Managerial firm's strategic investment decision in a real options framework*

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Abstract

This paper examines the investment behavior of a managerial firm facing competition by developing an investment timing model within the real option exercise game framework under incomplete information. Product market competition is modeled in a full preemption fashion in the sense that the first mover captures the whole market and the second mover's option to invest becomes worthless. The delegation of investment decision to a manager creates an agency conflict since the true quality of the underlying project is observed privately by the manager which gives her the scope for diverting part of the cash flows for private benefits. Thus, an optimal contract has to be designed which induces the agent to truthfully reveal the project's quality and exercise the option at a strategically optimal trigger level. Our results indicate that while competition tends to induce (over-) early-investment for both types of the project, the agency problem calls for delaying the investment for the low quality project, with the overall effect being dependent on the relative importance of preemption threat to the agency conflict. Accordingly, the existence of preemption threat can mitigate the (social) inefficiency stemming from agency conflict for the low quality project. Furthermore, competition provides additional incentives to the manager for truth-telling and as a result allows the owner to provide less (informational) rents to the manager. Finally, allowing for positive correlation between the competing firms' underlying project values has two consequences: First, while the amount of investment timing adjustment required due to competition decreases for the low quality project, the same increases for the high quality project. Second, the presence of correlation supplies (also) additional incentives to the manager for truth-telling and it suppresses the distortion in the low quality project's exercising trigger that originally stems from the agency problem.

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1 Introduction

The real options approach to investment has substantially altered the way how we think about irreversible investment opportunities. McDonald and Siegel (1986) were the first to formally show that optimal investment rules deviate from a simple NPV criterion and become "*an irreversible investment should only be undertaken if its expected payoff exceeds the sum of its cost and the value of waiting to invest*". Moreover, due to its option-like characteristics and by a standard convexity argument, an increase in the uncertainty surrounding an investment's payoff raises its value and also the value of waiting, thereby delays the investment. The standard real options approach is well summarized in Dixit and Pindyck (1994) and Trigeorgis (1996).

In the standard real options approach to investment under uncertainty, agents formulate optimal exercise strategies in isolation and ignore competitive interactions. However, in many real-world cases, exercise strategies cannot be determined separately, but must be formed as part of a strategic equilibrium. For instance, if firms fear preemption then the option to wait might become less valuable. Therefore, to understand investment in industries with competitive pressure, a game-theoretic analysis is called for[1]. Some recent contributions in the literature are as follows: Grenadier (2002), Botteron, Chesney, and Gibson-Asner (2003), Lambrecht and Perraudin (2003), Paxson and Pinto (2003), Miltersen and Schwartz (2004), Murto (2004), Pawlina and Kort (2006), Smit and Trigeorgis (2006) Miltersen and Schwartz (2007), Anderson, Friedman, and Oprea (2010) and Graham (2011).

Moreover, both the standard real options approach to investment and the simple NPV rule do not account for information asymmetries and agency conflicts. It is often assumed that the option's owner makes the exercise decision, i.e. no agency conflicts are allowed in the standard real options models. In most corporations, however, shareholders delegate the investment decision to managers, taking advantage of managers' expertise and knowledge. In such decentralized settings, both hidden information (e.g., managers are better informed than owners about projected cash flows, the level of competition, the firm's own and competitor firms' investment opportunities) and hidden actions (e.g., unobserved managerial effort, empire building) are likely to exist. A number of papers, particularly in the corporate finance literature, examine how corporate investment is influenced by problems of

[1] See Boyer, Gravel, and Lasserre (2004) for a recent useful review on the main contributions to the joint analysis of real options and strategic competition.

asymmetric information and agency[2]. Agency problems can be mitigated partially or fully by several practical mechanisms, which is the main theme of the contracting literature. The standard capital allocation literature provides predictions on whether firms over- or under-invest relative to the first-best no agency benchmark. In the real options literature, where investment timing is of interest, they translate into early- or delayed-investment[3]. The real option and traditional contracting (due to agency) literatures had remained separate (or combined limitedly) for a long time because of technical difficulties. For instance, real options are best understood in a continuous-time framework, while agency and contracting problems had traditionally been studied in discrete-time. Moreover, these models used very stylized setups, typically with two or three periods, that do not correspond to the standard models of investment used elsewhere in economics. Notice that, while one possibility is the agency issues arising between managers and shareholders[4], similar issues could exist between stockholders and bondholders or outside investors[5].

Can both over- and under-investment can occur in the (irreversible and flexible) investment decision of a managerial firm which is competing in the product market under preemption threat? Can such competition mitigate the (social) inefficiency stemming from agency conflict? Can competition serve as an incentive mechanism and allow the owner to decrease the (informational) rents extracted by the manager? What consequences does allowing for positive correlation between the competing firms' underlying projects values have, both on the competition and the agency problem? These are the main questions addressed in this study.

The core model in this paper can be described as follows: The firm owns a single project to invest and is flexible to choose its timing. Moreover, this investment decision is irreversible[6]. The investment decision is delegated to a manager, who privately observes the firm's own underlying project quality. An agency conflict then emerges as, for instance, the manager of a high quality project could claim to have a low quality project and divert

[2] See Stein (2001) for a useful summary on the impact of information and agency problems on investment behavior.

[3] Early-investment can be interpreted as over-investment, in a way the overall project life is longer eventually.

[4] Grenadier and Wang (2005), Philippon and Sannikov (2007), Lambrecht and Myers (2008), Shibata and Nishihara (2010) and Gryglewicz and Hartman-Glaser (2014) are recent studies that analyze the impact of such agency conflicts within a real option framework.

[5] For instance Mauer and Ott (2000), Morellec (2004), Mauer and Sarkar (2005), Morellec and Schürhoff (2011), Grenadier and Malenko (2011) and Bouvard (2012) examine the impact of agency conflicts arising between stockholders and bondholders or outside investors on firm value using the real options approach.

[6] It requires an initial expenditure (sunk cost) that should be paid by the time of investment.

part of the cash flows for her private benefits. Meanwhile, the firm is competing in the product market in a full preemption fashion[7]. Due to the incomplete information setting, the firm has only a belief on the exercise trigger of its competitor. Further, we allow for positive correlation between both firms' underlying project values. If there exists correlation, by observing privately the realization of the own underlying project quality the manager receives additional (private) information about its rival's behavior and updates her beliefs accordingly. To induce truth-telling the owner designs and offers a contract to the manager specifying a set of recommended exercise triggers and associated wages, one for each possible realization of project quality. Finally, upon exercise, the owner receives the value of the underlying project, pays the exercise price and the manager's exercise wage. On the other hand, upon preemption, the owner does not receive any value but may pay the manager a *preemption wage*.

As a first step, we derive the optimal investment behavior of an *entrepreneurial* firm under fear of preemption. We refer to these results as the first-best benchmark model results. Second, we derive the optimal investment behavior of a *managerial* firm under fear of preemption; in order to gain a first insight we assume *no correlation* and analyze the optimal wage scheme, i.e. derive the expressions for the exercise trigger levels and corresponding wages for each type of project. Comparing the exercise trigger levels with the first-best benchmark results, we find that, as usual in adverse selection models, there is no efficiency distortion at the top (high quality project)[8], whereas the low quality project is exercised later in order to satisfy the incentive constraint for the manager of a high quality project. Thus, the relative position of low quality project's trigger level compared to the standard real options case[9] very much depends on model parameters; in particular on the importance of preemption threat relative to the agency conflict[10]. Consequently, both over- and under-investment can occur within the investment decision of a managerial firm under preemption threat. Notice that, competition can mitigate the inefficiency stemming from agency by bringing the low quality project's exercising trigger back to the (socially) efficient trigger level[11]. Furthermore, competition lets the gap between the triggers serve

[7] The first mover captures the whole market and the second mover's option to invest becomes worthless.

[8] in the sense that the high quality project is exercised at the same level as it would be in a model without agency

[9] with no agency and no competition

[10] Notice that in the limiting cases our results collapses into the ones of Grenadier and Wang (2005) when only agency conflicts exist and into the ones of Lambrecht and Perraudin (2003) when only competition exists.

[11] We define the (social) inefficiency as any deviation from the basic model optimal exercise triggers.

to provide additional incentives to the manager for truth-telling and as a result allows the owner to supply less (informational) rents to the manager. This is our first main contribution to the real options literature.

Our other main contributions to the literature lie in the effect of positive *correlation* between the competing firms' underlying project values on competition and agency conflict. Introducing correlation has two interesting consequences within our extended real investment framework. First, regarding an *entrepreneurial* firm: In case of a high quality project, the early exercise of the competitor becomes more likely and the preemption threat grows. Hence, while the amount of investment timing adjustment required due to competition increases for the high quality project, the same decreases for the low quality project. Second, regarding a *managerial firm*: The correlation emphasizes the mentioned role of the gap between the triggers for providing additional incentives to the manager for truth-telling[12]. Moreover, the presence of correlation suppresses the distortion in the low quality project's exercising trigger that originally stems from the agency problem.

2 Literature Review

There are four major strands of literature that our paper relates to. The first one extends the real options framework to account for the agency conflicts between shareholders and managers, allowing the existence of moral hazard and/or adverse selection. The setting of our paper is most similar to that of Grenadier and Wang (2005) in this area. There are two main differences between their model and ours. They analyze a single firm without the fear of preemption. But, they allow in addition that the manager can influence probabilistically the quality of the project by initially exerting a costly and unobservable effort. They design an optimal contract that induces the manager first to exert high effort and second to reveal her private information on the actual project quality by choosing the appropriate investment timing. Similar to our work, they show that managers display greater inertia in their investment behavior, in that they invest later than implied by the no agency case. They find that the nature of the optimal contract depends explicitly on the relative severity of these two forces; in case one of them is highly severe, it dominates solely the contract since the other effect is automatically mitigated. The hidden action alone does not result in inefficiencies, while hidden information alone does. Eventually, in their

[12] and as a result, for allowing the owner to provide less (informational) rents to the manager

setting the interaction between hidden information and hidden action could reduce the inefficiency in investment timing, compared with the setting in which hidden information is the only friction. In our model, the competition interacts with the hidden information and that has similar consequences in reducing the inefficiencies. Last, in their hidden information setting only under-investment is achieved, while in our model both under- and over-investment are possible.

