision. For these reasons, the optimal compensation plan must respond to the idiosyncrasies of management decisions in a highly-innovative industry, rather than solely applying a standard pay-for-performance

scheme.

As mentioned above, the first step in order to devise a compensation package that aligns managers and shareholders interests is to include a variable pay. The second step, adding value to the standard pay-for-performance structures, must respond to the particularities of motivating managers to innovate more. The idea that managers should be rewarded according to the financial impact of innovations must not be accepted blindly and should take into account the lagging link between firm performance and innovation, which is typically greater in the short-run (Hoskisson et al. 1993), and the uncertainty present in the path of performance. Managers may allocate a significant amount of effort to long-term projects, but, if this effort proves to be financially unsuccessful due to exogenous reasons out of a manager’s control and responsibility, failing to reward manager’s risk-taking behavior would send the wrong signal for managers. The question that arises is how to reward the financial impact of innovations, instead of putting all the emphasis in a behavior assessment (rejected above due to the reasons presented), but still control for this kind of situations.

To do so, we are inspired by Manso (2011) approach and we incorporate the concept of tolerance to failure in our model. In fact, tolerance to failure is arguably one of the major drivers of private firms innovation successes (Ferreira et al. 2012). The way we plug-in this tolerance to failure is through the addition of a fixed payment term in the compensation structure of the manager. To some extent, the fixed component of the compensation structure aims at correcting the errors left by an incomplete variable-pay-only based structure. Importantly, this bonus payment is conditional on the discovery of the innovation, rather than on the exercise of the option to implement a given project. The fixed component serves, therefore, two purposes in our model: (i) to remunerate managers for allocating effort to risky long-term projects and (ii) to remunerate past failures and induce managers to avoid the short-term bias, answering to the demands of behavioral studies focused on the shortcomings of linking innovation incentives with a financial measure- rather than behavioral- of managerial engagement in R&D assessment (Makri et al. 2006). This approach allows the model to answer to the behavioral demands, since managers have room to fail, but still designing an incentive package focused on the marketability of innovation. To some degree, in order to induce managers to allocate more effort to long-term projects, managers should be paid like a scientist is (Werner and Tosi 1995).

## 2.5 Related Literature and Methodology

The model we propose herein differs from a large body of work that looks at agency problems in the context of a firm’s investment policy in two key points. First, our model follows the real options methodology, rather than considering a static framework. Second, our approach explicitly aims at modeling and aligning interests between conflicting agents through the effort allocation variable, rather than the investment trigger.

Regarding the methodological difference, we consider that a manager’s decision of effort

allocation is taken under a high level of uncertainty, as far as the cash-flows pay off the structure, which is coherent with the idea of innovation being riskier than simply following *status quo* type of decisions. Also, whenever a manager decides on how will her/his actions be split between short and long-term projects in a given period, there is a high level of irreversibility, as they can't simply go back in time and recoup the effort put in innovative projects. Finally, these decisions are not now-or-never actions, as managers have the ability to wait, collect information and then make a wiser decision (McDonald and Siegel 1986), especially in R&D-heavy projects where waiting has an increased value (Aghion and Tirole 1994, Ferreira et al. 2012). Due to the multi-dimensional context in which the manager-shareholder interactions unfolds, Real Options modeling is a superior methodology to cope with the three conditions of such context (Dixit and Pindyck 1994). Hence, the analysis of this type of decision must be done under a model that acknowledges all the value determinants of such decision, including aspects like the option to wait, so vital in the high-tech industry. Indeed, an appropriate identification of the context in which managers operate plays a crucial role in the identification of optimal management and incentive alignment practices, leading to the goal of the maximization of a firm's value.

Modeling the managers and shareholders agency relationship in the particular case of the choice of allocation of effort between short and long-term projects has been the subject of recent literature (Bhattacharya et al. 2017, Ferreira et al. 2012, Manso 2011, Edmans 2009). Edmans (2009) and Bhattacharya et al. (2017) provide a theoretical model which translates the issue of the trade-off between different short and long-term projects in a static and deterministic framework. The manager decides the scale of the investment and the allocation of effort towards different projects, conditional on the observed values of a set of exogenous variables, without any regard to the uncertainty of the decision, or the continuous interaction between the manager and the shareholder's interests throughout the process. Manso (2011), Ferreira et al. (2012) make a step further and improve from the basis grounded by previous models. To acknowledge the role that uncertainty has in the decision-making process, the authors use a class of Bayesian decision models known as bandit problems. Through a two-armed bandit problem theoretical approach, the authors embed a bandit problem into the specific principal-agent framework, where the true distribution of payoffs between different projects is considered uncertain, weighted by an exogenous probability of success. Our work differs from existing literature by adding a dynamic component to the models, rather than constraining the manager-shareholder interaction into a static set. By using a Real Options framework our model intends to make the leap from static models to continuous models and simultaneously acknowledging the role that uncertainty has whenever managers decide their combination of effort. To do so, the model treats the future outcomes of innovation endeavors as a stochastic variable.

Regarding the solution for the agency problem, we shift our analysis to the effort allocation variable as our companion variable. Literature focusing on the manager and shareholder agency problem in the particular case of a firm's R&D policy has also been a recent topic of study among academics. In fact, a recent branch of literature has focused on

the agency problem by explicitly looking at the investment trigger alignment between managers and shareholders (Grenadier and Wang 2005, Nishihara and Shibata 2008, Cardoso and Pereira 2015). Here we study a different problem: we focus on the alignment between managers and shareholders via the optimal effort allocation set instead. Having this mind, the model aims to extend the analysis to how can firm shareholders actively structure compensation incentives that align both managers and shareholders effort allocation optimal solutions.

In conclusion, we aim at contributing to the field laid out by this new breed of works as our model borrows insights such as the focus in effort allocation from Edmans (2009), Manso (2011), Ferreira et al. (2012), Bhattacharya et al. (2017) and we adapt the logic of interest alignment from Grenadier and Wang (2005), Nishihara and Shibata (2008), Cardoso and Pereira (2015) to our effort allocation variable. All following a real options approach.



## Chapter 3

# Basic model

Consider a firm facing a chance to invest in a R&D project. The firm is already active and produces a stream of cash flows through its assets-in-place. The firm faces the decision of negotiating a remuneration package for a manager whose responsible for managing two types of ventures: existing short-term projects (ST) and long-term innovative projects (LT). The opportunity of investing in the R&D project is unique to the firm so that it faces no competition for the project *ex-ante*. Managers while managing a portfolio of projects have to make two separate decisions. First, they need to decide on the effort allocated to run short-term projects (weight of  $w$ ) and long-term projects (weight of  $(1 - w)$ )<sup>1</sup>. The effort allocated to short-term projects represents the regular tasks of running an already active firm. The effort allocated to long-term projects is interpreted as the effort applied in early stages of a R&D project. The particular tweak of the model's intuition is that managers have to bear the opportunity cost of having to commit (store) today to some effort level associated with the development of the R&D project, which ultimate outcome will only unfold into the future. Second, the manager then runs a classic option to invest on the underlying R&D project. The manager is assumed to implement the project once a given threshold is crossed, maximizing its own value function. We assume that when the investment happens the firm operates under a natural monopoly setting and the firm faces no *ex-post* competition. Furthermore, the model assumes that shareholders cannot run the firm autonomously as they face intrinsic constraints, which can be interpreted as lack of managerial know-how or some external restriction imposed in the company's article of association.

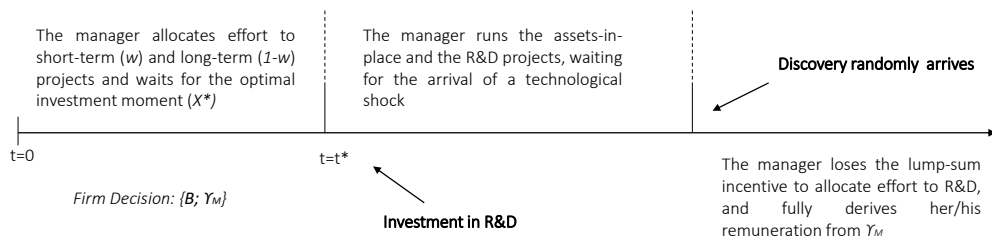
The principal-agent framework is derived under risk-neutral assumptions and both managers and shareholders are assumed to be rational and utility maximizers. An agency conflict derives from the assumption of the existence of information asymmetries between both, as owners are unable of properly observe key value drivers so that the option becomes worthless without a manager. Shareholders are not able to control manager's effort and actions, which implies that fully controlling managerial decisions is not a viable alternative. Nonetheless, taking into account how managers decide, shareholders can induce managers

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<sup>1</sup>The variable  $w$  can take any value as long as  $0 < w < 1$ .

to act in a given way by adjusting their compensation package. Hence, shareholders will choose to offer a manager the optimal contract which induces managers to choose a combination of effort  $\{w^*$  to ST projects;  $(1 - w^*)$  to LT projects $\}$  that maximizes the value of the firm.

The compensation scheme proposed by shareholders shares two main features. First, in order to induce managers to allocate effort in a way that maximizes their own utility, shareholders align both players' interests by offering managers the possibility to participate on the value of the firm through a variable pay component ( $\gamma_M$ ). Second, to ensure that managers allocate effort to a project in its exploratory stages, managers have to be offered a compensation for the risk they bear if the project does not produce any innovation success. Thus, shareholders add a fixed salary ( $B$ ) to the compensation package. Therefore, there are two key moments affecting the shareholder-manager interaction. During the stage in which managers allocate effort to discover a given technology, they are entitled to a fixed pay and a value-sharing bonus on the cash flows generated by the assets-in-place of the firm. Once the innovation discovery is made, the managers stop benefiting from the lump-sum innovation bonus and, in exchange, start receiving a variable component on the new cash flows generated by the innovative project. Importantly, the manager only loses the fixed pay when the innovation is discovered, not when the investment moment takes place. The manager enjoys a path-dependent compensation plan (Figure 3.1).



**Figure 3.1:** The decision framework for both managers and shareholders.

Once the effort allocation decision is successfully completed, the manager's problem reverts to a classic option to invest case. Similar to a call option, the manager faces the decision of choosing the proper investment timing. The managers face a trade-off between investing now or delaying her/his decision in order to collect information and spur a wiser decision in an uncertain world. Importantly, once the manager decides to implement the innovative project, the manager will bear a lump-sum effort cost ( $\xi$ ), which we translate into pecuniary terms as in Grenadier and Wang (2005). This effort cost reflects the execution costs associated with the investment implementation which may range from, for instance, additional hours of labor or reputation risks associated with the investment decision. Simultaneously, the stockholders will accommodate the full investment cost ( $K$ ).

For the sake of convenience, three additional assumptions are needed. First, we assume that the option to invest follows the framework of contingent claim with infinite maturity. When perpetual periods are considered, or even long-lived options, changes in time

are negligible when compared to the option's maturity. The assumption of no time-limit appears in related literature (e.g. Grenadier and Wang 2005). In our model's language, this translates into an assumption of a manager who is expected to remain in office for a considerable amount of time so that time is no constraint. Second, we assume the compensation solution to be less expensive than any other alternative (such as monitoring), otherwise the shareholder would use those alternative approaches to induce managers to decide optimally and our incentive mechanism would become pointless. Third, we dismiss the possibility of the manager acquire the project and run it by herself/himself by assuming that the manager is liquidity constrained and cannot obtain additional funding.

### 3.1 The manager's perspective

Let  $X$  represent the present value of the cash flows of an active firm, assumed to evolve stochastically as a Geometric Brownian Motion:

$$dX(t) = \alpha X(t)dt + \sigma X(t)dz(t), \quad (3.1)$$

where  $\alpha$  ( $\alpha = r - \delta$ ) is the instantaneous risk-neutral drift,  $\sigma$  is the instantaneous standard deviation, and  $dz$  is the increment of a standard Wiener process. We assume  $X \equiv X(0) > 0$ . Both the owner and the manager are risk neutral, with the risk-adjusted required rate of return equal to the risk-free rate denoted by  $r$ . Additionally,  $\delta$  ( $> 0$ ) is the dividend-yield, corresponding the opportunity cost of deferring the implementation of the project instead of immediately decide to invest.

In general terms, the global welfare function of the manager,  $V_M(X)$ , can be represented as shown below:

$$V_M(X) = w\gamma_M\psi X + B + (1 - w)M(X) \quad (3.2)$$

where  $w$  stands for the effort allocated by the managers to the short-term,  $(1 - w)$  for the effort allocated to long-term projects,  $\gamma_M$  for the value-sharing rate allocated to the managers,  $\psi$  for the impact of the manager's skills on the project's cash flows,  $X$  for the current cash flows generated by the firm's assets-in-place, and  $M(X)$  for the R&D investment option value.

Equation (3.2) represents the trade-off presented to managers while deciding their effort allocation strategy. On one hand, allocating effort towards short-term projects allows managers to benefit from the value of the firm's assets-in-place. On the other hand, allocating effort towards managing the R&D option allows managers to enjoy the upside of such project.

In order to understand how the effort allocation decision is ultimately made, we shall now address the valuation of the R&D option, a key component in the manager's decision-making process. As being a contingent claim, and following the standard arguments<sup>2</sup>, the option value for the manager,  $M(X)$ , must satisfy the following second-order

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<sup>2</sup>See Dixit and Pindyck (1994) for details.

ordinary differential equation (o.d.e.):

$$\frac{1}{2}\sigma^2 X^2 \frac{\partial^2 M(X)}{\partial X^2} + \alpha X \frac{\partial M(X)}{\partial X} - rM(X) + rB + \lambda[\gamma_M \psi \phi X - M(X)] = 0 \quad (3.3)$$

where two terms are added to the the traditional option valuation framework.

The last term on the left-hand-side of equation (3.3) considers the different outcomes that may arise from the R&D stage. If managers allocate effort to the discovery of any innovative technology and the outcome is a success, she/he will be entitled to a value-sharing-bonus ( $0 < \gamma_M > 1$ ). The impact of the new technology has an incremental effect on the existent cash flows— up until this moment generated exclusively from the firm’s on-going operations via existing assets-in-place—, by an incremental factor of  $\phi$ . Furthermore, our model considers that managerial skills have a direct impact on the value of the firm’s projects. A talented manager is the one that can add value to the firm through the way they manage the firm’s assets ( $\psi > 1$ ), a neutral-manager is the one whose influence on the project value is non-existent ( $\psi = 1$ ), and a less capable manager is the one whose management skills are detrimental to the project value so that she/he actually destroys value from it ( $\psi < 1$ ). The value added by managers to a project via their skill set is given by  $(\psi - 1)X$ . All in all, if successful, the manager’s welfare will be given by  $[\gamma_M \psi \phi X]$ . If not, the managers preserves the R&D option alive  $[M(X)]$ .

During the period between the manager allocates effort to a long-term project, the outcome is unknown and the investment has yet to be implemented, the manager is entitled to a variable component on the cash flows generated by the assets-in-place ( $\phi X$ ) and a fixed pay component ( $B > 0$ ) to induce the manager to allocate effort to a risky project. The term  $rB$  reflects the continuous fixed pay component of the manager’s compensation structure. When it becomes optimal to invest but the technological shock has not yet arrived, the manager is entitled to a fraction of the cash flows that the firm generates (given by  $\gamma_M$ ) and is still entitled to the fixed pay term. Again, since the firm is assumed to only remunerate the manager with a fixed pay the R&D stage and the innovation discovery itself (rather than the investment), only when the technological shock arrives she/he will exchange the fixed term pay for a full variable compensation structure. Therefore, this last term on the left-hand-side of equation (3.3) can be additionally interpreted as the expected change in manager’s wealth associated with the discovery of an investment project based on the new technology. This equation (3.3) captures the intuition shown above in Figure 3.1.

The probability of success during the research stages (technical uncertainty) is modeled as a Poisson arrival shock. From the time of this investment, the discovery process evolves randomly according to a Poisson distribution with a constant hazard rate  $\lambda(> 0)$ . In our model,  $\lambda$  is the mean arrival rate of an innovation shock, which, if successful, will add up to the cash flows of the company by an incremental factor of  $\phi$ . This approach has its roots in the works of Loury (1979), Dasgupta and Stiglitz (1980), Lee and Wilde (1980), Reinganum (1983), Dixit (1988) and have been applied in multiple models since then (e.g.

Weeds 2002).

The solution of the o.d.e takes the following form:

$$M(X) = \frac{\lambda\gamma_M\psi\phi X}{r + \lambda - \alpha} + \frac{rB}{r + \lambda} + A_1X^{\beta_1} + A_2X^{\beta_2} \quad (3.4)$$

where:

$$\beta_1 = \frac{1}{2} - \frac{r - \delta}{\sigma^2} + \sqrt{\left(\frac{r - \delta}{\sigma^2} - \frac{1}{2}\right)^2 + \frac{2(r + \lambda)}{\sigma^2}} > 1 \quad (3.5)$$

$$\beta_2 = \frac{1}{2} - \frac{r - \delta}{\sigma^2} - \sqrt{\left(\frac{r - \delta}{\sigma^2} - \frac{1}{2}\right)^2 + \frac{2(r + \lambda)}{\sigma^2}} < 0 \quad (3.6)$$

The general solution can be divided into two parts. The first two terms on the right-hand-side of equation (3.4) are the solution for the non-homogeneous part of the differential equation. The last two terms correspond to the solution for the homogeneous part of the differential equation.