The second strand of related literature analyzes how strategic behavior could be integrated with the contingent claims techniques employed in the real options literature. In particular, this area of research investigates the effect of (product market) competition on investment timing decisions. In some cases, firms do better by delaying until their competitors act first (attrition). In some situations, like in our model, a firm fears that a competitor may seize an advantage by acting first (preemption). The setting of our paper is most similar in this field to that of Lambrecht and Perraudin (2003). There exist mainly two differences between our model and theirs. First, in their model they do not allow for agency conflicts. Second, they are not accounting for possible correlations within the competitive environment which might alter, as in our model, the impact of competition[13].

Next, a rather classical strand of literature from which our paper adopts, links the severity of the principal-agent problem to the degree of competition in product markets. Hart (1983), Scharfstein (1988), Hermalin (1992), Schmidt (1997) and Aggarwal and Samwick (1999) consider whether product market competition induces managers to improve efficiency by increasing their supply of effort. In his influential work, Hart (1983) finds that competition can serve as an incentive mechanism in that it reduces managerial slack if there exists correlation between firms' costs. In our model, by allowing correlation we analyze whether a similar impact of competition on agency exists or not, but within a real investment decision framework. While Hart (1983) is one of the first to derive this result in a formal model, his analysis is restricted to perfect competition and hence avoids strategic interactions among competitors. Last, while Hart (1983) studies a hidden action problem, our model focuses on a hidden information problem. Aggarwal and Samwick (1999) separates from the other mentioned studies in the sense that Aggarwal and Samwick (1999) allow the compensation contracts in turn to influence (imperfect) competition in the product market. Their finding is that in order to soften the effects of product market competition

[13] Meanwhile, within their simpler setting they construct and analyze a (Bayesian Nash) equilibrium under incomplete information in which two or more firms invest subject to threats of preemption from competitors.

it can be optimal, as considered in our model, to include rival firms' performance in the incentive scheme of the own manager. As a limitation, their results are derived under the assumption of linear incentive schemes.

Last, there exists a recently developing literature that studies interactions among private information, unobservable effort and competition for the investment timing problem of firms. One of them is Maeland (2010). In this model, an owner of some project needs an expert (an agent) to manage the investment of the project. There are two or more agents with private information about their respective cost of investing in the project. The project owner organizes an auction, in which the agents participate. The investment strategy, formulated as an optimal stopping problem, is delegated to the auction winner. An optimal compensation function is derived, which induces the winner to follow the investment strategy preferred by the project owner. It is shown in this study that private information increases the project owner's cost of exercising the option, which may lead to under-investment. Our model differentiates itself from this study in the sense that this model rather studies a labor market (including outsourcing and suppliers) competition than product market competition. Consequently, the formulation of competition and some other driving forces of effects as well as implications in our model are substantially different from those of this study.

The remainder of the paper is organized as follows. Section 3 contains the model descriptions and analyzes. Particularly, Section 3.1 presents a *basic* model "a single *entrepreneurial* firm's investment behavior" which serves as a building block for the following Section 3.2, where the *first-best benchmark* model "the *entrepreneurial* firm's investment behavior affected by preemption fear" is introduced. Section 3.3 describes the setup of our *core principal-agent* model "optimal investment of a *managerial* firm threatened by *preemption*" and analyzes it thoroughly. Section 3.4 discusses limitations of our *core principal-agent* model. Section 4 concludes. The Appendix contains the solution details of the optimal contracts and proofs of relevant propositions.

3 Model and Analysis

3.1 Basic Model (Optimal investment of a single *entrepreneurial* firm)

Model

In this subsection, we develop a basic model of a single *entrepreneurial* firm's investment behavior which serves as a building block in our subsequent analysis of an *entrepreneurial* firm's behavior affected by preemption fear.

We assume throughout that investors are risk neutral and can borrow and lend freely at a constant risk-free rate of interest, $r > 0$[14].

The firm, acting over an infinite time horizon, owns a single project to invest and is flexible to choose its timing. Moreover, this investment decision is irreversible and results in future stochastic cash flows.

For the time being, we assume that the firm is *entrepreneurial*, i.e. the owner manages the firm, therefore at this stage there are no agency problems as there is no separation of ownership and control. Similarly, we assume that the firm is all-equity financed to rule out conflicts between the bondholders and the shareholders regarding the firm's investment decision.

Once investment takes place, the project generates two sources of value. One portion is $P(t)'$, while the other portion is θ' [15]. The investment requires an initial expenditure (sunk cost), expressed as K, that should be paid by the time of investment. Therefore the investment payoff is $(P(t)' + \theta' - K)$. Notice that, from the mathematical point of view the same problem without loss of generality could be equivalently formulated as $P(t)$ to be the whole project value, and θ $(= K - \theta')$ to be initial expenditure which has a component that realizes at time zero. Consequently the investment payoff is $(P(t) - \theta)$. The initial

[14] Note that, introducing risk aversion hardly alters the valuation analysis of the *entrepreneurial* firm under preemption threat, if one assumes sufficient completeness of markets and follows the risk-neutral asset valuation technique. In the agency context, with the limited-liability condition we achieve our investment inefficiency results, even under risk neutrality. Assuming managerial risk aversion itself would generate an investment inefficiency in this context. In order not to let this inefficiency interfere with our results and to keep our model parsimonious, when we model the *managerial* firm later in the analysis, we model both the owner and the manager to be risk neutral. An alternative way to allow the owner and the manager value payoffs differently, especially in the context of real options, is to relax the assumption that both the principal and the agent are equally patient and assign them different discount factors.

[15] θ' realizes at time zero.

way of defining the model is easily justifiable with the existing literature. However, for the rest of the analysis, to attain simplicity in notations and intuition we will follow this new simplified framework; high quality project maps to low cost project, and low quality project maps to high cost project.

Let the value $P(t)$ evolve as a geometric Brownian motion,

$$dP(t) = \alpha P(t)dt + \sigma P(t)dZ(t) \tag{1}$$

where α is the conditional expected percentage change in $P(t)$ per unit time, σ is the conditional standard deviation per unit time, and $dZ(t)$ is the increment of a standard Wiener process. This implies that the current value of the project is known, but future values are log-normally distributed with a variance that grows linearly with the time horizon. Let P_0 equal the value of the project at time zero. For convergence, we assume that $r > \alpha$. In this way, we also allow for an optimum investment decision timing to exist.

θ is random, however already realizes at time zero. θ could take on two possible values: θ_1 or θ_2, with $\theta_2 > \theta_1$. We denote $\Delta\theta = \theta_2 - \theta_1$. One could interpret a draw of θ_1 as a high quality project and a draw of θ_2 as a low quality project. The probability of drawing a low cost project θ_1 equals q. For the time being, the owner himself observes the project cost at time zero .

Due to its nature and the setting described above, the firm's investment opportunity is equivalent to an American perpetual call option on a stock[16]. In a standard call option setting, exercise yields the difference between the value $P(t)$ of the underlying asset and the exercise price θ.

Analysis

The derivation of the firm's value and optimal investment policy is standard. To save space, we provide the solution and refer the interested reader to Dixit and Pindyck (1994) for further details.

Proposition 1 *Under the above assumptions, a realized θ and a predetermined arbitrary*

[16] For such an option, optimal exercise time is when the underlying project value first reaches a constant (over time) trigger level.

exercise trigger $P > \theta$, the value of the firm at time zero is[17],[18]

$$V(P_0, \theta; P) = \left(\frac{P_0}{P}\right)^{\beta} (P - \theta) \tag{2}$$

where $\beta = \frac{1}{\sigma^2}\left[-(\alpha - \frac{\sigma^2}{2}) + \sqrt{(\alpha - \frac{\sigma^2}{2})^2 + 2r\sigma^2}\right] > 1$. *After observing θ, in order to maximize the firm value, the owner chooses the optimal exercise trigger level as,*

$$P^* = \frac{\beta}{\beta - 1}\theta \tag{3}$$

Proofs of this and subsequent results appear in the Appendix.

The θ is the NPV trigger level for $P(t)$ and investing in the project at this level generates a *positive* net present value. $P^* > \theta$ is the trigger level obtained by using the real options approach and therefore investing at this trigger level generates the *maximized* expected net present value.

3.2 First-Best Benchmark Model (Optimal investment of an *entrepreneurial* firm threatened by *preemption*)

Model

In this subsection, we extend the basic model from the previous subsection and analyze the *entrepreneurial* firm's investment behavior under preemption fear. This analysis will be the first-best benchmark when we later analyze the *managerial* firm's behavior under same conditions.

To model a threat of preemption, let us suppose that a firm i seeks an optimal investment policy (as already described in the previous section); however, another firm, labeled j, may invest first, in which case firm i loses any further opportunity to invest.[19] In order to avoid that the option value is destroyed completely due to this fierce form of competition, we assume that the competitor's characteristics are not fully known to the firm.

[17] We assume that $P \geq P_0$.

[18] Note that throughout the whole analysis we denote the trigger levels with P, without any subscript. It is different than the process itself, $P(t)$.

[19] Similar to Lambrecht and Perraudin (2003), we model competition within a *full* preemption setting, where there is no benefit of investing for the second mover. Milder outcomes would be obtained if *partial* preemption was allowed for. However, since our main results are more emphasized in the full preemption setting, and for simplicity, we restrict our analysis to this case. For partial preemption argument within real options exercise games cf. Botteron, Chesney, and Gibson-Asner (2003) and Pawlina and Kort (2006).