Furthermore, the option value for the manager,  $M(X)$  is subject to the following boundary conditions:

$$\lim_{X \rightarrow 0} M(X) = \frac{rB}{r + \lambda} \quad (3.7)$$

$$\lim_{X \rightarrow X_M^*} M(X) = \frac{\lambda\gamma_M\psi\phi X_M^*}{r + \lambda - \alpha} - \frac{\lambda B}{(r + \lambda)(1 - w)} - \frac{\xi}{1 - w} \quad (3.8)$$

$$\lim_{X \rightarrow X_M^*} \frac{\partial M(X)}{\partial X} = \frac{\lambda\gamma_M\psi\phi}{r + \lambda - \alpha} \quad (3.9)$$

where  $X_M^*$  represents the manager's trigger value for implementing the project.

The first boundary condition (equation (3.7)) establishes that as the cash flows of the active company ( $X$ ) approach zero, since the innovation affects the value of the firm through an incremental effect over this base, so should the value of the long-term project to the manager converge to  $\left(\frac{rB}{r + \lambda}\right)$ . This is the consequence of the way we designed the value of the firm post-innovation in relation with the prior-to-innovation firm value. In our model,  $\left(\frac{rB}{r + \lambda}\right)$  represents a severance pay a manager receives by exiting the company once the cash flows generated by this firm reaches the zero-bound. The second boundary condition (equation (3.8)), generally called the "value-matching condition" establishes the payoff for the managers when the project is implemented, so that for the level of cash flows at which is optimal to invest ( $X_M^*$ ), the value of the option must equal the net present value that the manager receives by undertaking the R&D project. According to the equation (3.8), for  $X = X_M^*$  the manager is entitled to a fraction  $\gamma_M$  of the incremental cash flows ( $\phi X$ ), taking into account the level of managerial skill ( $\psi$ ). More skilled managers, with the same innovation breakthrough ( $\phi X$ ), *ceteris paribus*, yield a greater value due to a higher  $\psi$ . Note that this term is weighted by an augmented discount factor of  $\left(\frac{1}{r - \alpha + \lambda}\right)$ , where the technical uncertainty associated with the outcome of the R&D stage (given by  $\lambda$ ) adds

up to the traditional market discount rate  $(r - \alpha)$ . To some extent, this augmented discount factor represents a global probability adjusted for the usual time-value of money and also the risk intrinsic to a R&D project as previously described. Additionally, the managers face two sources of losses: (i) the loss of the fixed pay  $\left(\frac{\lambda B}{(1-w)(r+\lambda)}\right)$ , which is independent of the implementation of the project but the manager still faces that loss when the discovery takes place, and (ii) the effort costs associated with the execution of the project  $\left(\frac{\xi}{1-w}\right)$ . The third boundary condition (equation (3.9)), known as "smooth-pasting condition" or "high-contact condition", ensures that the two value function tangentially meet at  $X = X_M^*$ , i.e., that  $M(X)$  is continuously differentiable along  $X$ .

Applying the first boundary condition (equation (3.7)) to the general equation for the value of the option (equation (3.4)), we get that  $\lim_{X \rightarrow \infty} A_2 X^{\beta_2} = -\infty$  (note that  $\beta_2 < 0$ ), which violates the first boundary condition. Consequently, in order to ensure that the first boundary condition is respected,  $A_2$  must be set equal to zero<sup>3</sup>. Therefore, the term  $A_2 X^{\beta_2}$  drops from the value of the option and we can rewrite the general solution as:

$$M(X) = \frac{\lambda \gamma_M \psi \phi X}{r + \lambda - \alpha} + \frac{rB}{r + \lambda} + A_1 X^{\beta_1} \quad (3.10)$$

The other two boundary conditions are used to get the remaining unknowns— the constant  $\beta$  and the trigger  $X_M^*$ . Following the standard procedures and using standard calculus, the solution for the value of the option to invest in a R&D project comes:

$$M(X) = \begin{cases} \left( \frac{\lambda \gamma_M \psi \phi X_M^*}{r + \lambda - \alpha} - \frac{\lambda B}{(r + \lambda)(1-w)} - \frac{\xi}{1-w} \right) \left( \frac{X}{X_M^*} \right)^\beta & X < X_M^* \\ \frac{\lambda \gamma_M \psi \phi X}{r + \lambda - \alpha} - \frac{\lambda B}{(r + \lambda)(1-w)} - \frac{\xi}{1-w} & X \geq X_M^* \end{cases} \quad (3.11)$$

and the investment trigger is given by:

$$X_M^* = \frac{\beta}{\beta - 1} \frac{(r - \alpha + \lambda)(B\lambda + (r + \lambda)\xi)}{(1-w)\gamma_M \lambda (r + \lambda)\phi\psi} \quad (3.12)$$

As already mentioned, the present model aims to go a step further and taking into consideration the role of effort allocation by managers. A standard real options model focused on the agency conflicts would stop the computation at the trigger level, using it as a benchmark variable to align the interests of managers and shareholders (e.g. Grenadier and Wang 2005, Nishihara and Shibata 2008, Cardoso and Pereira 2015). We extend the analysis of agency issues and we compute for each agent, their optimal effort allocation solution between short-term projects ( $w$ ) and long-term projects ( $1 - w$ ). Equation (3.13) and equation (3.14) gives us the optimal allocation of effort to short-term projects by managers— being the symmetric the optimal allocation of effort to long-term projects—, as the solution that maximizes the manager's welfare, taking into account the trade-off

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<sup>3</sup>Hereinafter,  $\beta_1$  is also termed as  $\beta$ , as it is the only relevant  $\beta$  parameter for our analysis.

between the different types of projects.

$$\max_w [w\gamma_M\psi X + B + (1 - w) M(X_M^*)] \quad (3.13)$$

$$w_M^* = 1 - \frac{\beta}{\beta - 1} \frac{(B\lambda + (r + \lambda)\xi) \left( \frac{(r - \alpha + \lambda)}{\lambda\phi} \right)^{\beta - 1}}{X\gamma_M(r + \lambda)\psi} \quad (3.14)$$

The equations above highlight the decision-making process undergone by the managers while deciding their effort allocation decision under an uncertain world.

### 3.2 The shareholder's perspective

Let us now analyze the shareholder's position. The shareholder also holds a contingent claim on the cash flows generated by the firm. The shareholder is initially, by definition, entitled to the totality of the cash flows produced by the company. However, as described above, the shareholder is constrained so that it delegates management duties to the manager, due to which the latter is given the contractual right to be entitled to a fraction of the cash flows pool by a factor of  $\gamma_M$ . Shareholders will capture the difference ( $\gamma_S = 1 - \gamma_M$ ). The problem is now posed under a symmetric perspective, and we start by considering the global welfare function of the shareholder,  $V_S(X)$ , which can be represented as shown below:

$$V_S(X) = w\gamma_S\psi X - B + (1 - w) S(X) \quad (3.15)$$

Equation (3.15) represents the trade-off presented to shareholder while deriving their effort allocation strategy. Note that now shareholders derive their optimal solution which may or not be the one selected by managers. The role of the optimal compensation package is to ensure that both players' solution will eventually converge.

Accordingly, the R&D option value of the shareholder,  $S(X)$ , must satisfy the following o.d.e:

$$\frac{1}{2}\sigma^2 X^2 \frac{\partial^2 S(X)}{\partial X^2} + \alpha X \frac{\partial S(X)}{\partial X} - rS(X) - rB + \lambda[\gamma_S\psi\phi X - S(X)] = 0 \quad (3.16)$$

The interpretation of the shareholder's o.d.e is symmetric to the manager's perspective and has some additional tweaks. First, the shareholder is now negatively impacted by the fixed pay she/he must pay to reward managerial R&D engagement ( $-rB$ ). Secondly, since shareholders have delegated the management function to a given agent, they are now passively exposed to manager's decisions on effort allocation, the reason why the agency problem is raised. The last term on the left-hand-side of the differential equation considers the different outcomes that may arise from the R&D stage. If the managers allocate effort to the discovery of any innovative technology and the outcome is a success, the shareholder will be entitled to a value-sharing-bonus ( $\gamma_S$ ) once the project is implemented. The impact

of the new technology will have an incremental effect on the level of the firm's cash flows by an exogenous factor of  $\phi$ . The shareholder will have to, once the managers decide to invest, share a variable pay component ( $\gamma_M$ ) with the manager, which will be also weighted by the skills of the manager ( $\psi$ ). Similarly to the manager's perspective, if the outcome is a failure, the firm preserves an option to invest in a future technology discovery [ $S(X)$ ]. Therefore, this term captures the expected change in shareholder's wealth associated with the discovery of an investment project based on the new technology.

The general solution of the o.d.e takes the following form:

$$S(X) = \frac{\lambda\gamma_S\psi\phi X}{r + \lambda - \alpha} - \frac{rB}{r + \lambda} + A_1X^{\beta_1} + A_2X^{\beta_2} \quad (3.17)$$

Furthermore, the shareholder-value function must satisfy the following boundary conditions:

$$\lim_{X \rightarrow 0} S(X) = -\frac{rB}{r + \lambda} \quad (3.18)$$

$$\lim_{X \rightarrow X_S^*} S(X) = \frac{\lambda\gamma_S\psi\phi X_S^*}{r + \lambda - \alpha} + \frac{\lambda B}{(r + \lambda)(1 - w)} - \frac{K}{1 - w} \quad (3.19)$$

$$\lim_{X \rightarrow X_S^*} \frac{\partial S(X)}{\partial X} = \frac{\lambda\gamma_S\psi\phi}{r + \lambda - \alpha} \quad (3.20)$$

where  $X_S^*$  represents the shareholder's trigger value for implementing the project.

The first boundary condition (equation (3.18)) is the symmetric of the absorbing-barrier condition shown for the manager's value-function, where the severance pay now affects negatively the value-function of the shareholder when the cash flows from the assets-in-place tend to zero. Following the same reasoning as described for the managers, we drop the term  $A_2X^{\beta_2}$  from the value of the option. According to equation (3.19), for  $X = X_S^*$  the shareholder is entitled to a fraction  $\gamma_S$  of the incremental cash flows ( $\phi X$ ), taking into account the level of managerial skill ( $\psi$ ). Additionally, the shareholders will fully bear the investment cost ( $K > 0$ ). Nonetheless, shareholders will now be positively impacted by the net saving associated with the fixed component of the manager's compensation plan, contingent on the success of the R&D stage  $\left(\frac{\lambda B}{(r + \lambda)(1 - w)}\right)$ . The third boundary condition (equation (3.20)) ensures that the two value function tangentially meet at  $X = X_S^*$ , i.e., that  $S(X)$  is continuously differentiable along  $X$ .

Following the standard procedures, the solution for the value of the option to invest in a R&D project comes:

$$S(X) = \begin{cases} \left( \frac{\lambda\gamma_S\psi\phi X_S^*}{r + \lambda - \alpha} + \frac{\lambda B}{(r + \lambda)(1 - w)} - \frac{K}{1 - w} \right) \left( \frac{X}{X_S^*} \right)^\beta & X < X_S^* \\ \frac{\lambda\gamma_S\psi\phi X}{r + \lambda - \alpha} + \frac{\lambda B}{(r + \lambda)(1 - w)} - \frac{K}{1 - w} & X \geq X_S^* \end{cases} \quad (3.21)$$



and the investment trigger is given by:

$$X_S^* = \frac{\beta}{\beta - 1} \frac{(r - \alpha + \lambda)(-B\lambda + (r + \lambda)K)}{(1 - w)\gamma_S\lambda(r + \lambda)\phi\psi} \quad (3.22)$$

Analogously to the manager's approach, the shareholder derives an optimal effort allocation strategy between short and long-term projects that maximizes her/his wealth. The solution is presented below<sup>4</sup>.

$$\max_w [w\gamma_S\psi X - B + (1 - w)S(X_S^*)] \quad (3.23)$$

$$w_S^* = 1 - \frac{\beta}{\beta - 1} \frac{(-B\lambda + K(r + \lambda)) \left( \frac{r - \alpha + \lambda}{\lambda\phi} \right)^{\frac{\beta}{\beta - 1}}}{X\gamma_S(r + \lambda)\psi} \quad (3.24)$$

The equations above highlight the decision-making process undergone by the shareholders where they compute what would be the effort allocation chosen by managers that would optimize the shareholder's welfare.

### 3.3 Optimal wage setting

Taking into consideration our assumption on the fixed compensation pay being exogenous ( $B$ ), the alignment of interests between players derive from an adjustment via the variable pay component ( $\gamma_M$  and  $\gamma_S$ ). The optimal compensation package ( $\gamma_M^*$ ,  $\gamma_S^*$ ) shares two main features: (i) it ensures the alignment between the manager's and shareholder's optimal solutions, i.e., when the compensation structure is optimal, the optimal allocation of effort between short and long-term projects which maximizes the wealth of the manager is also the one maximizing shareholder's wealth, and (ii) the optimal compensation structure maximizes the aggregate welfare, i.e., when the optimal solution is applied, the value produced for the stakeholders as an aggregate is maximum. It is due to this second feature that we can retrieve the solution as if the problem was raised under the eyes of the social planner<sup>5</sup>.

**Proposition 1.** *The variable pay that allows a full alignment between manager's and shareholder's effort allocation is given by:*

$$\gamma_M^* = \frac{\xi}{K + \xi} + \frac{\lambda}{r + \lambda} \frac{B}{K + \xi} \quad (3.25)$$

$$\gamma_S^* = \frac{K}{K + \xi} - \frac{\lambda}{r + \lambda} \frac{B}{K + \xi} \quad (3.26)$$

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<sup>4</sup>We assume an additional constraint in the model,  $K(r + \lambda) > B\lambda$ , otherwise  $w$  would be able to take values greater than 1. Hereinafter we take this assumption and we shall use it in further derivation analysis.

<sup>5</sup>See Appendix.

*Proof.* The immediate way of solving for the optimal compensation structure responsible for aligning the effort choices of both players is given by setting (3.24) equal to (3.14), and solving for  $\gamma$  of one of the agents, since  $\gamma_M = 1 - \gamma_S$ .  $\square$

The optimal variable pay that makes the full alignment possible depends on three factors<sup>6</sup>.

The first term of equation (3.25) and equation (3.26) reflects the effort structure of the investment moment. The interpretation is straightforward: the greater the managerial effort associated with the implementation of the project relative to the total cost burden faced by both agents, the greater will be the value-sharing rate demanded by managers to be aligned with the shareholders' position. By the same token, the greater the investment cost relative to the total cost burden faced by both agents, the greater will be the value-sharing rate demanded by shareholders to be aligned with the managers' solution.

The second term of equation (3.25) and equation (3.26) captures the effect of the likelihood of the R&D stages yielding a success in the optimal value-sharing component. This relation is deemed as positive, as the greater the probability (given by a greater value for the mean arrival rate  $\lambda$ ), *ceteris paribus*, the greater will be  $\gamma_M^*$ . The logic is quite intuitive: since the R&D stages are more probable to be a success, the sooner the manager will be able to optimally invest in a project based on that probable innovation discovery<sup>7</sup>, which implies that the manager will also sooner lose the benefit of receiving the bonus fixed pay to undertake R&D activities ( $B$ ), which, consequently, leads to managers demanding a higher value-sharing bonus to compensate such loss.

The third term of equation (3.25) and equation (3.26) positively relates  $\gamma_M^*$  and the ratio between the fixed pay ( $B$ ) and the total burden assumed by managers and shareholders with the implementation of the investment project ( $K + \xi$ ). The greater the fixed compensation during early R&D stages, i.e., before the arrival of the technological shock, *vis-à-vis* the costs associated with the execution of the project, the greater will be the value-sharing rate which aligns both players. To understand this positive relation, first of all, it is important to remember the idea that the fixed compensation, *per se*, is a source of agency problems. If the shareholder does not allow the manager to participate in the upside potential of a R&D project, there is no incentive for managers to take on riskier projects - the short-termism idea. That is why we combine the fixed pay with a variable component (Murphy 1999). Having this said, it is now logical to assume a positive relationship between the third term and the optimal sharing rate. The greater the fixed pay component relative to the costs of the investment execution, *ceteris paribus*, the greater the misalignment between both the manager and the shareholder. To solve this, a greater  $\gamma_M$  is required.

Replacing the optimal compensation structure for each agent in the respective function yields the optimal effort allocation strategy that ensures the perfect alignment between

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<sup>6</sup>For all the derivatives behind the analysis, see the analytical solutions in the Comparative Statics section.

<sup>7</sup>As the result of  $\frac{dX_M^*}{d\lambda} = \frac{\partial X_M^*}{\partial \lambda} + \frac{\partial X_M^*}{\partial \beta} \frac{\partial \beta}{\partial \lambda} < 0$ . See Appendix.

managers and shareholders<sup>8</sup>.