Thus, to introduce incomplete information, we assume firm i conjectures that firm j invests when $P(t)$ first crosses some level P_j, and that P_j is an independent draw from a distribution $F(P_j)$ with continuously differentiable density $F'(P_j)$ on the support $(\underline{P_j}, \overline{P_j})$. Note that, for simplicity we do not start with modeling a cost distribution for firm j, but we assume an exogenously given $F(P_j)$[20]. We can think of $F(P_j)$ as the belief about the competitor's trigger level absent any further information. However, for instance, due to the existence of a correlation between both firms' costs it seems reasonable to assume that the realization of firm i's cost θ carries some information about the distribution of firm j's exercise trigger[21]. Thus, by observing the realization of θ the owner receives additional information about its rival's behavior and updates his beliefs accordingly as specified in the *conditional* distribution $F(P_j|\theta)$ which is also assumed to have a continuously differentiable density $F'(P_j|\theta)$ on the interval, $(\underline{P_j}, \overline{P_j})$. Under positive correlation between the costs of the competing firms, it is expected there exists positive correlation also between the firm i's own cost and firm j 's trigger level. We capture this by assuming that the distribution of P_j conditional on θ_2 first order stochastically dominates the one conditional on θ_1, i.e. $F(P_j|\theta_1) \geq F(P_j) \geq F(P_j|\theta_2)$.[22] In order to rule out the case where firm j's trigger level is below or equal to the initial project value P_0, i.e. to prevent that firm i might be preempted already at time zero, we assume $\underline{P_j} = P_0$. This implies $F(P_0|\theta) = 0$.

Analysis

Proposition 2 *Under the above assumptions, a realized θ and a predetermined arbitrary exercise trigger $P > \theta$, the value of the firm at time zero is*[23]*,*

$$V(P_0, \hat{P}_0, \theta; P) = \left(\frac{P_0}{P}\right)^{\beta} (P - \theta) \left(\frac{1 - F(P|\theta)}{1 - F(\hat{P}_0|\theta)}\right) \tag{4}$$

where $\hat{P}_t := sup\{P_\tau : -\infty \leq \tau \leq t\}$. After observing θ, in order to maximize the firm value, the owner chooses the optimal exercise trigger level given by,

$$P^{**} = \frac{\beta + h(P^{**}|\theta)}{\beta + h(P^{**}|\theta) - 1}\theta \tag{5}$$

where, the hazard rate, $h(P|\theta) := \frac{P.F'(P|\theta)}{1-F(P|\theta)}$.

[20] One could step back and start with the competitor's cost distribution, instead of optimal trigger level distribution, and determine the (Bayesian Nash) equilibrium distribution endogenously. cf. Section 3 of Lambrecht and Perraudin (2003).

[21] for further justifications cf. Hart (1983)

[22] Further in the analysis, when interpreting the results, we assume hazard rate dominance, cf. section 3.3. This implies first order stochastic dominance.

[23] We assume that $P \geq P_0$.

Note that, compared to Eq. (2), Eq. (4) has an additional term in the end which corresponds to the conditional probability that firm i will not be preempted. The case that firm i is preempted, i.e. loses any further opportunity to invest, is not explicitly reflected in Eq. (4) since firm i gets zero net present value in that situation. We can conclude that, the *entrepreneurial* firm value under *preemption* threat is lower than the single *entrepreneurial* firm value. Note also, $P^{**} < P^{*}$ indicating that the fear of preemption lowers the optimal exercise trigger level, which is inline with our intuition.

It will prove useful in future calculations to determine at this point the present value of one unit of currency received at the first moment that a predetermined arbitrary exercise trigger level P is reached. Denote this present value operator by the discount function $D(P_0; P)$. This is simply the case where $(P - \theta)$ is replaced by 1 in Eq. (2) and can be stated as,

$$D(P_0; P) = \left(\frac{P_0}{P}\right)^{\beta} \tag{6}$$

On the other hand the present value of one unit of currency received at the first moment that a predetermined arbitrary exercise trigger level P is reached and preemption has not occurred before, $D(P_0, \hat{P}_0, \theta; P)$ is simply the case where $(P - \theta)$ is replaced by 1 in Eq. (4) and can be expressed as,

$$D(P_0, \hat{P}_0, \theta; P) = \left(\frac{P_0}{P}\right)^{\beta} \left(\frac{1 - F(P|\theta)}{1 - F(\hat{P}_0|\theta)}\right) \tag{7}$$

Eq. (4) expresses the firm value at time zero given a realized θ. Thus, the expected value of the firm, before θ is realized and following ex post the optimal trigger policy is,

$$W^{**}(P_0, \hat{P}_0) = qV^{**}(P_0, \hat{P}_0, \theta_1; P_1^{**}) + (1-q)V^{**}(P_0, \hat{P}_0, \theta_2; P_2^{**}) \tag{8}$$

$$= q\left(\frac{P_0}{P_1^{**}}\right)^{\beta} (P_1^{**} - \theta_1) \left(\frac{1 - F(P_1^{**}|\theta_1)}{1 - F(\hat{P}_0|\theta_1)}\right) + (1-q)\left(\frac{P_0}{P_2^{**}}\right)^{\beta} (P_2^{**} - \theta_2) \left(\frac{1 - F(P_2^{**}|\theta_2)}{1 - F(\hat{P}_0|\theta_2)}\right) \tag{9}$$

where $P_1^{**} := P^{**}(\theta_1)$ and $P_2^{**} := P^{**}(\theta_2)$.

3.3 Principal-Agent Model (Optimal investment of a *managerial* firm threatened by *preemption*)

Model

Suppose now that initially the principal (owner) delegates the investment decision to an agent (manager). We assume that, $P(t)$, the project value, is observable and contractible to both the owner and the manager, while θ is the initial expenditure which has a component privately observed only by the manager when it realizes at time zero[24] . An agency conflict then emerges as the manager of a low cost project could claim to have high costs and divert $\Delta\theta$ for private benefits. We assume that both the agent as well as the principal are risk neutral (with common discount rate r) and further the manager is protected by limited liability. To induce truth-telling the owner offers the manager a contract specifying a set of recommended exercise triggers P and associated wages w, one for each possible realization of costs. Notice, that we can focus on truth-telling contracts as the revelation principle applies to our standard hidden information problem. Hence, we assume that the manager truthfully reveals her type or, equivalently, that the principal can infer from the equilibrium exercise policy what type the agent was. The contract therefore specifies wage payments contingent on the observable (and verifiable) project value P at the time of exercise. Moreover, it can depend on whether or not and at which level of project value (denoted by P_j) firm i is preempted by firm j. Theoretically, for any possible exercise value P a wage $w(P)$, and for any possible preemption value P_j a wage $w(P_j)$ can be specified, provided that both $w(P) \geq 0$ and $w(P_j) \geq 0$.

Upon *exercise*, the owner receives the value of the underlying project, pays the exercise price θ and the manager's *exercise* wage $w(P)$. Sum of the manager's and owner's payoffs equals the payoff of the underlying option to invest. On the other hand, upon *preemption* , the owner does not receive any value but may pay the manager a *preemption* wage $w(P_j)$. The manager's payoff is simply determined by the contingent wage scheme $\{w(P), w(P_j)\}$. Given that θ has only two possible values we only need to specify two wage/exercise trigger pairs from which the manager can choose. We allow for the possibility of a pooling equilibrium in which only one wage/exercise trigger pair is offered. However, this pooling

[24] Notice that, the hidden information problem in the model setting of Grenadier and Wang (2005) is that the underlying project's future value contains a component that depends on the *project quality* that is only privately observed by the manager, whereas in our setting it is the *project costs* that are observed privately. However, the same problem, without loss of generality, could be equivalently formulated in either way.

equilibrium is always dominated by a separating equilibrium with two wage/exercise trigger pairs. Therefore, the owner offers a contract that promises a wage of w_1 if the option is exercised at P_1 and a wage of w_2 if the option is exercised at P_2. The revelation principle ensures that a manager who privately observes θ_1 exercises at the P_1 trigger, and a manager who privately observes θ_2 exercises at the P_2 trigger.

The owner's objective is to maximize his expected net payoff via its choice of the contract terms $w_1, w_2, w(P_j), P_1, P_2$[25]. Thus, the owner solves the optimization problem,

$$\max_{w_1,w_2,w(P_j),P_1,P_2} \quad q\left(\tfrac{P_0}{P_1}\right)^{\beta}\tfrac{1-F(P_1|\theta_1)}{1-F(\hat{P}_0|\theta_1)}(P_1-\theta_1-w_1)+(1-q)\left(\tfrac{P_0}{P_2}\right)^{\beta}\tfrac{1-F(P_2|\theta_2)}{1-F(\hat{P}_0|\theta_2)}(P_2-\theta_2-w_2) \\ -q\left[\int_{\hat{P}_0}^{P_1} w(P_j)\left(\tfrac{P_0}{P_j}\right)^{\beta} d\tilde{F}(P_j|\theta_1)\right]-(1-q)\left[\int_{\hat{P}_0}^{P_2} w(P_j)\left(\tfrac{P_0}{P_j}\right)^{\beta} d\tilde{F}(P_j|\theta_2)\right] \tag{10}$$

where $\tilde{F}(P|\theta) := \frac{F(P|\theta)}{1-F(\hat{P}_0|\theta)}$.

This optimization is subject to a variety of constraints. The manager is protected by limited-liability and corresponding constraints are,

$$w_1 \geq 0 \tag{11}$$

$$w_2 \geq 0 \tag{12}$$

$$w(P_j) \geq 0 \quad \forall P_j \in (\underline{P_j}, \overline{P_j}). \tag{13}$$

First of all the participation constraint is,

$$q\left(\frac{P_0}{P_1}\right)^{\beta}\frac{1-F(P_1|\theta_1)}{1-F(\hat{P}_0|\theta_1)}(w_1)+(1-q)\left(\frac{P_0}{P_2}\right)^{\beta}\frac{1-F(P_2|\theta_2)}{1-F(\hat{P}_0|\theta_2)}(w_2) \\ +q\left[\int_{\hat{P}_0}^{P_1} w(P_j)\left(\frac{P_0}{P_j}\right)^{\beta} d\tilde{F}(P_j|\theta_1)\right]+(1-q)\left[\int_{\hat{P}_0}^{P_2} w(P_j)\left(\frac{P_0}{P_j}\right)^{\beta} d\tilde{F}(P_j|\theta_2)\right] \geq 0 \tag{14}$$

This constraint ensures that the total expected value to the manager of accepting the contract is non-negative.