**Proposition 2.** *The effort allocation towards short-term projects that aligns both managers and shareholders is given by:*

$$w_{SP}^* = w_S^*(\gamma_S^*) = w_M^*(\gamma_M^*) = 1 - \frac{\beta(K + \xi) \left( \frac{r + \alpha - \lambda}{\lambda\phi} \right)^{\frac{\beta}{\beta-1}}}{X(\beta-1)\psi} \quad (3.27)$$

where  $w_{SP}^*$  stands for the optimal weight allocation under the perspective of the social planner.

As we analyzed, aligning the effort allocation of agents, under the basic version of our model, takes only into account three groups of variables: variables associated with the cost burden linked with the implementation of the R&D project, variables related with the technical uncertainty of the outcome of the R&D stage and with the market uncertainty of the project, and the fixed compensation term. Hence, Proposition 1 allows us to state that:

**Corollary 1.** *The optimal value-sharing rate is independent of key value drivers:  $X$ ,  $\alpha$  and  $\sigma$ . Furthermore, it is also independent of the managerial skill ( $\psi$ ) and the factor of improvement of cash flows associated with an innovation discovery ( $\phi$ ).*

Moreover, an important insight comes from the relation between the derivation procedure of an optimal value-sharing rate via effort allocation, our companion variable, and its impact on the agency conflict transposed in the investment triggers. We show that taking a step further and focusing on effort allocation does not neglect the traditional investment trigger mismatch issue between managers and shareholders. In particular, it is easy to show that when the optimal value-sharing rate is applied, not only the manager and the shareholder agree on the same distribution of effort allocation between short and long-term projects (Proposition 1), but also agree on the investment trigger. This finding of our model is relevant, as we show that it is possible to take a step further in modeling agency conflicts and consider a different companion variable, and still addressing the classic literature issue associated with investment triggers mismatches.

**Corollary 2.** *The optimal value-sharing rate ensures both the alignment of the effort allocation between different projects and of the investment triggers, between both players.*

*Proof.* See Appendix. □

Hence, replacing the optimal effort allocation strategy, by factoring in the optimal compensation policy for each agent in the respective trigger function yields the optimal investment timing strategy that ensures the perfect alignment between managers and shareholders. Thereby:

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<sup>8</sup>Applying the  $\gamma_M^*$  in the  $w_M^*$  results in the same solution as if one replaces  $\gamma_S^*$  in  $w_S^*$ .

**Proposition 3.** *The optimal investment trigger that aligns both managers and shareholders is given by:*

$$X_{SP}^* = X_S^*(w_S^*(\gamma_S^*), \bar{X}) = X_M^*(w_M^*(\gamma_M^*), \bar{X}) = \bar{X} \left( \frac{r - \alpha + \lambda}{\lambda \phi} \right)^{\frac{1}{1 - \beta}} \quad (3.28)$$

where the optimal allocation solution is designed while considering the current state of the firm, given by  $\bar{X}$ , the current level of cash flows generated by the firm at that moment.

The investment policy responsible for aligning the investment triggers of both investors is shown to be a function of the current level of the cash flows generated by the firm's assets-in-place, both the technical and the market uncertainty, the incremental effect of innovation and other key value drivers.

### 3.4 Comparative statics and Model Intuition

Under our model setting, we considered that managers running an innovation-oriented firm are called to action in two different moments. First, the manager of a high-tech firm is the responsible for allocating effort to the actual process of discovery of any innovative technology. Second, the manager decides the optimal timing to exercise the option to invest in a given project, which success is tied up to a stochastic technological shock. The following subsections focus on each of these decisions and in its relationship with the optimal compensation policy that aligns managers and shareholders interests by providing a comparative statics analysis. Note that the analysis of  $\gamma_M$  is truly the relevant one since that is the variable shareholders can control in our model setup in order to induce managers to act in a given direction. Looking at  $\gamma_S$  and the optimal compensation policy is merely an exercise of symmetry.

#### 3.4.1 Decision 1: Optimal Effort Allocation

It is particularly relevant to observe the impact of changes in the value-sharing rate in the way managers ultimately decide how to allocate effort. Taking the derivatives we get (table 3.1):

$$\frac{dw_M^*}{d\gamma_M} = \frac{\beta (B\lambda + (r + \lambda) \xi) \left( \frac{r - \alpha + \lambda}{\lambda \phi} \right)^{\frac{\beta}{\beta - 1}}}{X (\beta - 1) \gamma_M^2 (r + \lambda) \psi} > 0$$

$$\frac{dw_S^*}{d\gamma_M} = - \frac{\beta (-B\lambda + (r + \lambda) K) \left( \frac{r - \alpha + \lambda}{\lambda \phi} \right)^{\frac{\beta}{\beta - 1}}}{X (\beta - 1) (\gamma_M - 1)^2 (r + \lambda) \psi} < 0$$

**Table 3.1:** Partial Derivatives on Manager and Shareholder's optimal effort allocation ( $w_M^*$ ;  $w_S^*$ )

The positive slope indicates that higher levels of the value-sharing rate entitled to the managers lead them to allocate more effort to short-term projects (higher  $w$ ), rather than to long-term ones (lower  $(1 - w)$ ). The greater the share of value managers will be able to benefit from a given project, the less effort they need to allocate in order to reach the same level of wealth. In our model, this works under a multi-dimensional framework where (i) managers decide between short and long-term projects and (ii) managers, without incentives, prefer to allocate more effort to short-term and long-term for the reasons related by the vast short-termism literature. That is precisely what this positive slope indicates: the greater the sharing-rate rule for managers, which we assume to be the same for both projects, the less effort a rational manager will allocate to risky long-term projects to reach the same wealth goal.

Following the same logic, it comes as no surprise that there is a negative relationship between the desired managerial effort allocation to short-term projects under the perspective of the shareholders, and the variable pay they offer managers ( $\gamma_M$ ). In other words, there is a positive relationship between the desired managerial effort allocation to long-term project under the perspective of the shareholders, and the variable remuneration they have to pay to shareholders ( $\gamma_M$ ), so that the greater (lower) the variable pay shareholders have to remunerate to managers, the more (less) shareholders want managers to allocate effort to risky long-term projects. The economic interpretation derives from the notion that shareholders are only willing to increase the variable pay term if managers, on the other hand, are willing to take a less risk-averse approach towards their effort allocation decision between conservative short-term projects and risky long-term ventures.

### 3.4.2 Decision 2: Optimal investment timing

As the manager is the ultimately responsible for a firm's R&D investment policy, it is also important to observe the effect of the variable pay term on the optimal investment triggers— $X_S^*$  and  $X_M^*$ . Doing so allows us to extract useful conclusions regarding the dynamic of the model.

In the specific case of the fraction of cash-flows benefiting the manager ( $\gamma_M$ ), the impact of changes in the value-sharing rate goes in opposite directions as far as the trigger value for managers and shareholders is concerned. In the case of managers, the greater the value-sharing rate, the sooner managers want to implement the long-term project. Contrariwise, shareholders trigger value increases with greater values of the variable pay allocated to the managers. The economic intuition is straightforward: since the variable pay is a cost for shareholders, the greater this cost, the more demanding will be their requirements in order to invest in such project. For managers, the variable pay has the function of being a tail-wind in inducing managers to take riskier long-term investments, the reason why managers prefer to take the risk of engaging in such projects whenever the benefit they can withdraw from it increases. The following table (3.2) gives us the analytical solutions for the relevant derivatives.

---


$$\frac{dX_M^*}{d\gamma_M} = \frac{\beta(r - \alpha + \lambda)(B\lambda + (r + \lambda)\xi)}{(w - 1)(\beta - 1)\gamma_M^2\lambda(r + \lambda)\phi\psi} < 0$$


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$$\frac{dX_S^*}{d\gamma_M} = -\frac{\beta(r - \alpha + \lambda)(-B\lambda + (r + \lambda)K)}{(w - 1)(\beta - 1)(-1 + \gamma_M)^2\lambda(r + \lambda)\phi\psi} > 0$$


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**Table 3.2:** Variable pay and the Optimal trigger ( $X_M^*$ ;  $X_S^*$ )

Therefore, we find that a higher variable pay induces managers to react differently as far as their effort allocation decision and investment decision is concerned. As we concluded, higher value-sharing rates induce managers to, on one hand, reduce their effort allocated to long-term projects, but on the other hand these will respond by preferring to invest sooner in long-term projects.

### 3.4.3 Optimal Compensation Policy

We start by analyzing how does the optimal variable pay relate to its explanatory variables. Taking into account the solution from Proposition 1, and taking the derivatives we get:

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$$\frac{d\gamma_M^*}{d\lambda} = \frac{Br}{(r + \lambda)^2(K + \xi)} > 0 \quad \frac{d\gamma_M^*}{dB} = \frac{\lambda}{(r + \lambda)(K + \xi)} > 0$$

$$\frac{d\gamma_M^*}{dK} = -\frac{B\lambda + (r + \lambda)\xi}{(r + \lambda)(K + \xi)^2} < 0 \quad \frac{d\gamma_M^*}{dr} = -\frac{B\lambda}{(r + \lambda)^2(K + \xi)} < 0$$

$$\frac{\partial\gamma_M^*}{\partial\xi} = \frac{-B\lambda + K(r + \lambda)}{(r + \lambda)(K + \xi)^2} > 0$$


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**Table 3.3:** Partial Derivatives on Manager's optimal sharing-rate ( $\gamma_M^*$ )

We confirm the economic intuition presented in the section above, now supported with the proper comparative statics. We confirm the analysis presented above so that the optimal value-sharing rate to be applied to the managerial compensation structure is positively related with the probability of the R&D stage becoming a success, with the size of the lump-sum payment made by the shareholders to induce managers to allocate effort to these long-term projects and with effort cost associated with the investment moment borne by the managers, and negatively correlated with the investment cost fully borne by the shareholders and the risk-neutral rate.

## 3.5 Numerical Example

Let us now showcase the model with a numerical example. The basic parameters are shown in table (3.4).

Parameter	Value	Description
$K$	100	Investment Cost
$\xi$	10	Manager's Effort Cost
$r$	0.03	Risk-free interest rate
$\sigma$	0.30	Instantaneous Volatility
$\delta$	0.01	Dividend-Yield
$\lambda$	0.5	Mean arrival rate of a successful discovery in R&D stage
$X$	1000	Cash flows from the assets-in-place
$\phi$	0.5	Incremental improvement from a LT project
$B$	5	Fixed term pay granted to the manager
$\psi$	1.1	Value-added (over $X$ ) from managerial skill

**Table 3.4:** The base case parameters.

The main objective is to determine the optimal compensation package that aligns both players optimal effort solution. For now, let us assume a setting in which the fixed term  $B$  is exogenous and only  $\gamma$  is endogenous. We start by assuming a given default value for  $B$  and then we retrieve the optimal variable pay accordingly. Table (3.5) shows the output values.

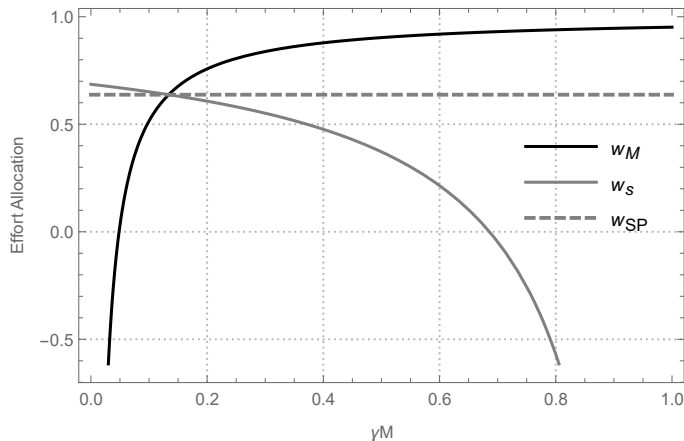
Parameter	Value
$\gamma_M^*$	0.134
$w_M^* = w_S^* = w_{SP}^*$	0.64
$X_M^* = X_S^* = X_{SP}^*$	769.5

**Table 3.5:** The output values for the parameters presented in table (3.4). The output values are approximated figures.

For the base-case parameters, the optimal variable pay which aligns the manager and the shareholder is 13.4%. That means that the price shareholders have to bear in order to induce managers to behave optimally is to allow managers to retain 13.4% of the value of the projects implemented, both short and long-term according to the specification of our model. If so, both managers and shareholder will be on the same page regarding the optimal effort distribution: 64% of the time and resources of managers shall be optimally allocated to manage short-term assets and the remaining, 36%, to R&D projects. Furthermore, and in accordance with Corollary 2, this optimal variable not only aligns managers and shareholders interests regarding the effort allocation, as it also aligns both players interests regarding the optimal investment timing. Under the base-case parameters, and with the optimal value-sharing rate, both the managers and shareholders will find optimal to invest at the same moment in time– when the value of the cash flows generated by the firm assets-in-place ( $X$ ) crosses the trigger \$769.5. Given the default values, the optimal decision for the manager would be to implement the project since the threshold has already been crossed ( $X_M^* < X = \$1000$ ).

### 3.5.1 Decision 1

Focusing on the effort allocation decision, Figure 3.2 shows the impact of different levels of variable pay ( $\gamma_M$ ) on the interaction between the manager's and the shareholder's optimal solution.



**Figure 3.2:** Managers and Shareholders optimal effort allocation for different variable pays ( $\gamma_M$ ). The computation is based on the parameters shown in table (3.4).

From Figure 3.2, we confirm that the agency conflict, given by the gap between both player's optimal solutions, is null when the variable pay equals the one that would be chosen by the social planner. This comes as the graphical proof of the derivation procedure used to derive the optimal compensation policy.

Additionally, not only we graphically observe that a higher variable pay allotted to managers leads them to decrease the effort allocated to long-term projects, and vice-versa in the case of shareholder, as we can go further and retrieve from this interaction that increasing values of variable pay conceded to the manager have a lower marginal impact on the redistribution of their effort allocation strategy. In fact, for very high-value sharing-rates, managers react increasingly less to such incentives, reason why the concave curve tends to a straight line<sup>9</sup>. Following this reasoning, we then conclude that there is a decreasing marginal effect of allowing managers to participate in the value of the project. The economic intuition is straightforward: for increasing value-sharing rates, managers can accomplish the same wealth target by increasing the effort allocated to short-term assets, a much safer alternative according to the risk profile of both projects. For high sharing-rates, managers react and adjust less.

Furthermore, we observe from the Figure 3.2 that the gap between manager's and shareholder's optimal solution increases for high sharing-rates. This result is only possible because, even if managers tend to be less reactive for high levels of  $\gamma_M$ , conversely,

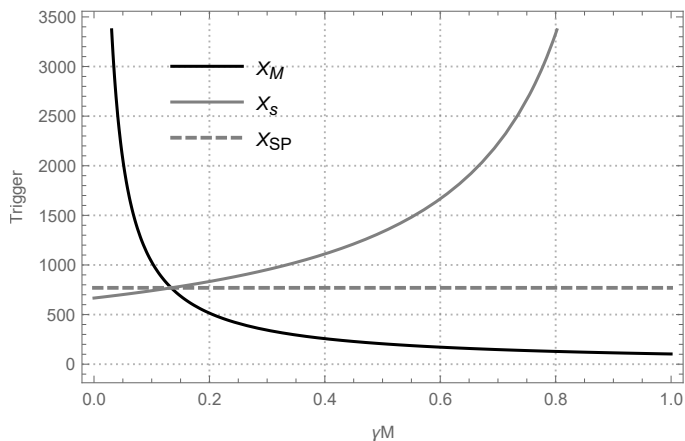
<sup>9</sup>Mathematically, this result is given by the negative second-order derivative of the optimal effort allocation by the manager with respect to the variable pay  $\left(\frac{d^2 w_M^*}{d(\gamma_M^*)^2}\right) < 0$



shareholders optimal solution shifts more rapidly, leading to an expansion of this gap. In this case, there is an increasing marginal effect of the variable pay component ( $\gamma_M$ ) in shareholder's effort allocation that they optimally desire managers to replicate. The economic intuition is straightforward: for high levels of the value-sharing rate, shareholders demand managers to increasingly allocate effort to the R&D stage to compensate them for such burden. Analogously, for low values of the sharing-rate, the agency conflict amplifies due to now more reactive managers and less reactive shareholders, showing off symmetric sensitivities to the variable pay term.

### 3.5.2 Decision 2

Shifting our analysis to the investment timing decision, Figure 3.3 shows the impact of different levels of variable pay ( $\gamma_M$ ) on the interaction between the manager and the shareholder's optimal solution.



**Figure 3.3:** Managers and Shareholders optimal investment timing for different variable pays ( $\gamma_M$ ). The computation is based on the parameters shown in table (3.4) and the optimal values for the effort allocation computed above ( $w^*$ ).

From Figure 3.3, we can conclude the validity of Corollary 2. For  $\gamma = \gamma_{SP}^*$ , the investment trigger from which managers and shareholder find optimal to invest is the same (\$769.5). Moreover, we confirm the negative (positive) relationship between  $\gamma_M$  and the investment trigger for R&D projects by managers (shareholders). In the case of managers, the greater the value-sharing rate, the sooner managers would want to implement the long-term project. Contrariwise, shareholders trigger value increases with greater values of the variable pay allocated to the managers.

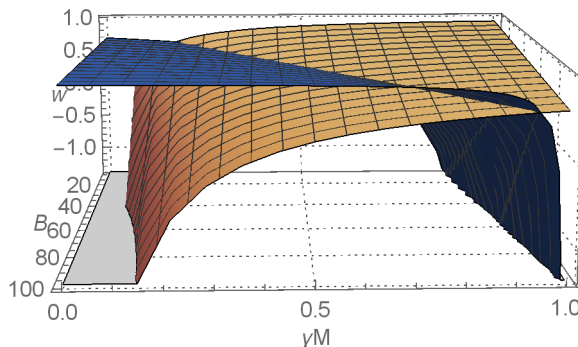
In addition, we find a decreasing (increasing) marginal effect of the size of the fraction of cash flows generated by the firm attributed to managers and the investment trigger of managers (shareholders). As the size of this fraction increases, the increase in the manager's investment trigger gets progressively less significant. At the same time, shareholders face the opposite effect: as  $\gamma_M$  increases, the shareholder's investment trigger decreases

gradually more, leading to an expansion of the agency gap between both players optimal solutions. Again, we find symmetric sensitivities to the variable pay term, now in the case of the investment timing decision.

### 3.5.3 Global Solution

In the previous sections, we have assumed a setting in which the fixed term  $B$  is exogenous and only  $\gamma$  is endogenous. We started by computing the optimal variable pay subject to a given *ad hoc* value for  $B$ . In this subsection, we retrieve the solution for the optimal global compensation package  $(\gamma_M^*, B^*)$ , by letting the fixed term to be an endogenous variable just as the floating component.

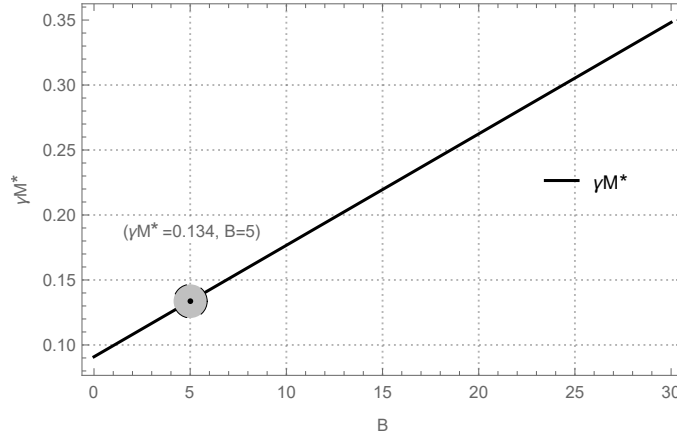
Let us consider that both the variable and the fixed term are not given *ex-ante* so that the shareholder when deciding the contract of the management team chooses an optimal pair of  $\gamma$  and  $B$ . Under this setting, we assume that there are two variables negotiated in the contracting stage, and each of them influences one another. The optimal combination of  $\gamma$  and  $B$  is depicted in Figure 3.4, where the optimal effort strategies of each agent are allowed to fluctuate for a given range of values of  $\gamma_M$  and  $B$ . The following figure (3.4) shows the derivation of the optimal global compensation package that ensures the perfect alignment between managers and shareholders effort solutions.



**Figure 3.4:**  $w_M^*$  and  $w_S^*$  for different values of  $\gamma_M$  and  $B$ . The derivation of the optimal global compensation package  $(\gamma_M^*, B^*)$  is given by the intersection between the two surfaces  $(w_M^*, w_S^*)$ . The computation is based on the parameters shown in table (3.4).

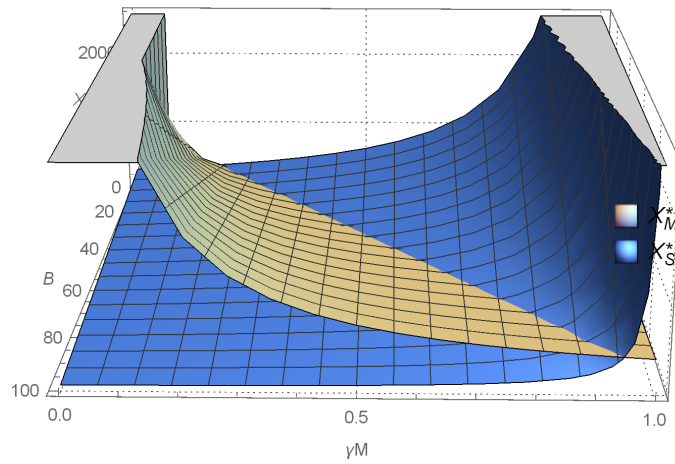
The optimal solution is given by the interception of the two surfaces as shown in Figure 3.4. The solution derived yields all the combinations of  $\{\gamma_M^*; B^*\}$  that allow the alignment between both players' interests. Since we model both surfaces for different values of two variables, the interception results in the following optimal equation:

$$\gamma_M^* = 0.0909090(90) + 0.00857633B^* \quad (3.29)$$



**Figure 3.5:** The intersection between the two surfaces ( $w_M^*, w_S^*$ ) results in the following equation. The point highlighted represents the numerical example solution.

The same solution (equation (3.29)) can also be derived as the interception equation of the surfaces correspondent to the manager's and shareholder's investment trigger solutions, as we concluded in Corollary 2 (Figure 3.6).



**Figure 3.6:** The derivation of the optimal global compensation package ( $\gamma_M^*, B^*$ ) is given by the intersection between the two surfaces ( $X_M^*, X_S^*$ ). The computation is based on the parameters shown in table (3.4). The intersection results in equation (3.29).

## Chapter 4

# Heterogeneous managerial skills

In contrast to the derivation of the basic model, we now relax the embedded assumption of equal managerial skills between directing short-term and long-term projects. In our framework, the managerial skills regarded as necessary to run a R&D project are not necessarily equal to the type of skills needed to manage assets-in-place. According to the principle of specialization, we should expect a manager with a high level of skills towards managing innovative projects to be able to add more value to a given R&D project than a manager whose expertise is higher in managing the assets-in-place type of projects and lower in innovative projects. We will then compare the basic model results and the new version of the model as far as the managerial decision-making is concerned. To do so, we shall focus on the impact of different managerial skills on the optimal trigger ( $X^*$ ) and on the optimal effort allocation strategy of both players ( $w^*$ ).

### 4.1 Model development

The derivation process is the same applied in the basic model version. Now, we just add a new set of variables ( $\psi_t, \psi_i$ ) to control for different levels of skill while managing short and long-term projects. Under this setting,  $\psi_t$  stands for the manager's skill as far as managing the short-term projects and  $\psi_i$  represents the manager's skill to direct R&D projects. A more traditional manager will have a higher  $\psi_t$ , contributing to amplify by a wider margin the cash flows the firm can generate from its existing assets-in-place, and a more innovation-oriented manager will have a higher  $\psi_i$ , extracting more value from a productive management of the firm's R&D projects.

Plugging in these new variables, we obtain the following key results<sup>1</sup>. For the manager we get:

**Proposition 4.** *Considering heterogeneous skills, the effort allocation towards short-term projects and the optimal trigger that aligns both managers and shareholder, in the perspec-*

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<sup>1</sup>For the full derivation procedure, see Appendix.

tive of the manager, are given by:

$$\max_w [w\gamma_M\psi_t X + B + (1-w)M(X_M^*)] \quad (4.1)$$

$$w_M^* = 1 - \frac{\beta}{\beta-1} \frac{(B\lambda + (r+\lambda)\xi) \left( \frac{(r-\alpha+\lambda)\psi_t}{\lambda\phi\psi_i} \right)^{\frac{\beta}{\beta-1}}}{X\gamma_M(r+\lambda)\psi_t} \quad (4.2)$$

$$X_M^* = \frac{\beta}{\beta-1} \frac{(r-\alpha+\lambda)(B\lambda + (r+\lambda)\xi)}{(1-w)\gamma_M\lambda(r+\lambda)\phi\psi_i} \quad (4.3)$$

For the Shareholder we get:

**Proposition 5.** *Considering heterogeneous skills, the effort allocation towards short-term projects and the optimal trigger that aligns both managers and shareholders, in the perspective of the shareholder, are given by:*

$$\max_w [w\gamma_S\psi_t X - B + (1-w)S(X_S^*)] \quad (4.4)$$

$$w_S^* = 1 - \frac{\beta}{\beta-1} \frac{(-B\lambda + (r+\lambda)K) \left( \frac{(r-\alpha+\lambda)\psi_t}{\lambda\phi\psi_i} \right)^{\frac{\beta}{\beta-1}}}{X\gamma_S(r+\lambda)\psi_t} \quad (4.5)$$

$$X_S^* = \frac{\beta}{\beta-1} \frac{(r-\alpha+\lambda)(-B\lambda + (r+\lambda)K)}{(1-w)\gamma_S\lambda(r+\lambda)\phi\psi_i} \quad (4.6)$$

From equation (4.2) we retrieve a positive relationship between the effort allocated to short-term projects and the managerial skills associated with directing innovative projects<sup>2</sup>. For the same wealth target, a more skilled manager in R&D projects will have to allocate less effort to such projects than a less skilled manager, *ceteris paribus*.

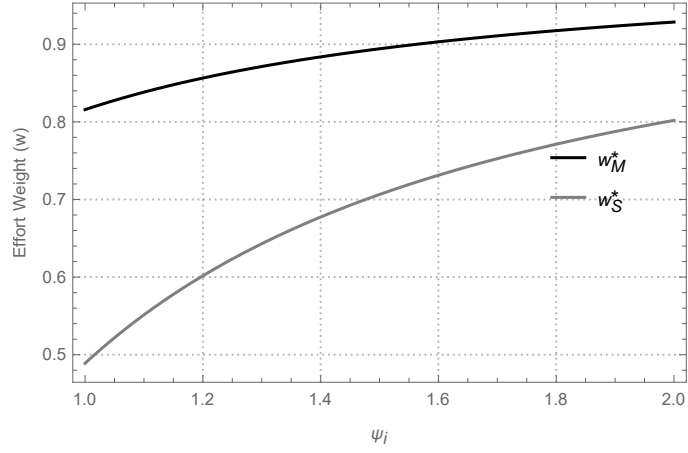
Interestingly, we also find the same relationship for shareholders<sup>3</sup>. For increasing levels of managerial skill regarding innovative projects, shareholders optimal effort allocation moves towards a more short-term projects heavy solution. This shows that, for the same wealth target, if the managers ability to extract value from R&D projects increases, then shareholders want managers to reduce their exposure to the risks of a R&D investment. In fact, we can conclude that the shareholders of a firm that has an innovative management team *vis-à-vis* another equivalent firm, but with a more conservative management team, will use their compensation policy to induce managers to allocate more effort to short-term projects when compared with the conservative team firm. To extract the same level of wealth, the conservative team must allocate comparatively more effort towards LT projects than the innovative firm, and the innovative firm shareholders aim to take advantage of

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<sup>2</sup>  $\frac{\partial w_M^*}{\partial \psi_i} > 0$ . See Appendix.

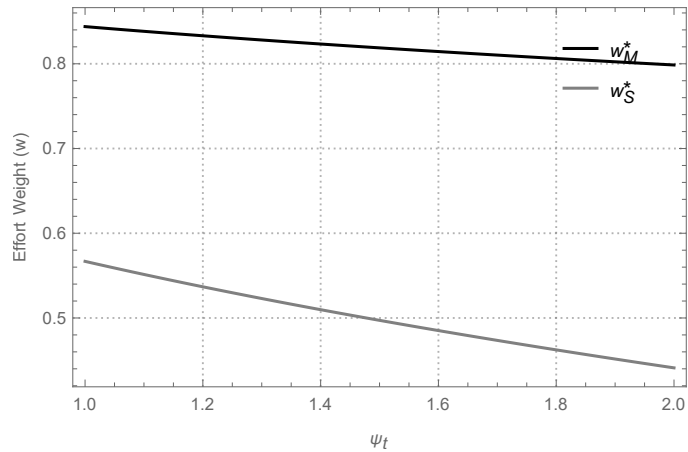
<sup>3</sup>  $\frac{\partial w_S^*}{\partial \psi_i} > 0$ . See Appendix.

such, by reducing their ultimate exposure to the risks intrinsic to the R&D projects. The following Figure 4.5 highlights these arguments.



**Figure 4.1:** Managers and Shareholders optimal effort allocation for different levels of innovative managerial skills ( $\psi_i$ ). The computation is based on the parameters shown in table (3.4).

Following the same logic, we find a negative relationship between the effort allocated to short-term projects and the skills of the manager to direct projects of such nature<sup>4</sup>. A manager who has a particularly high level of expertise in managing short-term assets will need to allocate more effort to R&D projects to achieve the same wealth target than a manager with less cleverness in directing the firm's assets-in-place, *ceteris paribus*. The same applies to the shareholders<sup>5</sup>, as shown in Figure 4.2.

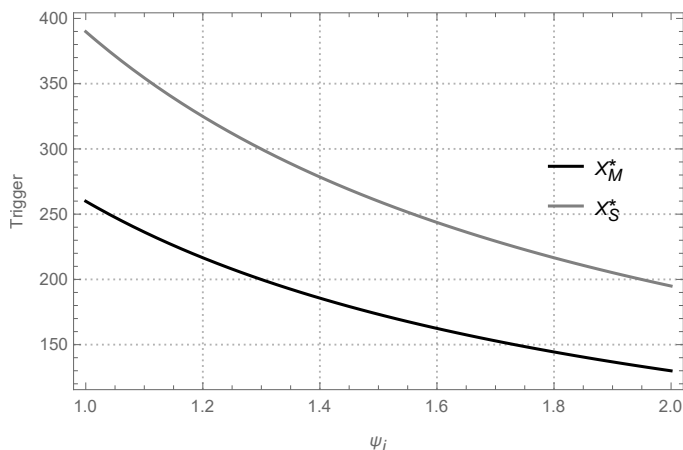


**Figure 4.2:** Managers and Shareholders optimal effort allocation for different levels of non-innovative managerial skills ( $\psi_t$ ). The computation is based on the parameters shown in table (3.4).

<sup>4</sup>  $\frac{\partial w_M^*}{\partial \psi_t} < 0$ . See Appendix.

<sup>5</sup>  $\frac{\partial w_S^*}{\partial \psi_t} < 0$ . See Appendix.

The optimal investment trigger is independent of the level of non-innovation-related managerial skills, being only affected by the level of skills associated with innovative projects (equation (4.3) and equation (4.6)). From Figure 4.3 we observe that the optimal investment trigger is negatively influenced by the innovation-related skills of the manager<sup>6</sup>. The idea is that managers that show higher levels of skill to direct R&D projects, *ceteris paribus*, find optimal to invest sooner than managers with a lower level of the same skills. As the managers have more expertise in R&D projects, which translates into a greater amplification of the cash flows generated by those projects due to manager's idiosyncratic contributions, the required value of the cash flows that justify an investment implementation will be less demanding. The same logic applies under the shareholder's perspective, as managers with greater expertise for R&D projects lead shareholder to show lower investment triggers<sup>7</sup>. Managerial adroitness in innovative projects affecting the investment timing decision (decision 2) is depicted in Figure 4.3.



**Figure 4.3:** Managers and Shareholders optimal investment timing for different managerial innovative skills ( $\psi_i$ ). The computation is based on the parameters shown in table (3.4).

Importantly, as one can easily retrieve from equation (4.2) and equation (4.5), the effect of skills are muted when both equations are set to be equal. What we have concluded in the basic version of the model remains true under a framework considering heterogeneous managerial skills, as aligning the effort allocation of both players takes only into account three groups of variables: variables associated with the cost burden linked with the implementation of the R&D project, variables related with the technical uncertainty of the outcome of the R&D stage and with the market uncertainty of the project, and the fixed compensation pay. Therefore, we conclude that:

**Corollary 3.** *The optimal value-sharing rate is independent of a manager's skill set ( $\psi_t$ ,*

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<sup>6</sup>  $\frac{\partial X_M^*}{\partial \psi_i} < 0$ . See Appendix.

<sup>7</sup>  $\frac{\partial X_S^*}{\partial \psi_i} < 0$ . See Appendix.

$\psi_i$ ).

*Proof.* See Appendix. □

## 4.2 Investment Dynamics

### 4.2.1 R&D Investment and the Business Cycle

The link between business life-cycle and R&D investing policies has been extensively covered by literature, and the relationship is usually deemed as negative. As firms mature, and the cash flows generated by their short-term assets increase, literature predicts a gradual decline in R&D intensity. For instance, during the growth stage, firms may overly invest to create a ‘lasting’ cost or demand advantage over competitors (Anthony and Ramesh 1992). The idea derives from the seminal works of strategic literature (Porter 1980), where the underlying idea is that a firm maximizes revenue growth early in its life cycle, to create permanent cost or demand advantages over competitors, but in its mature stage, growth slows down and investments are less rewarding. Spence (1977) attempted to derived analytically these strategic findings, and modeled how firms are able to deter entry by creating capacity and incurring significant capital expenditures early in the life cycle, making the product market unattractive to potential entrants.