[25] Note that, since $P_j \in (\underline{P_j}, \overline{P_j})$, $w(P_j) = 0$ elsewhere. Even though we allow $\overline{P_j}$ to be any value greater than P_2, we can already set $w(P_j) = 0$ for $P_j > P_2$ since firm i can never be preempted at a project value greater than the P_2 level.

There exist also constraints due to the hidden information of the manager. These incentive constraints ensure that managers exercise in accordance with the owner's expectations. Particularly, they induce the manager exercise low cost (θ_1) projects at the P_1 trigger and exercise high cost (θ_2) projects at the P_2 trigger. In this setting, the manager with private information have the incentive to lie on the actual project cost and divert free cash flows to themselves. For example, the manager could have an incentive to claim falsely that a lower cost project is a higher cost project and then divert the difference in values[26]. On the other hand, if profitable enough, the manager could have an incentive to lie and claim that a higher cost project is a lower cost project and then add the difference in values privately to gain eventually a higher wage and payoff. Any incentive compatible contract therefore has to satisfy Eqs. (15) and (16).

$$\left(\frac{P_0}{P_1}\right)^{\beta}\frac{1-F(P_1|\theta_1)}{1-F(\hat{P}_0|\theta_1)}(w_1) \geq \left(\frac{P_0}{P_2}\right)^{\beta}\frac{1-F(P_2|\theta_1)}{1-F(\hat{P}_0|\theta_1)}(w_2+\Delta\theta) + \int_{P_1}^{P_2} w(P_j)\left(\frac{P_0}{P_j}\right)^{\beta} d\tilde{F}(P_j|\theta_1) \quad (15)$$

$$\left(\frac{P_0}{P_1}\right)^{\beta}\frac{1-F(P_1|\theta_2)}{1-F(\hat{P}_0|\theta_2)}(w_1-\Delta\theta) \leq \left(\frac{P_0}{P_2}\right)^{\beta}\frac{1-F(P_2|\theta_2)}{1-F(\hat{P}_0|\theta_2)}(w_2) + \int_{P_1}^{P_2} w(P_j)\left(\frac{P_0}{P_j}\right)^{\beta} d\tilde{F}(P_j|\theta_2) \quad (16)$$

The second constraint is shown not to bind, so only constraint Eq. (15) is relevant for our discussion. It ensures that a manager of a low cost project chooses to exercise at P_1. By truthfully revealing the privately observed cost θ_1 through exercising at P_1, the manager receives the wage w_1. By misrepresenting the private cost and waiting until the trigger P_2, the manager receives the wage w_2 in case she is not preempted, or receives the wage $w(P_j)$ in case she is preempted. As a result, Eq. (15) ensures the expected present value of payoff from truthful revelation to be greater than or equal to the expected present value of the payoff from misreporting the private cost. These constraints are common in the literature on adverse selection. For example, entirely analogous conditions appear in the cash diversion models of Bolton and Scharfstein (1990) or more recently DeMarzo and Sannikov (2006).

All in all, the owner's problem can be summarized as the solution of the objective function in Eq. (10), subject to a total of six inequality constraints: one participation, two incentive constraints, and three limited-liability constraints.[27] The problem can be sub-

[26] This could be done by diverting cash for private benefits such as empire building or acquire perquisites.
[27] Of course there is a continuum of limited liability constraints for the preemption wages.

stantially simplified in that we can reduce the number of relevant constraints to two, which corresponds to the incentive constraint for a manager of a high cost (θ_2) project and the limited liability constraint for the high cost (θ_2) type.

Analysis

Although the owner's optimization problem is subject to six inequality constraints, the solution can be found through considering only two of the constraints. Appendix B contains the proves of four propositions: Propositions (4) — (7), that provide the underpinnings for this simplification. Proposition 4 shows that the limited-liability constraint for a manager of a project with θ_1 cost does not bind, while Proposition 5 shows that the participation constraint, Eq. (14), does not bind. Proposition 6 demonstrates that the limited liability constraint for a manager of a high cost (θ_2) type project binds, i.e. $w_2 = 0$. Proposition 7 implies that the incentive constraint for a manager of a high cost (θ_2) type project is never binding.

Solving the reduced program results in an optimal contract specifying exercise trigger/wage pairs (P_i, w_i), $i \in \{1, 2\}$, inducing the agent to reveal the truth and to deliver the corresponding cash flows without diverting to the owner. The precise form of the contract is stated in the following proposition.

Proposition 3 *Under the optimal contract in the setting with preemption threat, the manager of a low cost project exercises the investment option at P_1 receiving a wage of w_1, given by,*

$$\begin{aligned} P_1 &= -\frac{\beta + h(P_1|\theta_1)}{1 - \beta - h(P_1|\theta_1)}\theta_1 && (17) \\ w_1 &= \left(\frac{P_1}{P_2}\right)^{\beta} \frac{1 - F(P_2|\theta_1)}{1 - F(P_1|\theta_1)}\Delta\theta. && (18) \end{aligned}$$

The manager of a high cost project receives a zero wage, i.e. $w_2 = 0$, and exercises at the trigger,

$$P_2 = -\frac{\beta + h(P_2|\theta_2)}{1 - \beta - h(P_2|\theta_2)}\left[\theta_2 + \left(\frac{\beta + h(P_2|\theta_1)}{\beta + h(P_2|\theta_2)}\right)\left(\frac{1 - F(P_2|\theta_1)}{1 - F(P_2|\theta_2)}\right)\frac{q}{1-q}\Delta\theta\right]. \qquad (19)$$

The proof is in Appendix B.

In interpreting the above results, we will highlight the effects of competition and agency on the optimal exercise policy as well as their interactions. To gain a basic intuition let us first consider the case where the firm's own costs (θ) and the competitor's trigger level (P_j) are independent, consequently there exists no correlation between them[28]. This implies $F(P_j|\theta) = F(P_j)$ and $h(P_j|\theta) = h(P_j)$. In that case the trigger levels specified in the optimal contract simplify to the following expressions,

$$P_1 = -\frac{\beta + h(P_1)}{1-\beta-h(P_1)}\theta_1 = P_1^{**} \tag{20}$$

$$P_2 = -\frac{\beta + h(P_2)}{1-\beta-h(P_2)}\left[\theta_2 + \frac{q}{1-q}\Delta\theta\right] > P_2^{**} \tag{21}$$

$$w_1 = \left(\frac{P_1}{P_2}\right)^{\beta}\frac{1-F(P_2)}{1-F(P_1)}\Delta\theta. \tag{22}$$

Comparing these expressions with the *first-best benchmark* results, given by Eq. (5), we find that, as usual in adverse selection models, there is no distortion at the top (high quality/low cost project), in the sense that the low cost project is exercised at the same level as it would be in a model without agency ($P_1 = P_1^{**}$), whereas the high cost project is exercised later ($P_2 > P_2^{**}$) in order to satisfy the incentive constraint for the manager of a low cost project. Thus, allowing for agency in real investment under competition does not alter the low cost project's exercising trigger but increases the high cost project's exercising trigger. The $\left[\frac{\beta+h(P)}{\beta+h(P)-1}\right]$ terms stem from the presence of competition, while the additional term to θ_2, that is $[\frac{q}{1-q}\Delta\theta]$, comes from the agency conflicts. The superimposition of the two effects is clearly seen in these expressions above, when compared to the *first-best benchmark* results. Note that the position of P_2 relative to *basic model* results (P_2^{*}), given by Eq. (3), is ambiguous; while, agency has a tendency to increase high cost project's exercising trigger, competition puts downward pressure on it. The overall effect depends on model parameters, in particular on the severity of the preemption threat relative to the agency conflict. Therefore, both over- and under-investment can occur within the investment decision of a managerial firm under preemption threat. Notice that, under some circumstances competition could fully offset the inefficiency stemming from agency, and bring the high cost project's exercising trigger back to the (socially) efficient trigger level[29].

[28] Throughout the analysis, when we use the term uncorrelated we actually mean independence.

[29] We define the (social) inefficiency as any deviation from the basic model optimal exercise triggers. Because this results in a decrease in the (maximized) surplus that can be created by the real option. If information were complete and/or cooperative behavior were possible among competitors, the (social) efficiency loss would be mitigated. This is similar to the definition of Lambrecht and Perraudin (2003). In the context of agency conflict, our definition is also in line with the one of Grenadier and Wang (2005). They define social loss as the difference between the values of the basic model option value, and the sum

Under the optimal contract in the setting with preemption threat, the manager of a low cost project exercises the investment option at P_1 and receives the wage w_1. As seen in Eq. (22), w_1 is the product of $\Delta\theta$ and two factors. These factors that determine w_1 are $(\frac{P_1}{P_2})^\beta$ and $[\frac{1-F(P_2)}{1-F(P_1)}]$; while the former represents the discounting effect and it exists even in the absence of competition, the latter represents the effect of competition on agency. First, since $\beta > 1$ and $P_1 < P_2$, the discounting factor decreases with the gap between the triggers. That translates into, the bigger the gap the less wage has to be provided to the manager of a low cost project. Thus, the idea behind the fact that under the optimal contract the high cost project is exercised later, is about making use of the increased gap to provide additional incentives to the manager. Second, $[\frac{1-F(P_2)}{1-F(P_1)}]$ is the ratio of the probability of not being preempted if the manager follows the P_2 exercise trigger, to the probability of not being preempted if the manager follows the P_1 exercise trigger. Because $P_1 < P_2$, this ratio is less than unity and it decreases the wage the manager of low cost project requires. In short, the competition provides additional incentives to the manager for truth-telling and this is intuitive; if the manager of low cost project does not reveal the truth and decides to exercise the project later at P_2, then there is the possibility of being preempted, and consequently, of neither receiving any wages nor diverting any amount $(\Delta\theta)$ for private benefits.