Throughout the years, additional alternative explanations arrived, always under the base conclusion that R&D investing evolves negatively as firms develop into a mature status. Miller and Friesen (1984) showed that firms during the growth stages focus on sales growth and R&D in order to gain competitive advantages. In the mature stage, as firms stabilize around a given sales growth figure, R&D gradually loses its relevancy. Additionally, Hill et al. (2014) argues that firms while in the growth stage all too often shift their attention to issues such as new product development, hence, relying more heavily on R&D. As mature firms bring in higher levels of brand awareness, R&D becomes less important. In line with these arguments, Audretsch (1995) shows that as industries move from an emerging status to a mature one, the ratio of new product innovation per R&D dollar expended tends to decline. Moreover, Agarwal (1998) documents that patenting activity increases during the initial stages of the business life-cycle, and subsequently declines as firms approach maturity. In short, there is rich literature advocating for a negative link between R&D and industry life-cycle<sup>8</sup>. In the present subsection, our model presents a theoretical explanation for the empirical evidence on the link between the firm’s position in the life-cycle and its willingness to invest in R&D.

To do so, we proxy the relationship between the firm’s stage in the life-cycle and its engagement in R&D activities by looking at the role of the level of the cash flows generated by the firm through its assets-in-place and we study its role on the investing threshold.

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<sup>8</sup>Note that our model renders conclusions regarding both the business and the industry life-cycle since we have assumed that the investment in a successful R&D project generates a natural monopoly for the innovative firm.



We build this proxy under the base assumption that as firms tend to maturity, the level of the assets-in-place-related cash flows tends to increase (Damodaran 2009, Jaafar and Halim 2016). Additionally, we consider that a firm's engagement in innovation should be interpreted as increasing whenever the threshold decreases, since lower thresholds translate, *ceteris paribus*, into a quicker investment decision. Thereby, we look at how different levels of  $X$  (a proxy of the current state of the firm in the life-cycle) relate to the investment threshold (a proxy for innovation engagement).

Under an optimal compensation policy, the alignment between managers and shareholders investment triggers is ensured (Corollary 2), and the social-best investment trigger derives from plugging in the optimal variable pay  $\{\gamma^*\}$  for each agent in their respective investment functions. According to the sequential decision-making process, first, managers decide on their optimal effort allocation strategy between ST and LT projects. The social-planner solution is then derived as shown in previous sections<sup>9</sup>. Then, the manager integrates the optimal effort weights in their optimal investment strategy and we retrieve the social planner optimal investment trigger (4.7).

**Proposition 6.** *When managers have to choose an effort allocation strategy between short and long-term projects, and when managers add value to the projects they are responsible for managing, assuming an optimal compensation policy, the social-best investment timing strategy for the R&D project is given by:*

$$X^* \equiv X_{SP}^*(w^*(\bar{X})) = X_S^*(w^*(\bar{X})) = X_M^*(w^*(\bar{X})) = \bar{X} \left( \frac{(r - \alpha + \lambda) \psi_t}{\lambda \phi \psi_i} \right)^{\frac{1}{1 - \beta}} \quad (4.7)$$

In mathematical terms, the relationship between the current state of the firm in the life-cycle and its engagement in innovative projects is given by the derivative of  $X^*$  with respect to  $\bar{X}$ . Doing so, we get:

$$\frac{dX^*}{d\bar{X}} = \left( \frac{(r - \alpha + \lambda) \psi_t}{\lambda \phi \psi_i} \right)^{\frac{1}{1 - \beta}} > 0 \quad (4.8)$$

From equation (4.8) we retrieve that the investment trigger depends on the state variable. The positive derivative is line with the theoretical predictions, as higher levels of cash flows generated by a firm's assets-in-place lead to a higher investment trigger, *ceteris paribus*. In other words, as a firm/industry approaches the late-stages of the life-cycle, innovation is expected to lose relevancy, as the firm's criteria that triggers a R&D investment becomes increasingly daunting to attain. Importantly, this conclusion is endogenous to our model.

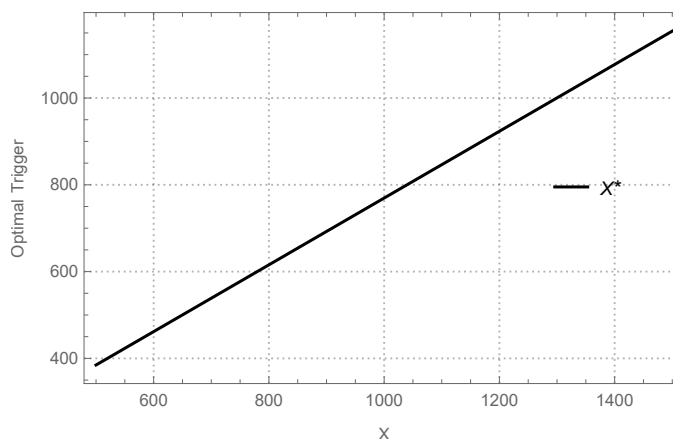
**Proposition 7.** *When managers have to choose an effort allocation strategy between short and long-term projects, and when managers add value to the projects they are responsible*

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<sup>9</sup>See Proposition 2.

for managing, under optimal conditions, there is a positive relationship between the cash flows generated by a firm's assets-in-place and the social-best investment trigger solution so that firms tend to invest in R&D sooner (later) during the early (late) stages of the firm's life-cycle, *ceteris paribus*.

Figure 4.4 highlights this argument:



**Figure 4.4:** The effect of the cash flows generated via assets-in-place( $X$ ) on Social-planner's optimal investment trigger( $X^*$ ). The computation is based on the parameters shown in table (3.4).

As an innovation-oriented firm produces innovation and converts R&D projects into assets-in-place, the firm gradually increases the fraction of its total value deriving from those assets-in-place. As this conversion takes place and the firm evolves through its life-cycle,  $X$  increases. This endogenous dynamic leads firms to become less willing to invest in future R&D projects, as the investment trigger also increases. Note that this life-cycle feature of our model adds up to the GBM explanation for the growth of the firm and its evolution throughout the life-cycle.

The later an industry/a company is in the life-cycle, the less disruptive it should be expected to be. Only for industries/companies where the fraction of its total value is not yet significantly dependent on the assets-in-place, does our model predict firms to be especially keen on implementing R&D projects.

#### 4.2.2 R&D Investment and Market Uncertainty

The investment-uncertainty binomial has long been the center of an extant literature. The real options branch largely dictates a negative sign to such relationship, as uncertainty is synonym of less and delayed investment. Seminal real options models (McDonald and Siegel 1986, Dixit and Pindyck 1994, Bernanke 1983) suggest that under a state of the world where a given investment opportunity shares the irreversibility, uncertainty and flexibility conditions, firms may find value in delaying investments (less investment) whenever uncertainty spikes, *ceteris paribus*. As uncertainty increases, real options theory tells us that the

incentive to delay should grow stronger and the gap between the expected benefit and cost necessary to trigger investment should wide. According to the conventional framework, agents must bear the trade-off between the extra returns from an early investment and the benefits of increased information as a consequence of waiting for the right moment to implement a project (Bloom et al. 2007). Nevertheless, recent studies show theoretical conclusions rather ambiguous, as the sign depends, among other things, on assumptions about the production function, the market structure, the shape of adjustment costs, the importance of investment lags, the degree of investment irreversibility, and managerial risk aversion.

Strictly from a real options point of view, since in our model setup R&D investment shares the three conditions of above, we should expect the impact of uncertainty to deter R&D investments to prevail. As we will discuss, when we consider an additional stage in the decision-making process of managers - effort allocation- the indirect effects of such variable dominate the opposite direct effect described in real options literature, so that the link between uncertainty and R&D investment turns to the opposite direction.

The effect of uncertainty on R&D investment, the center of our research, is mixed (Czarnitzki and Toole 2011, 2013, Stein and Stone 2013, Jiang et al. 2009, Comin and Mulani 2009, Wang et al. 2017) and somewhat under-explored. Czarnitzki and Toole (2011, 2013) examine a panel of German manufacturing firms and find that firms invest less in R&D when the absolute value of the sales of innovative products becomes more volatile. In contrast, Jiang et al. (2009), Van Vo and Le (2017) report a positive correlation between idiosyncratic return volatility and R&D investment and Stein and Stone (2013) also find that uncertainty captured by implied volatility from equity options increases R&D investment. Much of these mixed results derive from the interaction of competitive concerns in the firm's R&D policy. For instance, Czarnitzki and Toole (2011, 2013) evidence suggests that strategic rivalry tends to erode, at least partially, the value of waiting to invest in R&D. Additionally, Van Vo and Le (2017) show that the firms preemptive behavior is the main force driving the positive relation between uncertainty and R&D investment, as they further show evidence that the effect of idiosyncratic return volatility on R&D investment is more pronounced for firms in more competitive industries.

In our model, during the decision-making process, managers face two forms of uncertainty: technical uncertainty over the success of the discovery stage and market uncertainty over the profitability offered by these long-term innovative projects. We will study how market uncertainty affects the investment decision.

Our goal of studying the impact of market uncertainty in the optimal investment trigger can be mathematically defined as taking the full derivative of the investment trigger function that maximizes the welfare in an economy with respect to an uncertainty measure. To do so, we derive the social-planner trigger ( $X^*$ ) with respect to  $\beta$ , and then we make use of the well-known result of a negative relationship between  $\beta$  and our uncertainty variable ( $\sigma$ ), to retrieve the final solution. The total derivative of the optimal investment trigger (equation (4.9)) is given below.

$$\frac{dX^*}{d\beta} = \frac{\partial X^*}{\partial \beta} + \frac{\partial X^*}{\partial w^*} \frac{\partial w^*}{\partial \beta} > 0 \quad (4.9)$$

Note that this full derivative is the limiting ratio of the change in the investment trigger's function value to the change in the value of  $\beta$  (small changes), taking into account the exogenous  $\beta$  direct effect as well as indirect effects, since  $\beta$  also effects the optimal effort weight allocation decision which, according to our sequential decision-making approach, ends up affecting the investment trigger derivation. The full derivative is given as follows:

$$\frac{dX^*}{d\beta} = \frac{\bar{X} \left( \frac{(r - \alpha + \lambda) \psi_t}{\lambda \phi \psi_i} \right)^{\frac{1}{1 - \beta}} \log \left( \frac{(r + \alpha - \lambda) \psi_t}{\lambda \phi \psi_i} \right)}{(\beta - 1)^2} > 0 \quad (4.10)$$

Thereby, applying the chain rule allows us to deconstruct the full derivative and understand the dynamic inherent to both the direct and the indirect effects of volatility in the optimal investment policy. Doing so, we get:

$$\frac{\partial X^*}{\partial \beta} = \frac{(r - \alpha + \lambda) (K + \xi)}{(w - 1) (\beta - 1)^2 \lambda \phi \psi_i} < 0 \quad (4.11)$$

$$\frac{\partial X^*}{\partial w^*} = \frac{\beta (r - \alpha + \lambda) (K + \xi)}{(w - 1)^2 (\beta - 1) \lambda \phi \psi_i} > 0 \quad (4.12)$$

$$\frac{\partial w^*}{\partial \beta} = \frac{(K + \xi) \left( \frac{(r + \alpha - \lambda) \psi_t}{\lambda \phi \psi_i} \right)^{\frac{\beta}{\beta - 1}} \left( -1 + \beta + \beta \log \left( \frac{(r + \alpha - \lambda) \psi_t}{\lambda \phi \psi_i} \right) \right)}{\bar{X} (\beta - 1)^3 \psi_t} > 0 \quad (4.13)$$

Making use of the well-known result ( $\frac{\partial \beta}{\partial \sigma} < 0$ ), we convert all the results of above with respect to  $\sigma$ , the volatility of the cash flows generated by the firm and the variable with real economic significance in our analysis. Doing so, we get:

$$\frac{\partial X^*}{\partial \sigma} < 0 \quad (4.14)$$

Hence, the full derivative of the optimal investment timing with respect to  $\sigma$  leads us to state that,

**Proposition 8.** *When managers have to choose an effort allocation strategy between short and long-term projects, and when managers add value to the projects they are responsible for managing, under optimal conditions, there is a negative relationship between market uncertainty and the social-best investment trigger solution, so that firms tend to invest sooner (later) in R&D projects in the presence of high (low) volatility.*

The decomposition of the three terms affecting the link between the optimal investment trigger and  $\beta$  allows us to understand the result obtained in the full derivative. Let us

address each of these terms and the economic interpretation of each.

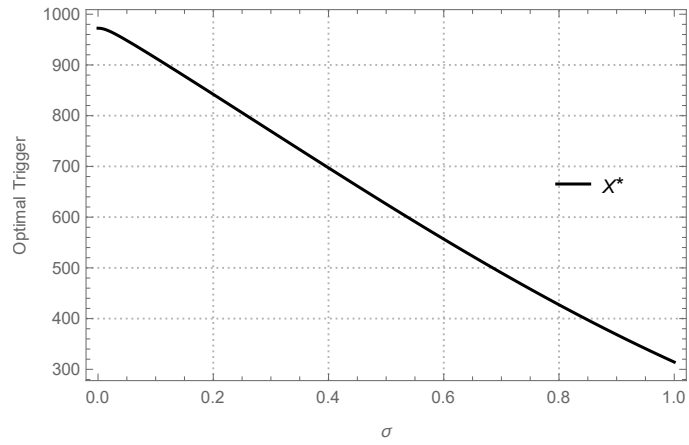
From equation (4.11) we find that the direct impact of market uncertainty in the manager's optimal investment decision is that she/he ought to invest later in projects with greater volatility. This result is coherent with conventional real options theory and the notion that under an increasingly uncertain state of the world, there is an also increasing value in collecting information to spur a decision which is, at least partially, irreversible, such as the one being modeled. This term captures the direct sensibility of a firm's investment policy to the volatility of its cash flows. Nevertheless, this does not mean that the social-best solution also depends negatively on uncertainty. To conclude about that, we shall go a step further and analyze the indirect effects of volatility in the effort allocation decision.

The second equation (4.12) captures the relationship between the optimal manager's optimal trigger and the effort allocated to short-term projects. The positive link between these two variables has economic meaning: the more (less) effort is allocated to the R&D stage, the lower will be the trigger required by the manager to implement the R&D project. The economic interpretation is thus straightforward: a manager that allocates more of her/his time and effort to the innovation discovery stage (lower  $w$ ) is more likely to also invest sooner in a project based on the correspondent innovation breakthroughs.

The last equation (4.13) shows the negative (positive) link between the social-best effort allocation to ST (LT) projects and market uncertainty. The greater the level of market uncertainty faced by the cash flows generated by a given firm, the greater will also be the required effort to be allocated to R&D projects so that both managers and shareholders interests are aligned. In face of more unstable times, the equilibrium solution in which agency problems are mitigated is much more daunting for managers, as they are required to ramp-up their effort allocation towards risky long-term innovation projects.

Thereby, we analytically show that the full derivative of the social-planner investment trigger with respect to  $\beta$  ( $\sigma$ ) is positive (negative). The indirect sensibility of uncertainty in the allocation decision exerts a dominant effect over the direct impact common to the real options view on uncertainty and the trade-off between acting now and waiting.

This key finding adds up to the existent range of possible explanations for the link between investment timing and uncertainty shown in empirical literature. Indeed, we extend the current theoretical literature in this regard and we offer an alternative approach, via the sequential decision making embedded in our model, to explain why innovation-oriented firms may invest sooner in a context of higher uncertainty. Importantly, we show this result without the inclusion of any particular consideration about the production function, the market structure, the shape of adjustment costs, the importance of investment lags, the degree of investment irreversibility, or the managerial risk aversion. Our finding is endogenous to our model and it is the consequence of the multi-task framework in which managers are designed to operate. Under our numerical example, Figure 4.5 shows the impact of cash flows volatility in the social-planner investment trigger.



**Figure 4.5:** The total effect of volatility ( $\sigma$ ) on the Social-planner's investment trigger( $X^*$ ). The computation is based on the parameters shown in table (3.4).

## Chapter 5

# Industry Dynamics and R&D

The following section relaxes the assumption previously made and we now allow firms to compete *ex-ante* for R&D projects. In this framework, we establish a game where an incumbent firm competes with an outsider idle firm for an investment in a R&D project. With this, we aim to shed light on industry dynamics regarding the R&D investment process. In order to showcase this, let us first define briefly the setup of our competitive setting.