Correlation

Let us consider the more general case where firm i's own cost (θ) is *positively* correlated with the competitor's trigger level (P_j) [30], which could be motivated for instance by the existence of a common component in both firms' costs or a demand shock affecting the industry to which these firms belong (cf. Hart (1983)). Regarding the correlation we explicitly impose *hazard rate dominance*, i.e. $h(P_j|\theta_1) \geq h(P_j) \geq h(P_j|\theta_2)$.[31] Introducing correlation has interesting additional impact on the interaction between agency and competition within the real investment framework. Before investigating that, we first analyze the *entrepreneurial* firm under preemption threat. Observing the firm's own costs leads to an update of the belief about the competitor's trigger level. In case of a low cost project, the early exercise of the competitor is more likely. Due to the increased preemption threat, the optimal

of the owner and manager options. They suggest that social loss is driven by the distance of the triggers to the optimal exercise triggers of the basic model.

[30] Remember that we simply consider the optimal response of firm i to a given conditional distribution of the competitor's exercising trigger level.

[31] Notice again that hazard rate dominance implies first order stochastic dominance, which is often a necessary technical assumption in the adverse selection models.

exercise trigger of firm i is adjusted downwards, i.e. $P_1^{**,corr} < P_1^{**,nocorr}$. On the other hand, in case of a high cost project, the preemption threat is lower. Consequently, the optimal exercise trigger of firm i is adjusted upwards, i.e. $P_2^{**,corr} > P_2^{**,nocorr}$. Notice that this effect of correlation is present independent of the agency problem and can be seen by analyzing Eq. (5) [32], which is a part of the first-best benchmark model results.

Now consider a *managerial* firm under preemption threat. First of all, the mentioned effect of correlation on competition, via the $\frac{\beta+h(P|\theta)}{\beta+h(P|\theta)-1}$ terms in Eqs. (17) and (19), is also present in this case. Additionally, as seen in Eq. (19), there exists a term multiplying the agency distortion, that is $A := \left[\frac{\beta+h(P_2|\theta_1)}{\beta+h(P_2|\theta_2)}\right] * \left[\frac{1-F(P_2|\theta_1)}{1-F(P_2|\theta_2)}\right]$. This term represents the impact of correlation on agency. We analyze it within a numerical example in the next subsection and find that when the model parameters are set reasonably, it is less than unity[33], and actually even closer to zero than to unity. This means that, the presence of correlation dampens largely the increase in the high cost project's exercising trigger which originally stems from the agency conflict. Next, as seen in Eq. (18), the correlation influences w_1 via the factor that represents the effect of competition on agency, i.e. $[\frac{1-F(P_2|\theta_1)}{1-F(P_1|\theta_1)}]$. Due to the first order stochastic dominance property of $F(P|\theta)$, positive correlation pushes this term further below unity [34]. Therefore, the gap between the triggers provides additional incentives to the manager for truth-telling. The intuition behind is simple: The manager of low cost project knows that it is more likely that the competitor has lower trigger levels. This decreases greatly the incentives for the low cost project manager to follow untruthfully the P_2 exercise trigger. Because, the probability of being preempted and receiving nothing is actually higher than the one in the absence of correlation. To summarize, the correlation on top of competition provides additional incentives to the manager for truth-telling and it dampens the distortion in the high cost project's exercising trigger[35] which originally stemmed from agency conflict.

A Numerical Example

To illustrate our results and to analyze the $A := \left[\frac{\beta+h(P_2|\theta_1)}{\beta+h(P_2|\theta_2)}\right] * \left[\frac{1-F(P_2|\theta_1)}{1-F(P_2|\theta_2)}\right]$ term, we present in this subsection a numerical example. We do so for the basic model and for various

[32] by particularly noting that $\frac{\partial}{\partial h}\left[\frac{\beta+h}{\beta+h-1}\right] < 0$ and taking the assumption on the hazard rate dominance into account

[33] Note that, $A = 1$ when there is no correlation.

[34] A further assumption, such as $h(P|\theta)$ is increasing in P, is needed. We made already such an assumption to satisfy the second-order condition during the proof of the Proposition 2. This is true for standard distributions such as uniform, negative exponential, Weibull and Pareto.

[35] that is $[\frac{q}{1-q}\Delta\theta]$

cases of the model with additional agency conflict and/or preemption fear, with/without the presence of positive correlation. Table (1) shows the exercise triggers for the low cost (P_1) and high cost (P_2) projects under the optimal contract, as well as the wage (w_1) that the manager of a low cost project receives. Model parameters are set as $\beta = 2$, $\theta_1 = 10$, $\theta_2 = 30$, $q = 0.5$ [36]. We use the negative exponential distribution for $F(P_j|\theta_i)$, whose c.d.f. is $F(P_j|\theta_i) = 1 - e^{-P_j*[0.5/\theta_i]}$ and hazard rate is $h(P_j|\theta_i) = P_j * [0.5/\theta_i]$, for $i \in \{1, 2\}$. Modeling it this way allows for positive correlation and particularly implies that $E(P_j|\theta_1)$ is set to be equal to P_1^*, and $E(P_j|\theta_2)$ is set to be equal to P_2^*. For the case of no correlation, the unconditional c.d.f is $F(P_j) = 1 - e^{-P_j*[0.5/\overline{\theta}]}$ and hazard rate is $h(P_j) = P_j * [0.5/\overline{\theta}]$, where $\overline{\theta} = (\theta_1 + \theta_2)/2$. That results in the unconditional expectation $E(P_j)$ to be set as $(P_1^* + P_2^*)/2$ and overall we attain the first order stochastic dominance property[37]. Note that, for the rest of the analysis we use the notation of $F(P_j|.)$ to represent all the conditional, $F(P_j|\theta_i)$, and the unconditional, $F(P_j)$, distributions[38]. As a robustness check we investigate also the cases where we set the parameters: $q = 0.25$, $q = 0.75$ and/or $\beta = 1.5$, $\beta = 5$ as well as where we model $F(P_j|\theta_i)$ as uniform distribution. Our results remain still valid. Notice that, the model parameters are set reasonably and extreme values for the parameters, such as β values very close to 1, q values very close to 0 and 1, are avoided.

The $\frac{P_1}{20.00}$ and $\frac{P_2}{60.00}$ values in Table (1) represent the normalized deviation in the exercise triggers as a multiple of the basic model triggers, that are $P_1^* = 20.00$ and $P_2^* = 60.00$. The $\frac{P_1}{20.00}$ values correspond to the effect of only competition&correlation. However, since the P_2 exercise trigger value can be affected by both the agency problem and the competition&correlation, the $\frac{P_2}{60.00}$ values represent an overall impact. While the $\left[\frac{\beta+h(P|.)}{\beta+h(P|.)-1}\right] / \left[\frac{\beta}{\beta-1}\right]$ term represents the role of competition in this deviation, the $\left[\theta_2 + \frac{q}{1-q}\Delta\theta * A\right] / [\theta_2]$ term represents the role of agency. Remember that, A is the term reflecting the effect of correlation on agency in Eq. (19). Finally, $(\frac{P_1}{P_2})^\beta$ and $[\frac{1-F(P_2|.)}{1-F(P_1|.)}]$ are the coefficients of $\Delta\theta$ in Eq. (18); while the former represents the discounting effect, the latter represents the effect of competition on agency.

First, comparing the results of the model with only agency conflict (column 2) to the basic

[36] To achieve $\beta = 2$, one can set $\alpha = 0.02$, $r = 0.04$, $\sigma = 0.2$

[37] For instance, conditional on $\theta = \theta_1$, the $F(P_j|\theta_1)$ is equal to $1 - e^{-P_j*[0.5/10]}$, consequently $E(P_j|\theta_1) = 20$. This means that the manager of a low cost project believes that on average the competitor's trigger level is equal to firm i's basic model low cost project trigger, which is $P_1^* = 20$.

[38] The same representation also applies to the hazard rate notation, $h(P_j|.)$.

model results, we see that there is no impact of the agency on P_1, while P_2 increased to 1.67 times of its basic model value. In the case where there is additionally the preemption fear (column 5), we observe that competition has an effect of lowering both P_1 and P_2; P_1 to %85 of its initial value and P_2 to %69 of its initial value. The impact of agency conflict, that is only on P_2, remained the same and together with the effect of competition P_2 increased to 1.14 times of its basic model value. This illustrates that both over- and under-investment can occur within the investment decision of a managerial firm under preemption threat. Regarding w_1, we see that compared to the model with only agency conflict (column 2), here $w_1 = 0.34$, which is much smaller than 0.80. That stems from the change in the $[\frac{1-F(P_2|.)}{1-F(P_1|.)}]$ component of w_1, which proves that the competition provides additional incentives to the manager for truth-telling. Second, notice the impact of correlation on the exercise triggers, for the model with preemption fear (column 4 relative to column 3): 17.02 slightly decreased to 15.62, while 44.24 slightly increased to 46.85. Next, we examine the effect of positive correlation in the case of *managerial* firm under preemption threat (column 6 relative to column 5). We observe that, the correlation dampens the distortion in the high cost project's exercising trigger which originally stemmed from agency conflict. The coefficient for this distortion, i.e. $\left[\theta_2 + \frac{q}{1-q}\Delta\theta * A\right] / [\theta_2]$, decreased from 1.67 to 1.18, because its component A dropped from 1.00 to 0.28. Regarding w_1, we see that compared to the model with the absence of correlation, here $w_1 = 0.25$, which is smaller than 0.34. This stems from the $[\frac{1-F(P_2|.)}{1-F(P_1|.)}]$ part of w_1, which proves that the correlation on top of competition provides additional incentives to the manager for truth-telling.

3.4 Model Limitations

In this section we discuss the limitations of our principal-agent model described in Section 3.3.

First, in our way of modeling the owner and the manager value payoffs indifferently. One might want to relax the assumption that both the principal and the agent are equally patient. Impatience can be modeled for agents by assigning them a discount factor different (greater) than β, that is used to discount future cash flows. Particularly, managerial impatience impact the incentive constraints. Thus, this generalization can alter the predictions about investment timing. Grenadier and Wang (2005) implement this in their setting and find that on one hand, introducing impatience creates further incentives for the low cost type agent, therefore less distortion at the high cost trigger level is required.

Table 1: Exercise triggers for the low cost (P_1) and high cost (P_2) projects under the optimal contract. And, the wage (w_1) that the manager of a low cost project receives (Note that $w_2 = 0$). $\frac{P_1}{20.00}$ and $\frac{P_2}{60.00}$ represent the deviation in the exercise triggers as a multiple of the basic model triggers. $\left[\frac{\beta+h(P|.)}{\beta+h(P|.)-1}\right] / \left[\frac{\beta}{\beta-1}\right]$ represents the role of competition in this deviation. $\left[\theta_2 + \frac{q}{1-q}\Delta\theta * A\right] / [\theta_2]$ represents the role of agency in this deviation. A is the term reflecting the effect of correlation on agency in Eq. (19). Finally, $(\frac{P_1}{P_2})^\beta$ and $[\frac{1-F(P_2|.)}{1-F(P_1|.)}]$ are the coefficients of $\Delta\theta$ in Eq. (18); while the former represents the discounting effect, the latter represents the effect of competition on agency. Model parameters are set as $\beta = 2$, $\theta_1 = 10$, $\theta_2 = 30$, $q = 0.5$. For the negative exponential distribution, the c.d.f. is $F(P_j|.) = 1 - e^{-P_j*[0.5/.]}$ and the hazard rate is $h(P_j|.) = P_j * [0.5/.]$.

	Basic	*Agen.*	*Comp.*	*Comp. +Corr.*	*Agen. +Comp.*	*Agen. +Comp. +Corr.*
P_1	20.00	20.00	17.02	15.62	17.02	15.62
$\frac{P_1}{20.00} = \left[\frac{\beta+h(P_1\|.)}{\beta+h(P_1\|.)-1}\right] / \left[\frac{\beta}{\beta-1}\right]$	1.00	1.00	0.85	0.78	0.85	0.78
P_2	60.00	100.00	44.24	46.85	68.44	53.98
$\frac{P_2}{60.00}$	1.00	1.67	0.74	0.78	1.14	0.90
$\left[\frac{\beta+h(P_2\|.)}{\beta+h(P_2\|.)-1}\right] / \left[\frac{\beta}{\beta-1}\right]$	1.00	1.00	0.74	0.78	0.69	0.77
$\left[\theta_2 + \frac{q}{1-q}\Delta\theta * A\right] / \theta_2$	1.00	1.67	1.00	1.00	1.67	1.18
$A := \left[\frac{\beta+h(P_2\|\theta_1)}{\beta+h(P_2\|\theta_2)}\right] * \left[\frac{1-F(P_2\|\theta_1)}{1-F(P_2\|\theta_2)}\right]$	1.00	1.00	1.00	1.00	1.00	0.28
w_1	-	0.80	-	-	0.34	0.25
$(\frac{P_1}{P_2})^\beta$	-	0.04	-	-	0.06	0.08
$[\frac{1-F(P_2\|.)}{1-F(P_1\|.)}]$	-	1.00	-	-	0.28	0.15

On the other hand, they show that there occurs distortion at the low cost trigger level, so that also over-investment can exist in their model. They note that this generalized problem does not change the basis of the problem and much of the solution methodology is the same. Therefore, allowing impatience in our principal-agent model would not alter our core results, but would add one more layer to analyze. It may prove interesting to investigate it.

Second, in our core principal-agent model we are restricted to a binary distribution of project costs for ease of presentation. A natural and straightforward extension is allowing for a continuous distribution of own costs, $G(\theta)$ for $\theta \in (\underline{\theta}, \bar{\theta})$. The only effect the continuous cost distribution has on the competition side of the model is that it affects the updating of believes about the competitor's costs, such that we now have a continuum of distribution functions, $F(P_j|\theta)$. We need to assume that for any admissible pair $\theta_u > \theta_v$, the distribution $F(P_i|\theta_u)$ first order stochastically dominates the distribution $F(P_j|\theta_v)$ [39]. In this setting the principal designs a truth-telling contract specifying a function $w(\theta)$ of exercise wages and a function of recommended exercise strategies $P(\theta)$. Limited-liability requires the wage function to stay non-negative and there exist a continuum of incentive constraints, one for each cost level. Besides a few technical difficulties the solution of the agency problem in this setting is standard (cf. Grenadier and Wang (2005)) and delivers the usual result that the manager of the highest cost project ($\bar{\theta}$) does not receive any rents and the lowest cost project ($\underline{\theta}$) is exercised efficiently. Because, the basic approach is the same and our main results are expected to remain valid, we skip the detailed discussion of the continuous cost distribution case. This extension is particularly valuable when one wants to analyze the *symmetric* (Bayesian Nash) equilibrium, as described in the next paragraph, where the competitor's belief about the firm i's costs is also modeled in a continuous fashion.

Next, so far our attention has been restricted to the behavior of a managerial firm facing preemption risk. Our analysis is based on deriving the optimal response of a firm, given the (conditional) distribution of the competitor's optimal exercising trigger level. One could step back, start with the competitor's project cost (or quality) distribution and determine the (Bayesian Nash) equilibrium[40] trigger level distribution endogenously, in which both

[39] or the stronger assumption of *hazard rate dominance*, i.e. $h(P_j|\theta_u) \leq h(P_j|\theta_v)$.

[40] For an introduction to the theory of static games of incomplete information and Bayesian Nash equilibrium, see for example Ch.6 of Fudenberg and Tirole (1993); in particular the discussion of first-price auctions with continuum of types is valuable to the analysis here.

firms take strategic real investment decisions. As the mentioned analysis, without further assumptions, is technically quite involved and closed-form solutions are available only in very special cases we refer the interested reader to Lambrecht and Perraudin (2003) for a complete analysis in the context of real option exercise games with incomplete information and under preemption threat, but without the presence of agency conflicts. They establish existence of a unique (Bayesian Nash) equilibrium in which due to the preemption risk, the investment option is exercised earlier relative to investing at the non-strategic (without competition) trigger level. Therefore, in equilibrium, they get the same standard result that competition with a first-mover advantage mutes the value of the option to wait and brings the investment trigger closer to the net present value trigger. They present their unique *symmetric* equilibrium's optimal investment triggers as the solution to a particular differential equation they give. As a next step, they assume a Pareto distribution for the competitor's project cost distribution and that yields closed-form solutions for the investment triggers. It is interesting to note that, their *symmetric* equilibrium's exercise triggers are the same as they have derived for the optimal response of a single firm under preemption threat. Having used the same framework, this could also be the case for our model. It is important to mention that, as long as the preemption threat in our model under equilibrium also generates the standard outcome of lowered investment triggers, our main conclusions drawn for the effect of competition on agency problem, as well as for the impact of positive correlation, will remain valid.

Notice that, the crucial ingredient in the equilibrium analysis, as well as in our analysis, is incomplete information about the competitor's costs. Under complete information the option value to wait could be completely destroyed, given the firms have the same costs and preemption is full. Studies analyzing real option exercise games under complete information include for instance Grenadier (1996) , Trigeorgis (1996), Botteron, Chesney, and Gibson-Asner (2003) and Pawlina and Kort (2006). The main finding of this strand of literature is that if a firm is fearful that a competitor may enter the market first, and if further the market is perceived to be not deep enough to support more than one firm, then the option value of delaying may not be very high, and can even become zero.

Finally, similar to Lambrecht and Perraudin (2003), we model competition within a full preemption setting, where there is no benefit of investing for the second mover. Augmenting our principal-agent model setting to allow for partial preemption can be done as follows: For each cost realization the principal specifies two trigger/wage pairs; one for the case where the firm moves first, other for moving second. The first mover trigger is expected to be slightly higher as being preempted does not necessarily result in zero profit anymore. The second mover virtually faces no competition any more and hence can invest at the optimal non-strategic (without competition) trigger. Consequently, milder outcomes would be obtained if partial preemption was allowed for. However, since our main results are more emphasized in the full preemption setting, and for simplicity, we restrict our analysis to this case. For partial preemption argument within real options exercise games cf. Botteron, Chesney, and Gibson-Asner (2003) and Pawlina and Kort (2006).

4 Conclusion

This paper adds agency to a standard real option exercise game under incomplete information. Competition is modeled as full preemption in the sense that the first mover has the advantage to seize the market fully and the second mover has no value to invest anymore. The delegation of investment decision to a manager creates an agency conflict since investment cost (project quality) is unobservable to the principal which gives the manager opportunity for diverting part of the cash flows for own private benefits. Thus, an optimal contract has to be designed which induces the agent to reveal truthfully the project's actual costs (project quality) and exercise the investment option at a strategically optimal trigger level.

Our main results indicate that competition lets the gap between the triggers serve to provide additional incentives to the manager for truth-telling and as a result allows the owner to supply less (informational) rents to the manager. Our other major findings derive from analyzing the effect of positive *correlation* between the competing firms' underlying project values on competition and agency conflict. Introducing correlation has two interesting consequences within our extended real investment framework. First, regarding an *entrepreneurial* firm: While the amount of investment timing adjustment required due to competition decreases for the low quality project, the same increases for the high quality project. Second, regarding a *managerial firm*: The correlation emphasizes the mentioned role of the gap between the triggers for providing additional incentives to the manager for truth-telling[41]. Moreover, the presence of correlation suppresses the distortion in the low

[41] and as a result, for allowing the owner to provide less (informational) rents to the manager

quality project's exercising trigger that originally stems from the agency problem.