Consider a framework where two firms face a chance to invest in a R&D project. The incumbent firm is already active and produces a stream of cash flows via its short-term assets. The outsider idle firm ( $O$ ) represents a potential entrepreneur whose competing for the R&D project with the active firm. The outsider, nonetheless, has no initial cash flows and the investment in the project would set the constitution of a new firm. The incumbent faces the decision of negotiating a remuneration package for a manager whose responsible for managing two types of ventures: existing short-term projects (ST) and long-term innovative projects (LT). Managers of incumbent firms are assumed to decide optimally on the effort allocated to run short-term projects and long-term projects. Conversely, for the outsider managers, since they have no projects prior to the potential investment in the R&D project, there is no effort allocation decision to be made. The managers of the outsider firm, when active, allocate 100% of their effort to managing the R&D project. As before, we assume that when the investment happens the firm operates under a natural monopoly setting and retains 100% of the market share for the product market generated by the investment in the R&D venture. Furthermore, we start by considering that both the non-innovation-related skills ( $\psi_{incumbentST} = \psi_{outsiderST} = \psi_t$ ) and the innovation-related skills ( $\psi_{incumbent} = \psi_{outsider} = \psi_i$ ) are equal for incumbent and outsider managers.

The incumbent's social-planner solution is already a known result. Let us now analyze the outsider's position, under the perspective of the entrepreneur, in order to ensure consistency in our analysis. Whenever the entrepreneur decides to invest, we assume her/him to hold 100% of the newly-created firm and to accumulate the shareholder role alongside with management duties. The value function of the outsider firm,  $O(X)$ , must satisfy the following o.d.e:

$$\frac{1}{2}\sigma^2 X^2 \frac{\partial^2 O(X)}{\partial X^2} + \alpha X \frac{\partial O(X)}{\partial X} - rO(X) + \lambda[\psi_i \phi X - O(X)] = 0 \quad (5.1)$$

subject to the following boundary conditions:

$$\lim_{X \rightarrow 0} O(X) = 0 \quad (5.2)$$

$$\lim_{X \rightarrow X_O^*} O(X) = \frac{\lambda\psi_i\phi X_O^*}{r + \lambda - \alpha} - (K + \xi) \quad (5.3)$$

$$\lim_{X \rightarrow X_O^*} \frac{\partial O(X)}{\partial X} = \frac{\lambda\psi_i\phi}{r + \lambda - \alpha} \quad (5.4)$$

Note that the only significant difference between the process of derivation of the value function of the outsider's and the incumbent's social planner has to do with the effort allocation decision. In the case of the incumbent firm, a social-best solution is derived by factoring in the optimal solution for the effort allocation between short and long-term projects, that ensures the full alignment between managers and shareholders. Indeed, the optimal range for the allocation of effort to a given project ranges from  $[0,1]$ . In the case of the outsider, there is no such thing as an optimal effort allocation strategy, since, when the project is implemented, the outsider is idle and all the effort of managers is directed to manage the R&D project- the only project in the outsider's investment portfolio.

Following the standard procedures, the solution for the value of the option to invest in a R&D project comes:

$$O(X) = \begin{cases} \left( \frac{\lambda\psi_i\phi X_O^*}{r + \lambda - \alpha} - (K + \xi) \right) \left( \frac{X}{X_O^*} \right)^\beta & X < X_O^* \\ \frac{\lambda\psi_i\phi X}{r + \lambda - \alpha} - (K + \xi) & X \geq X_O^* \end{cases} \quad (5.5)$$

where the trigger is given by,

$$X_O^* = \frac{\beta}{\beta - 1} \frac{(r - \alpha + \lambda)(K + \xi)}{\lambda\phi\psi_i} \quad (5.6)$$

Now that we have derived the investment triggers for both competing firms, we can easily derive an optimal threshold around which preemption shifts from the incumbent to the outsider, and vice-versa. Hence, by equalizing both triggers, which we get from equation (5.6) and equation (4.7), we obtain the following threshold ( $X^{threshold}$ ):

$$X^{threshold} = \frac{\beta}{\beta - 1} (K + \xi) \frac{1}{\psi_t} \left( \frac{(r + \alpha - \lambda)\psi_t}{\lambda\phi\psi_i} \right)^{\frac{\beta}{\beta - 1}} \quad (5.7)$$

1. If the current cash flows generated by the incumbent firm are lower than the threshold, the incumbent firm will find optimal to invest earlier than the outsider idle firm.



With that, the incumbent firm preempts the outsider firm (equation (5.8)).

$$X < \frac{\beta}{\beta - 1} (K + \xi) \frac{1}{\psi_t} \left( \frac{(r + \alpha - \lambda) \psi_t}{\lambda \phi \psi_i} \right)^{\frac{\beta}{\beta - 1}} \quad (5.8)$$

2. If the current cash flows generated by the incumbent firm are greater than the threshold, then it is a social-best solution for the outsider firm to invest early in the R&D project and the preemptive behavior shifts from the incumbent to the outsider firm (equation (5.9)).

$$X > \frac{\beta}{\beta - 1} (K + \xi) \frac{1}{\psi_t} \left( \frac{(r + \alpha - \lambda) \psi_t}{\lambda \phi \psi_i} \right)^{\frac{\beta}{\beta - 1}} \quad (5.9)$$

## 5.1 R&D Life-cycle and Preemptive behavior

An important factor inherent to the preemption game analysis has to do with the underlying levels of cash flows generated by the firm, in particular, through its own assets-in-place ( $X$ ). Addressing the relationship between those and the threshold that sets up the cash-flow level from which insiders quit from their preemptive approach and allow outsiders to invest earlier in R&D projects, enables us to proxy a relationship between the current state of a firm in the life-cycle (given by  $X$ ) and its engagement in long-term innovative projects, now under a competitive framework.

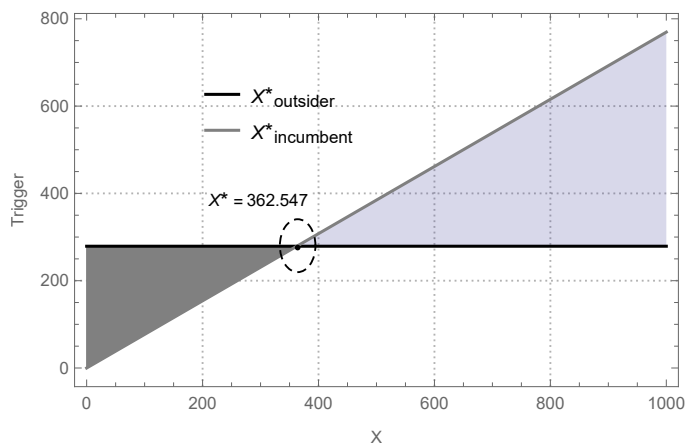
The link between business life-cycle and R&D investing policies has been the subject of a vast literature, as mentioned above, and the relationship is usually deemed as negative. The trend of firms growing and approaching maturity goes hand in hand with a trend of lower innovation and less R&D investment. We now study whether the benefit-cost ratio and the firm's endogenous incentives to acquire technology is highest in the firm's early life cycle stages or during the late stages and how does that impact the preemptive game framework.

First of all, in our preemption game, the stance of a firm towards innovation is seen through the interaction between the level of cash flows generated by short-term assets and the threshold above which outsiders preempt incumbents. Importantly, from equation (5.7) we observe that the cash-flow threshold is not affected, as it is independent of the current level of cash flows produced by the incumbent. Nonetheless, the easiness by which it is crossed is affected by it, since the preemption decision ultimately comes down to the comparison between this threshold and  $X$ . As we described above, for values of  $X$  lower (higher) than the threshold, the incumbent firm deters (allows) the entrance of the potential competitor.

Having this in mind, it is now straightforward to retrieve the link between a firm's life-cycle and the preemption game. A mature company is different from an early stage firm in many factors, including the level of cash flows generated by their short-term projects.

Indeed, the level of cash flows produced by a firm’s assets-in-place is logically expected to increase as a firm grows and approaches a steady-state growth path, as the value of a mature firm gradually converts to the value of their existing assets (Damodaran 2009, Jaafar and Halim 2016). Contrariwise, growth firms derive a relatively higher portion of their value from growth assets– long-term assets–, as their capacity to generate cash flows from existing assets is still underdeveloped. Following this logic, it is easy to see that as a firm matures and  $X$  increases, for the same level of threshold, the probability of an outsider firm being preempted increases. Only for sufficiently low values ( $X < X^{threshold}$ ), i.e., when the incumbent is still in the early stages of the life-cycle, it will deter the entrance of an outsider. In short, as a firm approaches maturity, the firm becomes increasingly less likely to preempt an outsider in a preemption game associated with investment in innovation.

Figure 5.1 shows how the investment decision is affected by the current level of the incumbent’s cash flows produced via its assets-in-place.



**Figure 5.1:** The role of the current cash-flow level generated by the incumbent’s assets-in-place on incumbent’s and outsider’s triggers. The gray area represents the value range of the cash flows generated by the incumbent firm ( $X$ ) in which the outsider preempts the incumbent. The black area shows the range of  $X$  in which the incumbent firm deters the entrance of the outsider. The computation is based on the parameters shown in table (3.4).

Our model is line with literature findings as it stresses an endogenous negative relationship between a firm’s growth path and R&D engagement, as the model shows that only for low levels of cash flows generated by the incumbent from its existing assets, will they preempt an outsider from investing in a long-term innovative project.

As an innovation-oriented firm produces innovation and converts R&D projects into assets-in-place and the firm evolves through its life-cycle,  $X$  increases. This endogenous dynamic works so that incumbent firms becomes more prone to be preempted by outsiders in future R&D projects, as  $X^{threshold}$  increases. An endogenous life-cycle link with R&D investment is internal to our model which allows us to state that,

**Proposition 9.** *When effort allocation has to be optimally decided by the incumbent firm, and when managers add value to the projects they are responsible for managing, under optimal conditions, incumbent firms during the early stages of the life-cycle tend to invest in R&D sooner than those that happen to be in a mature state before the innovation arrives. The probability of an installed firm preempting the entrance of an outsider in a R&D projects decreases with its level of cash flows generated by its assets-in-place.*

We showed that under a monopolistic setup, firms tend to invest in innovation as soon as these are in the early stages of the life-cycle (Proposition 7). We extended this analysis in a game where active and outsider firms compete for innovation, retrieving the key finding that competitive dynamics justify why innovation-oriented firms do not remain innovators forever, as there are endogenous dynamics intrinsic to the firms that avoid this outcome.

## 5.2 Uncertainty and Preemptive behavior

We now expand the scope of Proposition 8 and we analyze the significant implications of such finding in a game where an incumbent and an outsider firm compete for a given R&D project. We aim at studying how different levels of uncertainty affect both the incumbent and the outsider optimal investing policies and, with that, how those different levels justify the preemptive behavior of each of these players.

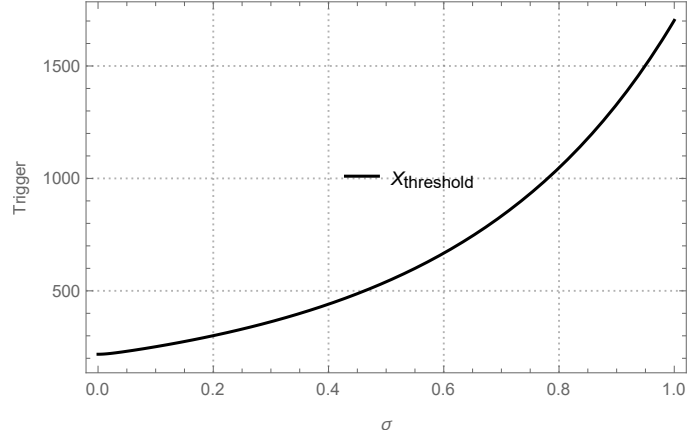
Mathematically, the impact of uncertainty in the competition game between both players is given by the derivative of the threshold that defines the inflection of the preemptive behavior with respect to the uncertainty variable. Doing so, we get:

$$\frac{\partial X^{threshold}}{\partial \beta} = - \frac{(K + \xi) \left( \frac{(r + \alpha - \lambda) \psi_t}{\lambda \phi \psi_i} \right)^{\frac{\beta}{\beta - 1}} \left( -1 + \beta + \beta \log \left( \frac{(r + \alpha - \lambda) \psi_t}{\lambda \phi \psi_i} \right) \right)}{(\beta - 1)^3 \psi_t} < 0 \quad (5.10)$$

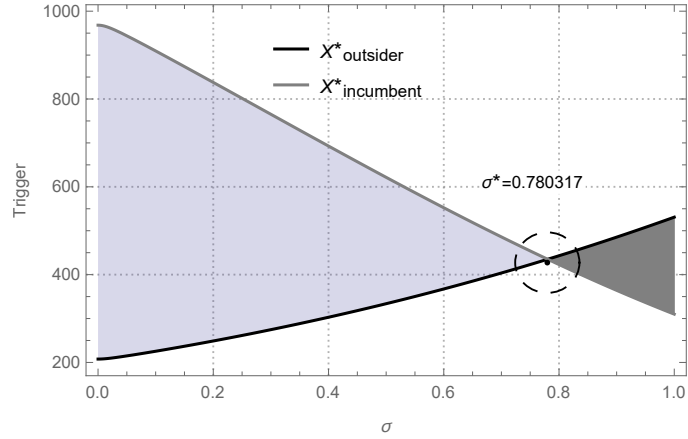
Making use of the well-known result  $\left( \frac{\partial \beta}{\partial \sigma} < 0 \right)$  we get:

$$\frac{\partial X^{threshold}}{\partial \sigma} > 0 \quad (5.11)$$

From the result above we retrieve a positive relationship between the threshold above which the preemptive approach changes from the incumbent to the outsider and the level of uncertainty. Indeed, uncertainty has a key impact on a firm's competition for R&D projects, as higher levels of uncertainty, by raising the threshold, increase the value range of cash flows generated by the firm in which installed firms deter the entrance of outsiders. In other words, an increase of the volatility of the cash flows in a given industry leads incumbent firms to increase their preemptive approach towards outsiders as far as R&D investing is concerned, as the required cash-flow level above which outsiders preempt installed firms also increases (Figure 5.2).



**Figure 5.2:** The effect of volatility ( $\sigma$ ) on the threshold ( $X^{threshold}$ ). Higher volatility leads to a higher threshold. The computation is based on the parameters shown in table (3.4).



**Figure 5.3:** The total effect of volatility ( $\sigma$ ) on incumbent's and outsider's triggers. The gray area represents the value range of the cash flows generated by the incumbent firm ( $X$ ) in which the outsider preempts the incumbent. The black area shows the range of  $X$  in which the incumbent firm deters the entrance of the outsider. The computation is based on the parameters shown in table (3.4).

The intersection of both curves yields the  $\sigma^*$  (0.780317) above (below) which installed firms avoid (allow) the entrance of outsiders, and invest earlier (later) in a given R&D project. From Figure 5.3 we observe that for sufficiently high values of uncertainty ( $\sigma > \sigma^*$ ), the incumbent firms dominate the outsider and deter they entrance into a R&D investment. Conversely, for low values of uncertainty ( $\sigma < \sigma^*$ ), outsiders behave preemptively and invest earlier than incumbents. This analysis allows us to expand the scope of Proposition 8, and state that,

**Corollary 4.** *When effort allocation has to be optimally decided by the incumbent firm, and when managers add value to the projects they are responsible for managing, under optimal*

*conditions, incumbent firms operating in industries with high (low) volatility tend to invest in R&D sooner (later) than those that happen to be idle before the innovation arrives. In high volatility environments, the predatory behavior of incumbent forms is amplified.*

Therefore, uncertainty surges as a possible explanation for why installed firms preempt outsiders, and vice-versa. Importantly, in our model, it is uncertainty that leads firms to forestall competitors calling investment opportunities sooner. This finding sets us apart from literature (e.g Weeds 2002) whose models show a logic inverse to our own, where lower investment triggers of incumbent firms are the consequence of considering the risk of competition. It is the fear of a competitor stealing the investment opportunity that drives installed firms to act early under an uncertain state of the world. Differently, in our model, the competitive and the preemptive behavior of the incumbent are the direct consequence of firms operating in high-volatility type of environments.

### 5.3 Model development: The role of skills in the Preemptive Game

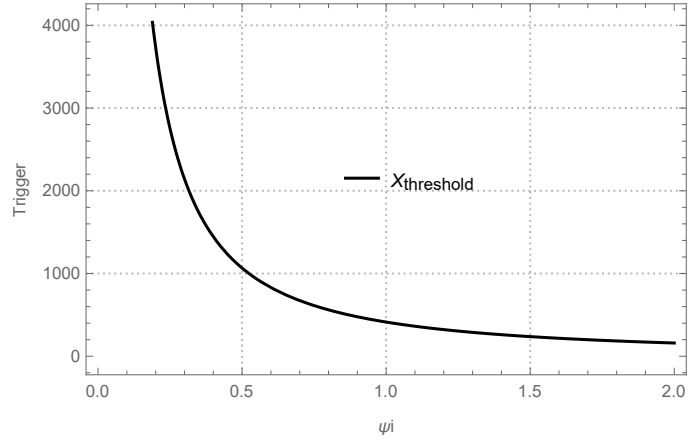
In the following section, we study the role of managerial skill and how does that ultimately affect the way incumbent and outsiders compete for R&D investments. First, we start by holding our assumption of equal managerial skill between the incumbent's and the outsider's management team. Then, we relax this assumption and we assess how the manager's heterogeneous innovative skills in both companies impact the preemption game.