Some extensions of the model would prove interesting. First, stock price reactions according to observed investment behavior of the firm are worth studying. The effect of investment decision announcement (early, on time, delayed) signals private information (on project quality/costs) to the market. Moreover, this action (or no-action) might contain information about the agency conflicts within the firm, as well as the beliefs of the firm about the competitors. Notice that, since under the efficient-market hypothesis stock price changes reflect the information revelation instantly, the manager's compensation contract can be contingent on the firm's stock price as well. Second, it is promising to investigate the consequences of introducing competition, as well as positive *correlation*, to a model of moral hazard as in Grenadier and Wang (2005), in which the agent can influence the probability of a low cost (high quality) project by exerting costly and unobservable effort.

5 Appendix

Appendix A. Derivations for the Basic and First-Best Benchmark Models

Proof of Proposition 1. The derivation is standard. See for example, Dixit and Pindyck (1994).□

Proof of Proposition 2.

$$V(P_t, \hat{P}_t, \theta; P) = \mathbb{E}_t \left[e^{-r(T_P - t)} (P - \theta) \mathbf{1}_{P_j(\theta) > P} \middle| P_j(\theta) > \hat{P}_t \right] \tag{23}$$

where $T_P = inf\{t \geq 0; P_t \geq P\}$. Since we assume $P_j(\theta)$ and P are independent, therefore

$P_j(\theta)$ and T_P are independent,

$$\begin{aligned}
V(P_t, \hat{P}_t, \theta; P) &= \mathbb{E}_t\left[e^{-r(T_P-t)}(P-\theta)\right]\mathbb{E}_t\left[\mathbf{1}_{P_j(\theta)>P}\middle|P_j(\theta)>\hat{P}_t\right] && (24)\\
&= (P-\theta)\mathbb{E}_t\left[e^{-r(T_P-t)}\right]\mathrm{Prob_t}\left[P_j(\theta)>P\middle|P_j(\theta)>\hat{P}_t\right] && (25)\\
&= (P-\theta)\left(\frac{P_t}{P}\right)^{\beta}\mathrm{Prob_t}\left[P_j(\theta)>P\middle|P_j(\theta)>\hat{P}_t\right] && (26)\\
&= (P-\theta)\left(\frac{P_t}{P}\right)^{\beta}\frac{\mathrm{Prob_t}(P_j(\theta)>P)}{\mathrm{Prob_t}(P_j(\theta)>\hat{P}_t)} && (27)\\
&= (P-\theta)\left(\frac{P_t}{P}\right)^{\beta}\frac{1-F(P|\theta)}{1-F(\hat{P}_t|\theta)} && (28)\\
V(P_0, \hat{P}_0, \theta; P) &= (P-\theta)\left(\frac{P_0}{P}\right)^{\beta}\frac{1-F(P|\theta)}{1-F(\hat{P}_0|\theta)}. && (29)
\end{aligned}$$

First order condition with respect to P, $\partial V(P_0, \hat{P}_0, \theta; P)/\partial P = 0$, gives the optimal exercise trigger level,

$$P^{**} = \frac{\beta + h(P^{**}|\theta)}{\beta + h(P^{**}|\theta) - 1}\theta \tag{30}$$

where $h(P|\theta) := \frac{P.F'(P|\theta)}{1-F(P|\theta)}$. Note that a sufficient although not necessary condition for the second-order condition, $\partial^2 W(P_0, \hat{P}_0, \theta; P)/\partial P^2 < 0$, to hold is that $h(P|\theta)$ is increasing in P. This is true for standard distributions such as uniform, negative exponential, Weibull and Pareto[42]. □

Appendix B. Solution to the optimal contracting under the Principal-Agent setting

For simplicity of our analysis and without loss of generality we set $\hat{P}_0 = P_0$; together with our previous assumption $F(P_0|\theta) = 0$ it implies $F(\hat{P}_0|\theta) = 0$ and $\tilde{F}(P_j|\theta) = F(P_j|\theta)$. In order to avoid singularities, we further assume $F(P_2|\theta) < 1$ and $F(P_1|\theta) > 0$, i.e. the probability that firm j has a trigger level less than P_1 or greater than P_2 is not zero.

Proposition 4 *The limited-liability constraint for a manager of a project with θ_1 cost does not bind, i.e. $w_1 > 0$.*

[42] This setting and the related derivations are covered by Section 2 of Lambrecht and Perraudin (2003).

Proof. Rearranging Eq. (15) we obtain,

$$
\begin{aligned}
w_1 &\geq \frac{(P_0/P_2)^{\beta}(1-F(P_2|\theta_1))}{(P_0/P_1)^{\beta}(1-F(P_1|\theta_1))}(w_2+\Delta\theta) + \int_{P_1}^{P_2} w(P_j)\left(\frac{P_0}{P_j}\right)^{\beta} dF(P_j|\theta_1) &(31)\\
&\geq \left(\frac{P_1}{P_2}\right)^{\beta}\frac{(1-F(P_2|\theta_1))}{(1-F(P_1|\theta_1))}(w_2+\Delta\theta) + \int_{P_1}^{P_2} w(P_j)\left(\frac{P_0}{P_j}\right)^{\beta} dF(P_j|\theta_1). &(32)
\end{aligned}
$$

Together with the limited-liability constraints $w_2 \geq 0$ and $w(P_j) \geq 0$,

$$
\begin{aligned}
w_1 &\geq \left(\frac{P_1}{P_2}\right)^{\beta}\frac{(1-F(P_2|\theta_1))}{(1-F(P_1|\theta_1))}(w_2+\Delta\theta) + \int_{P_1}^{P_2} w(P_j)\left(\frac{P_0}{P_j}\right)^{\beta} dF(P_j|\theta_1) &(33)\\
&\geq \left(\frac{P_1}{P_2}\right)^{\beta}\frac{(1-F(P_2|\theta_1))}{(1-F(P_1|\theta_1))}(\Delta\theta)\\
&> 0
\end{aligned}
$$

□

Proposition 5 *The participation constraint, Eq. (14), does not bind.*

Proof. Eq. (33) implies that,

$$
q\left(\frac{P_0}{P_1}\right)^{\beta}\frac{1-F(P_1|\theta_1)}{1-F(\hat{P}_0|\theta_1)}(w_1) > 0. \tag{34}
$$

Since,

$$
\begin{aligned}
(1-q)\left(\frac{P_0}{P_2}\right)^{\beta}\frac{1-F(P_2|\theta_2)}{1-F(\hat{P}_0|\theta_2)}(w_2) + q\int_{\hat{P}_0}^{P_1} w(P_j)\left(\frac{P_0}{P_j}\right)^{\beta} d\tilde{F}(P_j|\theta_1) & &(35)\\
+(1-q)\int_{\hat{P}_0}^{P_2} w(P_j)\left(\frac{P_0}{P_j}\right)^{\beta} d\tilde{F}(P_j|\theta_2) &\geq 0
\end{aligned}
$$

the sum of two above expressions results in participation constraint not binding,

$$
\begin{aligned}
q\left(\frac{P_0}{P_1}\right)^{\beta}\frac{1-F(P_1|\theta_1)}{1-F(\hat{P}_0|\theta_1)}(w_1) + (1-q)\left(\frac{P_0}{P_2}\right)^{\beta}\frac{1-F(P_2|\theta_2)}{1-F(\hat{P}_0|\theta_2)}(w_2)\\
+q\int_{\hat{P}_0}^{P_1} w(P_j)\left(\frac{P_0}{P_j}\right)^{\beta} d\tilde{F}(P_j|\theta_1) + (1-q)\int_{\hat{P}_0}^{P_2} w(P_j)\left(\frac{P_0}{P_j}\right)^{\beta} d\tilde{F}(P_j|\theta_2) &> 0.
\end{aligned}
$$

□

Propositions 4 and 5 allow us to express the owner's maximization problem as the objective in Eq. (10), subject to Eqs. (12), (13), (15) and (16). The Lagrangian reads,

$$
\begin{aligned}
\mathscr{L} = & \left[\left(\frac{P_0}{P_1}\right)^{\beta}\frac{1-F(P_1|\theta_1)}{1-F(P_0|\theta_1)}(P_1-\theta_1-w_1)-\int_{P_0}^{P_1} w(P_j)\left(\frac{P_0}{P_j}\right)^{\beta} dF(P_j|\theta_1)\right] \quad (36)\\
+ \left(\tfrac{1-q}{q}\right) & \left[\left(\frac{P_0}{P_2}\right)^{\beta}\frac{1-F(P_2|\theta_2)}{1-F(P_0|\theta_2)}(P_2-\theta_2-w_2)-\int_{P_0}^{P_2} w(P_j)\left(\frac{P_0}{P_j}\right)^{\beta} dF(P_j|\theta_2)\right]\\
+ \lambda_1 & \left[\left(\frac{P_0}{P_1}\right)^{\beta}\frac{1-F(P_1|\theta_1)}{1-F(P_0|\theta_1)}(w_1)-\left(\frac{P_0}{P_2}\right)^{\beta}\frac{1-F(P_2|\theta_1)}{1-F(P_0|\theta_1)}(w_2+\Delta\theta)\right.\\
& \left.-\int_{P_1}^{P_2} w(P_j)\left(\frac{P_0}{P_j}\right)^{\beta} dF(P_j|\theta_1)\right]\\
+ \lambda_2 & \left[\left(\frac{P_0}{P_2}\right)^{\beta}\frac{1-F(P_2|\theta_2)}{1-F(P_0|\theta_2)}(w_2)+\int_{P_1}^{P_2} w(P_j)\left(\frac{P_0}{P_j}\right)^{\beta} dF(P_j|\theta_2)\right.\\
& \left.-\left(\frac{P_0}{P_1}\right)^{\beta}\frac{1-F(P_1|\theta_2)}{1-F(P_0|\theta_2)}(w_1-\Delta\theta)\right]\\
+ \lambda_3 & \quad w_2\\
+ \int_{P_0}^{P_2}\lambda_4(j) & \quad w(P_j)dP_j
\end{aligned}
$$

with corresponding complementary slackness conditions for the four constraints.