#### 5.3.1 Equal skills

The effect of different levels of managerial skill towards innovative projects is mathematically given by the derivative of the threshold with respect to the variable capturing such managerial skills. Accordingly, we get:

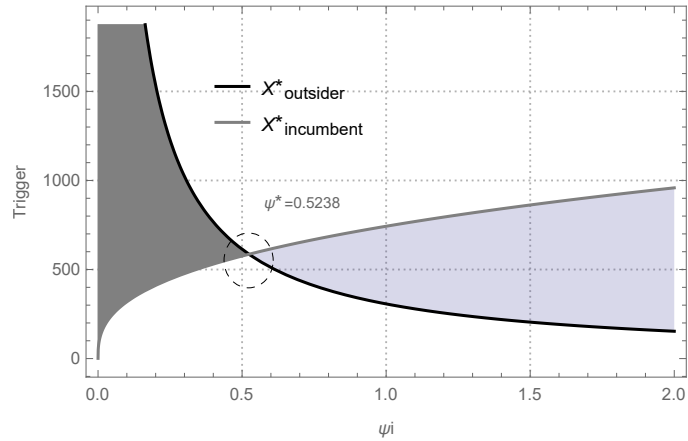
$$\frac{\partial X^{threshold}}{\partial \psi_i} = - \frac{\beta^2 (K + \xi) \left( \frac{(r + \alpha - \lambda) \psi_t}{\lambda \phi \psi_i} \right)^{\frac{\beta}{\beta - 1}}}{(\beta - 1)^2 \psi_t \psi_i} < 0 \quad (5.12)$$

From this result, we observe that higher levels of managerial skill as far as managing long-term innovative projects in both the installed and the outsider firm lead to a lower threshold above which the preemptive approach becomes the best answer for the outsider. The required cash-flow level above which outsiders preempt installed firms decreases with skilled teams towards innovation so that the range of cash-flows in which incumbent deters the entrance of outsiders is reduced.



**Figure 5.4:** The effect of the value-added by the incumbent and outsider managerial skill( $\psi_i$ ) on the threshold ( $X^{threshold}$ ). Higher level of innovative skills leads to a lower threshold. The computation is based on the parameters shown in table (3.4).

Figure 5.5 shows how different levels of managerial skill affect the interaction between both players. The intersection of both curves yields the  $\psi^*$  (0.5238) below (above) which installed firms avoid (allow) the entrance of outsiders, and invest early (later) in a given R&D project. The main conclusion is that the higher the value-added by managers of both companies when directing long-term innovative projects, the lower the range, hence, the probability, in which incumbent firms find optimal to prevent outsiders from investing in a given R&D project.



**Figure 5.5:** The effect of the value-added by the incumbent and outsider managerial skill( $\psi_i$ ) on the incumbent's and the outsider's triggers. The gray area represents the value range of the cash-flows generated by the incumbent firm ( $X$ ) in which the outsider preempts the incumbent. The black area shows the range of  $X$  in which the incumbent firm deters the entrance of the outsider. The computation is based on the parameters shown in table (3.4).

This analysis can also be conducted by explicitly modeling for the threshold in terms

of the manager's skills as far as directing R&D projects is concerned, rather than through cash-flows. Re-arranging equation (5.7) and solving for  $\psi_i$ :

$$\psi_i^{threshold} = \frac{(r - \alpha + \lambda) \psi_t \left( \frac{X (\beta - 1) \psi_t}{\beta (K + \xi)} \right)^{\frac{\beta}{\beta - 1}}}{\lambda \phi} \quad (5.13)$$

where for levels of managerial skill below the threshold ( $\psi_i < \psi_i^{threshold}$ ), the incumbent deters the entrance of the outsider, and for levels of managerial skill above the threshold ( $\psi_i > \psi_i^{threshold}$ ), the outsider preempts the incumbent firm.

### 5.3.2 Different skills

In contrast to the previous sections, let us now consider a framework where the competing firms are allowed to showcase management teams with different levels of managerial skill as far as long-term projects<sup>1</sup>.

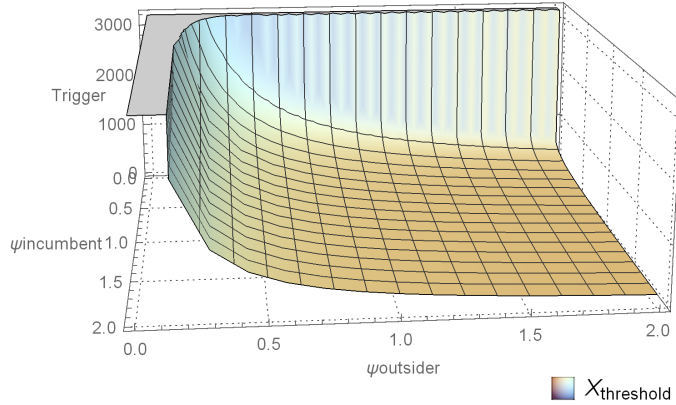
The derivation procedure is the same used in the version with homogeneous firms. The only relevant difference affecting the threshold derivation is that now we consider different managerial innovation-related skills between the installed and the outsider firm, given by  $\{\psi_{incumbent}, \psi_{outsider}\}$ . Plugging in these new variables, we derive the threshold as:

$$X^{threshold} = \frac{\beta}{\beta - 1} (K + \xi) \frac{\psi_{incumbent}}{\psi_t \psi_{outsider}} \left( \frac{(r + \alpha - \lambda) \psi_t}{\lambda \phi \psi_{incumbent}} \right)^{\frac{\beta}{\beta - 1}} \quad (5.14)$$

Then, we look at how the threshold above which the outsider preempts the incumbent firm depends on the difference between both firms management teams. Figure 5.6 shows the impact of different levels of  $\{\psi_{incumbent}, \psi_{outsider}\}$  in the threshold.

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<sup>1</sup>For reasons of simplicity, let us assume that only the skills associated with innovative projects can differ between incumbent and outsiders. The skills associated with non-innovative projects ( $\psi_t$ ) are assumed to remain equal for both companies.



**Figure 5.6:** The effect of the value-added by the incumbent and outsider managerial skill ( $\psi_{incumbent}, \psi_{outsider}$ ) on the threshold ( $X^{threshold}$ ). The computation is based on the parameters shown in table (3.4)

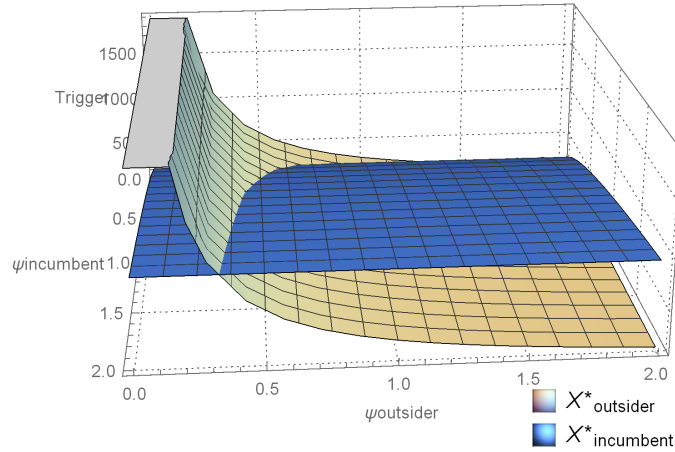
From the figure above we retrieve that the threshold above which outsiders preempt incumbents increases with lower values of managerial skill regarding R&D for both players. There are two regions of values of  $(\psi_{incumbent}, \psi_{outsider})$  where the threshold suffers an upward inflection towards high threshold levels: when  $\psi_{outsider}$  tends to zero and when  $\psi_{incumbent}$  also tends to zero. All in all, we observe that incumbents are more likely to deter the investment in R&D from a competitor when the managerial skill of one of the management teams is significantly low.

Contrariwise, the likelihood of outsiders developing a preemptive attack towards an innovative project increases with the level of managerial skills towards directing R&D projects shown by the managers of both teams. The greater the combination of skill of both firms, the lower will be the threshold, hence, the lower the range of cash flows in which the installed firm avoids the outsider's investment. Note that this a particular case of the section above: when both firms have increasingly and equal managerial skill values, the threshold becomes lower. Therefore, we may state that,

**Proposition 10.** *The probability of an outsider preempting an installed firm regarding the investment in a R&D project is particularly low when (i) the managerial skill towards innovative projects of the incumbent firm is low and/or (ii) when the managerial skill towards innovative projects of the outside firm is low. The probability of an outsider preempting an installed firm regarding the investment in a R&D project is particularly high when the managerial skill level towards innovative projects of both the incumbent and the outsider firm is high.*

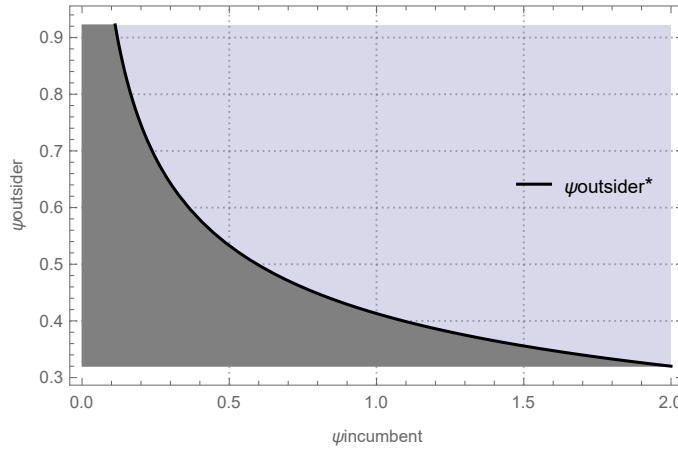
The following Figure 5.7 shows the interaction between the optimal investment policies of both the outsider and the incumbent firms for different levels of managerial skill.





**Figure 5.7:** The effect of the value-added by the incumbent and outsider managerial skill ( $\psi_{incumbent}, \psi_{outsider}$ ) on incumbent's and outsider's triggers. The computation is based on the parameters shown in table (3.4)

The intersection between both surfaces yields the equation correspondent to the combinations of skill ( $\psi_{incumbent}^*, \psi_{outsider}^*$ ) that generate the threshold. Different combinations produce different levels of threshold, according to Figure 5.8.



**Figure 5.8:** The different combinations of ( $\psi_{incumbent}, \psi_{outsider}$ ) that produce the threshold ( $X^{threshold}$ ). The gray area represents the value range of ( $\psi_{incumbent}, \psi_{outsider}$ ) in which the outsider preempts the incumbent. The black area shows the range of ( $\psi_{incumbent}, \psi_{outsider}$ ) in which the incumbent firm deters the entrance of the outsider. The computation is based on the parameters shown in table (3.4).

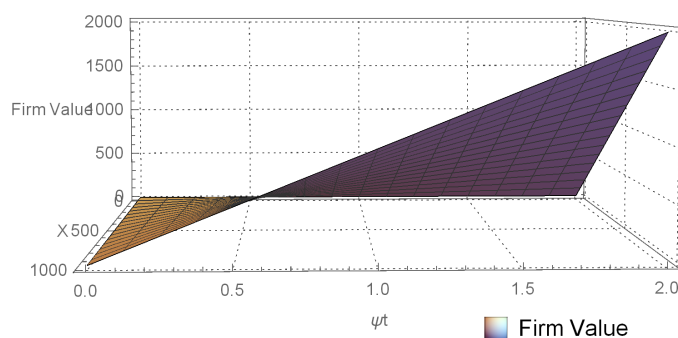
Figure 5.8 highlights the relationship between the preemption game dynamic and the level of expertise of managers directing R&D project in both companies as described above. Note that for every combination of ( $\psi_{incumbent}, \psi_{outsider}$ ) below the line, the incumbent preempts the outsider, and vice-versa for values above the line.

## 5.4 Policy Implications

At the firm level, the theoretical models introduced in the current dissertation allow us to outline a set of policy implications.

We derived a key finding related to how a firm's life-cycle affects the preemption game between an installed firm and an outsider competing for an innovative project. The model rendered that the probability of an installed firm preempting the entrance of an outsider in a R&D project decreases with the incumbent's level of cash flows generated by the asset-in-place, hence, we extrapolate that as installed firms approach maturity, it is more likely an outcome in which outsiders win the race for a given disputed R&D project. To acknowledge this endogenous R&D cycle should be seen as critical for successfully managing a firm through the maturity stage.

First, consider that as a firm goes through the maturity stage, the value of the company will gradually, as a result of less R&D projects in the incumbent's investment portfolio, tend towards the value of the assets-in-place. Therefore, companies seeking to remain financially sustainable throughout maturity and avoid decline should focus their effort on increasing the productivity of short-term projects. Among many alternatives, our model considers the potential role of managerial short-term expertise to capture such effect. Figure 5.9 shows how the value of a firm whose value depends entirely on the short-term assets relate to different levels of  $\psi_t$ .



**Figure 5.9:** The effect of the value-added by managerial short-term skill ( $\psi_t$ ) on firm's value. The computation is based on the parameters shown in table (3.4)

As we observe, the wrong manager can be detrimental to a firm's financial sustainability, but the right manager can amplify the value of the very same firm throughout the maturity stage.

Second, we also take into consideration policies that firms shall engage to avoid the threat of losing the leading-status whereas competing for R&D projects.

Knowing that an important part of the threat of preemptive attacks by outsiders has to

do with how incumbent firm's managers choose their effort allocation, firms may consider having two groups of segmented managers – one fully dedicated to run the assets-in.-place ( $w = 1$ ) and another other fully committed to the management of the long-term projects ( $w = 0$ ). Doing so, allows the latter group to face the outsider firm's managers, 100% committed to the long-run projects, and with that build a defensive policy.

Finally, the probability of an outsider preempting an installed firm regarding the investment in a R&D project is particularly low, among other combinations, when the managerial skill towards innovative projects of the incumbent firm is low and/or when the managerial skill towards innovative projects of the outside firm is low (Proposition 10). This proposition carries an important policy implication. If shareholders of the company want to develop mechanisms of defense to avoid entering in a maturity stage due to the inevitable predatory actions of outsiders, the incumbent firm may consider to actively attempt lowering the level of managerial expertise for innovative projects in the outsider firm, by, for instance, acting preemptively in the market for managers, avoiding high  $\psi_i$  managers to work for outsiders. Acquiring managers with high  $\psi_i$  for a given industry and engaging in a "brain drain" strategy may prove to be helpful to avoid preemption.

## Chapter 6

# Conclusions

We derive an optimal compensation package, through a mix of a fixed and a variable pay term, that ensures that managers and shareholders are aligned as far as the optimal effort allocation strategy. Furthermore, we show that the resultant optimal compensation policy also allows aligning both agents' optimal investment timing policies. The optimal value-sharing rate is a function of the cost burden associated with a R&D project, of the size of the fixed term and of the uncertainty of the project. We find that the optimal compensation package is independent of key value drivers, the financial impact of the project and from the manager's skill set.

Extending the reach of our model, we show that when managers (i) contribute to the value of the firm through their skills and (ii) are entitled to the decision of choosing their effort allocation strategy, under optimal conditions, the optimal investment timing is negatively related with the market uncertainty. We show that this comes as a corollary of considering the two-stage framework, and we add an endogenous explanation to the link between uncertainty and investment in the Real Options branch. Moreover, we show that as firms evolve through their life-cycle they become less willing to invest in future R&D projects, as the investment trigger also increases. Our model predicts that the later an industry/a company is in the life-cycle, the less disruptive it should be expected to be.

When we consider a framework where an installed firm competes with an outsider for a R&D project, our model renders that, as uncertainty increases, incumbents are more likely to preempt outsider idle firms. Additionally, we retrieve that the probability of the incumbent firms being preempted by outsiders increases with the level of cash flows produced by the assets-in-place. Thereby, firms are expected to become less preemptive as they approach maturity which allows us to portray an endogenous link between a firm's life-cycle and its engagement in R&D investments, considering now industry dynamics. Incumbents may opt for building defensive tactics by, for instance, actively attempting to avoid outsiders to acquire managers with a high level of expertise in R&D projects or having segmented managerial teams.

The model and ulterior policy findings should be the subject of further scientific scrutiny. Empirical tests on the link between volatility and the preemptive approach of

incumbent firms and on the possible life-cycle explanation for the R&D ups and downs throughout the lifetime of a firm are of the utmost relevance in order to fully understand how agency conflicts affect innovation-seeking companies. Doing so will allow the community to make the leap from existing static models to dynamic ones, as hereby developed, with the key confirmation given by an empirical test.

# Appendix

## Proof of Proposition 1

$$\gamma_M^* = \frac{\xi}{K + \xi} + \frac{\lambda}{r + \lambda} \frac{B}{K + \xi} \quad (6.1)$$

$$\gamma_S^* = \frac{\xi}{K + \xi} - \frac{\lambda}{r + \lambda} \frac{B}{K + \xi} \quad (6.2)$$

There are two approaches which yield the results from Proposition 1. The first approach comes from setting the equations of the optimal allocation of effort equal between managers and shareholders, and solving for  $\gamma$  of one of the agents, since  $\gamma_M = 1 - \gamma_S$ . Doing so, we get :  $w_S^* = w_M^*$ .

The second approach yielding the optimal compensation derives from retrieving the optimal effort allocation strategy from the perspective of the social planner. This comes from the feature of the optimal compensation structure that establishes that the optimal solution is the one that maximizes the welfare of the economy as a whole. Thus, we can conclude that if the optimal effort allocation for a social planner ( $w_{SP}^*$ ) gives us the same solution as by replacing the optimal compensation structure for each agent in the respective optimal effort allocation function, then Proposition 1 is true.

Solving the social planner value function follows the same procedures of the derivation cases for managers and shareholders. There are, however, two particular tweaks in the model: (i) the compensation effect is not considered since the effect is muted by a social planner- which can be understood as a founder owning 100% of the equity of the firm and entitled to the management duties-, and, consequently, (ii) the social planner has to bear the full investment cost ( $K$ ) and the effort costs associated ( $\xi$ ). Under the perspective of the social planner, the respective value function,  $SP(X)$ , in a R&D project must satisfy the following o.d.e:

$$\frac{1}{2}\sigma^2 X^2 \frac{\partial^2 SP(X)}{\partial X^2} + \alpha X \frac{\partial SP(X)}{\partial X} - rSP(X) + \lambda[\psi\phi X - SP(X)] = 0 \quad (6.3)$$

subject to the following boundary conditions:

$$\lim_{X \rightarrow 0} SP(X) = 0 \quad (6.4)$$

$$\lim_{X \rightarrow X_{SP}^*} SP(X) = \frac{\lambda\psi\phi X_{SP}^*}{r + \lambda - \alpha} - \frac{K + \xi}{1 - w} \quad (6.5)$$

$$\lim_{X \rightarrow X_{SP}^*} \frac{\partial SP(X)}{\partial X} = \frac{\lambda\psi\phi}{r + \lambda - \alpha} \quad (6.6)$$

Following the standard procedures, the solution for the value of the option to invest in a R&D project comes:

$$SP(X) = \begin{cases} \left( \frac{\lambda\psi\phi X_{SP}^*}{r + \lambda - \alpha} - \frac{K + \xi}{1 - w} \right) \left( \frac{X}{X_{SP}^*} \right)^\beta & X < X_{SP}^* \\ \frac{\lambda\psi\phi X}{r + \lambda - \alpha} - \frac{K + \xi}{1 - w} & X \geq X_{SP}^* \end{cases}$$

where the trigger is given by,

$$X_{SP}^* = \frac{\beta}{\beta - 1} \frac{(r - \alpha + \lambda)(K + \xi)}{(1 - w)\lambda\phi\psi} \quad (6.7)$$

The problem, then, becomes a maximization issue, such as in previous cases. The solution comes:

$$\max_w [w\psi X + (1 - w)SP(X_{SP}^*)] \quad (6.8)$$

$$w_{SP}^* = 1 - \frac{\beta(K + \xi) \left( \frac{r + \alpha - \lambda}{\lambda\phi} \right)^{\frac{\beta}{\beta - 1}}}{X(\beta - 1)\psi} \quad (6.9)$$

where the optimal solution for the social planner equals  $w_S^*(\gamma_S^*) = w_M^*(\gamma_M^*)$ , *q.e.d.*

**2.** We want to prove that the managerial investment trigger depends negatively on the likelihood of the arrival of a technological shock ( $\lambda$ ).

$$\frac{dX_M^*}{d\lambda} = \frac{\partial X_M^*}{\partial \lambda} + \frac{\partial X_M^*}{\partial \beta} \frac{\partial \beta}{\partial \lambda} < 0 \quad (6.10)$$

$$\frac{\partial X_M^*}{\partial \lambda} = \frac{-B\alpha\beta\lambda^2 + (r - \alpha)\beta(r + \lambda)^2\xi}{(w - 1)(\beta - 1)\gamma_M\lambda^2(r + \lambda)^2\phi\psi} < 0 \quad (6.11)$$

$$\frac{\partial X_M^*}{\partial \beta} = \frac{(r - \alpha + \lambda)(B\lambda + (r + \lambda)\xi)}{(w - 1)(\beta - 1)^2\gamma_M\lambda(r + \lambda)\phi\psi} < 0 \quad (6.12)$$

$$\frac{\partial \beta}{\partial \lambda} = \sqrt{\frac{1}{\left(\frac{1}{2} + \frac{r - \delta}{\sigma^2} + \frac{2(r + \lambda)}{\sigma^2}\right)\sigma^2}} > 0 \quad (6.13)$$

Note that we arrive at this result by imposing the following restriction,  $(r - \alpha)\beta(r + \lambda)^2\xi < -B\alpha\beta\lambda^2\alpha$ , otherwise this static would have no economic significance, as a higher

probability of arriving a positive shock would induce managers to delay the investment, *ceteris paribus*.

Thus, we show that the managerial investment trigger depends negatively on the mean arrival rate of a technological shock ( $\lambda$ ), *q.e.d.*

### Proof of Corollary 2

The alignment of interests via effort allocation is a consequence of the derivation procedure and its proof reverts to the Proof of Proposition 1. The alignment of interests via investment trigger can be derived as follows.

Replacing  $\gamma_M^*$  on Manager's optimal trigger function:

$$X_M^*(\gamma_M^*) = \frac{\beta}{\beta - 1} \frac{(r - \alpha + \lambda)(B\lambda(r + \lambda)\xi)}{(1 - w)\gamma_M^*\lambda(r + \lambda)\phi\psi} \quad (6.14)$$

we get:

$$X_M^*(\gamma_M^*) = \frac{\beta}{\beta - 1} \frac{(r - \alpha + \lambda)(K + \xi)}{(1 - w)(\lambda\phi\psi)} \quad (6.15)$$

Replacing  $\gamma_S^*$  on Shareholder's optimal trigger function:

$$X_S^*(\gamma_S^*) = \frac{\beta}{\beta - 1} \frac{(r - \alpha + \lambda)(-B\lambda(r + \lambda)K)}{(1 - w)\gamma_S^*\lambda(r + \lambda)\phi\psi} \quad (6.16)$$

we get:

$$X_S^*(\gamma_S^*) = \frac{\beta}{\beta - 1} \frac{(r - \alpha + \lambda)(K + \xi)}{(1 - w)(\lambda\phi\psi)} \quad (6.17)$$

So, we prove that  $X_S^*(\gamma_S^*) = X_M^*(\gamma_M^*)$ .

**4. Derivation of the value functions for managers and shareholders under heterogeneous skills.**

The option value for the manager,  $M(X)$ , must satisfy the second order ordinary differential equation (o.d.e.):

$$\frac{1}{2}\sigma^2 X^2 \frac{\partial^2 M(X)}{\partial X^2} + \alpha X \frac{\partial M(X)}{\partial X} - rM(X) + rB + \lambda[\gamma_M \psi_i \phi X - M(X)] = 0 \quad (6.18)$$

The solution of the o.d.e takes the following form:

$$M(X) = \frac{\lambda\gamma_M \psi_i \phi X}{r + \lambda - \alpha} + \frac{rB}{r + \lambda} + A_1 X^{\beta_1} + A_2 X^{\beta_2} \quad (6.19)$$

where:

$$\beta_1 = \frac{1}{2} - \frac{r - \delta}{\sigma^2} + \sqrt{\left(\frac{r - \delta}{\sigma^2} - \frac{1}{2}\right)^2 + \frac{2(r + \lambda)}{\sigma^2}} > 1 \quad (6.20)$$

$$\beta_2 = \frac{1}{2} - \frac{r - \delta}{\sigma^2} - \sqrt{\left(\frac{r - \delta}{\sigma^2} - \frac{1}{2}\right)^2 + \frac{2(r + \lambda)}{\sigma^2}} < 0 \quad (6.21)$$



Furthermore, the option value for the manager,  $M(X)$  is subject to the following boundary conditions:

$$\lim_{X \rightarrow 0} M(X) = \frac{rB}{r + \lambda} \quad (6.22)$$

$$\lim_{X \rightarrow X_M^*} M(X) = \frac{\lambda\gamma_M\psi_i\phi X_M^*}{r + \lambda - \alpha} - \frac{\lambda B}{(r + \lambda)(1 - w)} - \frac{\xi}{1 - w} \quad (6.23)$$

$$\lim_{X \rightarrow X_M^*} \frac{\partial M(X)}{\partial X} = \frac{\lambda\gamma_M\psi_i\phi}{r + \lambda - \alpha} \quad (6.24)$$

Following the standard procedures and using standard calculus, the solution for the value of the option to invest in a R&D project comes:

$$M(X) = \begin{cases} \left( \frac{\lambda\gamma_M\psi_i\phi X_M^*}{r + \lambda - \alpha} - \frac{\lambda B}{(r + \lambda)(1 - w)} - \frac{\xi}{1 - w} \right) \left( \frac{X}{X_M^*} \right)^\beta & X < X_M^* \\ \frac{\lambda\gamma_M\psi_i\phi X}{r + \lambda - \alpha} - \frac{\lambda B}{(r + \lambda)(1 - w)} - \frac{\xi}{1 - w} & X \geq X_M^* \end{cases}$$

and the investment trigger is given by:

$$X_M^* = \frac{\beta}{\beta - 1} \frac{(r - \alpha + \lambda)(B\lambda(r + \lambda)\xi)}{(1 - w)\gamma_M\lambda(r + \lambda)\phi\psi_i} \quad (6.25)$$

Plugging in these new variables, we obtain the following key results:

$$\max_w [w\gamma_M\psi_t X + B + (1 - w)M(X_M^*)] \quad (6.26)$$

$$w_M^* = 1 - \frac{\beta}{\beta - 1} \frac{(B\lambda + (r + \lambda)\xi) \left( \frac{(r - \alpha + \lambda)\psi_t}{\lambda\phi\psi_i} \right)^{\frac{\beta}{\beta - 1}}}{X\gamma_M(r + \lambda)\psi_t} \quad (6.27)$$

The value function of the shareholder,  $S(X)$ , must satisfy the following o.d.e:

$$\frac{1}{2}\sigma^2 X^2 \frac{\partial^2 S(X)}{\partial X^2} + \alpha X \frac{\partial S(X)}{\partial X} - rS(X) - rB + \lambda[\gamma_S\psi_i\phi X - S(X)] = 0 \quad (6.28)$$

The general solution of the o.d.e takes the following form:

$$S(X) = \frac{\lambda\gamma_S\psi_i\phi X}{r + \lambda - \alpha} - \frac{rB}{r + \lambda} + A_1 X^{\beta_1} + A_2 X^{\beta_2} \quad (6.29)$$

The shareholder-value function must satisfy the following boundary conditions:

$$\lim_{X \rightarrow 0} S(X) = -\frac{rB}{r + \lambda} \quad (6.30)$$

$$\lim_{X \rightarrow X_S^*} S(X) = \frac{\lambda \gamma_S \psi_i \phi X_S^*}{r + \lambda - \alpha} + \frac{\lambda B}{(r + \lambda)(1 - w)} - \frac{K}{1 - w} \quad (6.31)$$

$$\lim_{X \rightarrow X_S^*} \frac{\partial M(X)}{\partial X} = \frac{\lambda \gamma_S \psi_i \phi}{r + \lambda - \alpha} \quad (6.32)$$

Following the standard procedures, the solution for the value of the option to invest in a R&D project comes:

$$S(X) = \begin{cases} \left( \frac{\lambda \gamma_S \psi_i \phi X_S^*}{r + \lambda - \alpha} + \frac{\lambda B}{(r + \lambda)(1 - w)} - \frac{K}{1 - w} \right) \left( \frac{X}{X_S^*} \right)^\beta & X < X_S^* \\ \frac{\lambda \gamma_S \psi_i \phi X}{r + \lambda - \alpha} + \frac{\lambda B}{(r + \lambda)(1 - w)} - \frac{K}{1 - w} & X \geq X_S^* \end{cases}$$

and the investment trigger is given by:

$$X_S^* = \frac{\beta}{\beta - 1} \frac{(r - \alpha + \lambda)(-B\lambda(r + \lambda)K)}{(1 - w)\gamma_S\lambda(r + \lambda)\phi\psi_i} \quad (6.33)$$

Analogously to the manager's approach, the shareholder derives an optimal effort allocation strategy between short and long-term projects that maximizes her/his wealth. The solution is presented below:

$$\max_w [w\gamma_S\psi_t X - B + (1 - w)S(X_S^*)] \quad (6.34)$$

$$w_S^* = 1 - \frac{\beta}{\beta - 1} \frac{(-B\lambda + (r + \lambda)K) \left( \frac{(r - \alpha + \lambda)\psi_t}{\lambda\phi\psi_i} \right)^{\frac{\beta}{\beta - 1}}}{X\gamma_S(r + \lambda)\psi_t} \quad (6.35)$$

**5.** We want to show the impact of different managerial skills in the optimal effort solutions of managers and shareholders.

For managers:

$$\frac{\partial w_M^*}{\partial \psi_i} = \frac{\beta^2 (B\lambda + (r + \lambda)\xi) \left( \frac{(r + \alpha - \lambda)\psi_t}{\lambda\phi\psi_i} \right)^{\frac{\beta}{\beta - 1}}}{X(\beta - 1)^2 \gamma_M (r + \lambda) \psi_i \psi_t} > 0 \quad (6.36)$$

$$\frac{\partial w_M^*}{\partial \psi_t} = - \frac{\beta (B\lambda + (r + \lambda)\xi) \left( \frac{(r + \alpha - \lambda)\psi_t}{\lambda\phi\psi_i} \right)^{\frac{\beta}{\beta - 1}}}{X(\beta - 1)^2 \gamma_M (r + \lambda) \psi_i \psi_t} < 0 \quad (6.37)$$

For shareholders:

$$\frac{\partial w_S^*}{\partial \psi_i} = \frac{\beta^2 (-B\lambda + (r + \lambda) \xi) \left( \frac{(r + \alpha - \lambda) \psi_t}{\lambda \phi \psi_i} \right)^{\frac{\beta}{\beta - 1}}}{X (\beta - 1)^2 \gamma_S (r + \lambda) \psi_i \psi_t} > 0 \quad (6.38)$$

$$\frac{\partial w_S^*}{\partial \psi_t} = - \frac{\beta (-B\lambda + (r + \lambda) \xi) \left( \frac{(r + \alpha - \lambda) \psi_t}{\lambda \phi \psi_i} \right)^{\frac{\beta}{\beta - 1}}}{X (\beta - 1)^2 \gamma_S (r + \lambda) \psi_i \psi_t} < 0 \quad (6.39)$$

We arrive at this results by imposing the following restriction,  $(r + \lambda) \xi > -B\lambda$ .

**6.** We want to show the impact of different managerial skills in the optimal investment timing solutions of managers and shareholders.

For managers:

$$\frac{\partial X_M^*}{\partial \psi_i} = \frac{\beta (r - \alpha + \lambda) (B\lambda (r + \lambda) \xi)}{(w - 1) (\beta - 1) \gamma_M \lambda (r + \lambda) \phi \psi_i^2} < 0 \quad (6.40)$$

For shareholders:

$$\frac{\partial X_S^*}{\partial \psi_i} = \frac{\beta (r - \alpha + \lambda) (-B\lambda (r + \lambda) \xi)}{(w - 1) (\beta - 1) \gamma_S \lambda (r + \lambda) \phi \psi_i^2} < 0 \quad (6.41)$$

We arrive at this results by imposing the following restriction,  $(r + \lambda) \xi > -B\lambda$ , as described before.

### Proof of Corollary 3

$$w_S^* = w_M^* \quad (6.42)$$

$$1 - \frac{\beta}{\beta - 1} \frac{(-B\lambda + (r + \lambda) K) \left( \frac{(r - \alpha + \lambda) \psi_t}{\lambda \phi \psi_i} \right)^{\frac{\beta}{\beta - 1}}}{X \gamma_S (r + \lambda) \psi_t} = 1 - \frac{\beta}{\beta - 1} \frac{(B\lambda + (r + \lambda) \xi) \left( \frac{(r - \alpha + \lambda) \psi_t}{\lambda \phi \psi_i} \right)^{\frac{\beta}{\beta - 1}}}{X \gamma_M (r + \lambda) \psi_t} \quad (6.43)$$

The variable pay that allows a full alignment between the manager's and shareholder's effort allocation is given by:

$$\gamma_M^* = \frac{\xi}{K + \xi} + \frac{\lambda}{r + \lambda} \frac{B}{K + \xi} \quad (6.44)$$

$$\gamma_S^* = \frac{\xi}{K + \xi} - \frac{\lambda}{r + \lambda} \frac{B}{K + \xi} \quad (6.45)$$

which is the same solution for the homogeneous managerial skills version of the model shown in the Proof of Proposition 1, *q.e.d.*

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