At this point, remember that $P_j \in (\underline{P_j}, \overline{P_j})$ and we have obtained previously $w(P_j) = 0$ for $P_j > P_2$. Although we allow $\underline{P_j}$ to take values less than P_1, we can also set $w(P_j) = 0$ for $P_j < P_1$ due to the optimality argument such that a positive preemption wage within this range does not give any further incentives to the agent[43] but is costly to the principal[44]. For further investigation on the preemption wages within the interval (P_1, P_2) we first set $w(P_j) = 0$, $\forall P_j \in (\underline{P_j}, \overline{P_j})$. After obtaining for the optimal solution, we verify this assumption.

[43] Eqs. (15) and (16) do not include these terms.
[44] Eq. (10) includes these terms with negative coefficients.

The first-order condition with respect to w_1 gives,

$$-\left(\tfrac{P_0}{P_1}\right)^{\beta}(1-F(P_1|\theta_1))+\lambda_1\left(\tfrac{P_0}{P_1}\right)^{\beta}(1-F(P_1|\theta_1))-\lambda_2\left(\tfrac{P_0}{P_1}\right)^{\beta}(1-F(P_1|\theta_2))=0 \quad (37)$$

$$\Leftrightarrow \qquad \lambda_2(1-F(P_1|\theta_2))=(\lambda_1-1)(1-F(P_1|\theta_1)). \quad (38)$$

The first-order condition with respect to w_2 gives,

$$\lambda_3\left(\frac{P_0}{P_2}\right)^{-\beta}=\left(\frac{1}{q}-1-\lambda_2\right)(1-F(P_2|\theta_2))+\lambda_1(1-F(P_2|\theta_1)). \quad (39)$$

The first-order condition with respect to P_1 gives,

$$P_1=-\frac{\beta+h(P_1|\theta_1)}{1-\beta-h(P_1|\theta_1)}\left[\theta_1+w_1-\lambda_1 w_1+\frac{\beta\frac{1-F(P_1|\theta_2)}{1-F(P_1|\theta_1)}+\frac{P_1F'(P_1|\theta_2)}{1-F(P_1|\theta_1)}}{\beta+h(P_1|\theta_1)}\lambda_2(w_1-\Delta\theta)\right]. \quad (40)$$

The first-order condition with respect to P_2 gives,

$$P_2=-\frac{\beta+h(P_2|\theta_2)}{1-\beta-h(P_2|\theta_2)}\left[\theta_2+w_2-\lambda_2\frac{q}{1-q}w_2+\frac{\beta\frac{1-F(P_2|\theta_1)}{1-F(P_2|\theta_2)}+\frac{P_1F'(P_2|\theta_1)}{1-F(P_2|\theta_2)}}{\beta+h(P_2|\theta_2)}\lambda_1\frac{q}{1-q}(w_2+\Delta\theta)\right]. \quad (41)$$

Eq. (38), together with a previous assumption $(F(P_j|\theta_1)\geq F(P_j)\geq F(P_j|\theta_2))$, implies either of the following cases to hold: (i) $\lambda_1=1,\lambda_2=0$ or (ii)$\lambda_1-\lambda_2>1$.

Under the first case above, $\lambda_2=0$, the first-order condition with respect to w_2, Eq. (39), implies that $\lambda_3>0$ and hence $w_2=0$.

Showing the similar result for the case where $\lambda_2>0$ is slightly more involved. In this case both incentive constraints bind. Substituting out w_1 from both, we obtain,

$$\left(\frac{P_1}{P_2}\right)^{\beta}\left[\frac{1-F(P_2|\theta_1)}{1-F(P_1|\theta_1)}-\frac{1-F(P_2|\theta_2)}{1-F(P_1|\theta_2)}\right]w_2=\Delta\theta\left[1-\left(\frac{P_1}{P_2}\right)^{\beta}\frac{1-F(P_2|\theta_1)}{1-F(P_1|\theta_1)}\right]. \quad (42)$$

We show $\lambda_3>0$ within a proof by contradiction. Assume initially that $\lambda_3=0$. Then, Eqs. (38) and (39) imply,

$$\left(\lambda_2-\frac{1}{q}+1\right)(1-F(P_2|\theta_2)) = \lambda_1(1-F(P_2|\theta_1)) \quad (43)$$

$$\lambda_2(1-F(P_1|\theta_2)) = (\lambda_1-1)(1-F(P_1|\theta_1)). \quad (44)$$

Dividing and rearranging results in,

$$\left[\frac{\lambda_1\lambda_2+\lambda_1\left(1-\frac{1}{q}\right)-\left(1-\frac{1}{q}\right)-\lambda_2}{\lambda_1\lambda_2}\right]\frac{1-F(P_2|\theta_2)}{1-F(P_1|\theta_2)}=\frac{1-F(P_2|\theta_1)}{1-F(P_1|\theta_1)} \quad (45)$$

Since $\lambda_2 > 0$ and $\lambda_1 - \lambda_2 > 1$ we obtain $\lambda_1 > 1$. This results in the term in square brackets of Eq. (45) to be strictly less than one, which in turn implies $\frac{1-F(P_2|\theta_2)}{1-F(P_1|\theta_2)} > \frac{1-F(P_2|\theta_1)}{1-F(P_1|\theta_1)}$. Using this result in Eq. (42), we find that the left hand side of Eq. (42) is negative, while the right hand side is clearly positive, a contradiction[45]. Therefore, λ_3 can not be zero also for $\lambda_2 > 0$. We can conclude that $\lambda_3 > 0$ holds in general and as a consequence $w_2 = 0$, which is summarized in the following proposition.

Proposition 6 *The limited liability constraint for a manager of a high cost (θ_2) project binds, i.e. $w_2 = 0$.*

Notice that, regarding the two incentive constraints, Eq. (38) implies that either Eq. (15) binds alone, or both Eqs. (15) and (16) bind simultaneously. First, remember that we obtain Eq. (42) when we equate the binding incentive constraints to each other by substituting out w_1. However, we can see that the outcome of Prop. 6 is in conflict with Eq. (42). Therefore, Eq. (42) can never hold and we can conclude that Eq. (16) does not bind, $\lambda_2 = 0$, but Eq. (15) binds alone .

Proposition 7 *The incentive constraint for a manager of a high cost (θ_2) project is never binding while the one for the low cost (θ_1) project always binds.*

So far the problem is simplified in that we are left only with the incentive constraint for a manager of a high cost (θ_2) project, together with the conditions $w_2 = 0$ and $w(P_j) = 0$ $\forall P_j \in (\underline{P_j}, \overline{P_j})$.

Proof of Proposition 3. Making use of the Propositions (4) – (7), we simplify the optimal trigger levels P_1 and P_2, expressed previously by Eqs. (40) and (41),

$$P_1 = -\frac{\beta + h(P_1|\theta_1)}{1-\beta-h(P_1|\theta_1)}\theta_1 \tag{46}$$

$$P_2 = -\frac{\beta + h(P_2|\theta_2)}{1-\beta-h(P_2|\theta_2)}\left[\theta_2 + \left(\frac{\beta + h(P_2|\theta_1)}{\beta + h(P_2|\theta_2)}\right)\left(\frac{1-F(P_2|\theta_1)}{1-F(P_2|\theta_2)}\right)\frac{q}{1-q}\Delta\theta\right] \tag{47}$$

Finally, as Eq. (15) binds we get the optimal value of w_1,

$$w_1 = \left(\frac{P_1}{P_2}\right)^{\beta}\frac{1-F(P_2|\theta_1)}{1-F(P_1|\theta_1)}\Delta\theta \tag{48}$$

[45] Note that for the special case of *no correlation*, $F(P|\theta) = F(P)$, Eq. (39) implies $w_2 = 0$ (Prop. 6), and we get a contradiction directly from Eq. (42) leading to the conclusion that the incentive constraint for a manager of a high cost (θ_2) project is never binding (Prop. 7).

□

Note that during our analysis, for preemption wages within the interval (P_1, P_2) we set $w(P_j) = 0, \forall P_j \in (\underline{P_j}, \overline{P_j})$. In order to verify this assumption we can argue first that any positive value of $w(P_j)$, compared to the zero value, decreases the objective function of the principal. Second, we know that the incentive constraint Eq. (15) binds, but the incentive constraint Eq. (16) does not bind. Moreover, for any positive value of $w(P_j)$, Eq. (15) gets stricter; in order to satisfy it back the objective function should get worse. On the other hand, for any positive value of $w(P_j)$, Eq. (16) gets looser; the not binding constraint remains not binding, therefore it does not influence the objective function. Consequently, we can conclude that any positive value of $w(P_j)$ can only worsen the objective function while feasibility is kept. Or, alternatively one can argue that any positive wage decreases the objective function of the principal. Therefore, the concern is to limit the total of wages and particularly decide on how to allocate this total amount to w_1, w_2 and to $w(P_j)$. In the optimal solution, we find that only w_1 is non-zero. This gives the highest incentives to the manager to invest at the P_1 trigger. Giving any wage later, such as in the case of preemption or for investing at the P_2 trigger, will decrease the preemption fear of the manager for delaying the investment. And that needs either the w_1 to increase, or P_1 to decrease. Both changes would affect the objective function negatively. Therefore, the solution is optimal and the $w(P_j) = 0$, but we should also be sure that this incentive mechanism does not give too much incentives to invest at P_1, when the manager is not facing a low cost (θ_2) project. By checking that the incentive constraint Eq. (16) does not bind we see that this is not the case, therefore conclude that it is indeed optimal to set $w(P_j) = 0, \forall P_j \in (\underline{P_j}, \overline{P_j})$.

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