Selective Disclosure and Overinvestment

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Abstract

We show that the freedom to selectively disclose project performances can lead to severe overinvestment. The ensuing inefficiency problem is particularly significant if the agent is myopic, and/or has a lot of room in selective disclosure. In some extreme cases, sure-loss projects are pursued, and the social welfare could be negative in equilibrium.

Keywords Disclosure, Overinvestment

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1 Introduction

Consider a firm manager deciding the number of projects (with uncertain returns) to pursue, and what progress reports about the pursued projects to make public subsequently. He is concerned about both the short-run (due to incentive schemes or loss of control) and the long-run firm values. While the long-run firm value is determined by the realized returns of invested projects, the short-run firm value is determined by the market's belief conditional on the verifiable information disclosed voluntarily by the manager. The manager's investment decision therefore depends not only on the projects' expected returns, but also how it facilitates the management of the short-term market expectation via disclosure.

Similarly, consider an entrepreneur of a startup firm who may sell part of it to some venture capitalists or through an IPO in the near future. In deciding which and how many R&D projects to undertake, he naturally takes into account the firm's overall outlook at the time of the sales. The entrepreneur often has access to private information about the interim progress of the R&D projects pursued and he can selectively present part of his information to external financers. Again, the investment decision and the subsequent disclosure decision are interconnected.

Next, consider a seasoned academic researcher who may go to the job market in the near future. As his/her intrinsic ability is more or less known, the potential employer's major consideration is the quality of the portfolio of his/her ongoing working projects. It is clear that the researcher has some freedom in presenting his/her research portfolio (as long as the reported information is truthful). In deciding which and how many projects to pursue, the researcher has to consider not only their expected returns, but also how they affect the presentation of his/her research portfolio at the job market.

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In the examples above, an agent, concerned about both the near-term outlook and the long-term value of his portfolio, has to decide the investment scale, taking into account the subsequent disclosure about the portfolio's interim performance. We model this scenario by extending the setup of Shin (2003) to include an ex-ante investment stage. Specifically, in the initial stage, an agent chooses the number of ex-ante identical projects (with uncertain returns) to undertake, with the marginal cost increasing in the investment scale. Subsequently, in the interim stage, some of the project outcomes realize (independently), and the agent decides which of these outcomes to disclose. The disclosure is voluntary and verifiable, meaning that the agent cannot lie but he does not have to tell the whole truth. Based on these reports (as well as the equilibrium belief about the agent's strategy), an observer forms an expected value about the portfolio's value. Finally, in the expost stage, all project outcomes realize. The agent's payoff is a convex combination of the observer's expected value in the interim stage and the expost portfolio value.[1] As the observer's role in this game is passive and does not derive any payoff, the social welfare coincides with the agent's payoff.

Our main research question is how voluntary disclosure interacts with ex-ante investment incentives. Following Shin (2003), we focus on equilibria in which the agent plays the sanitization strategy in the reporting stage, namely, reporting all successful outcomes and concealing all failures. In order to increase the number of successful outcomes that can be reported, thus inducing a favorable perception by the observer, the agent may initiate an excessive number of projects, even though some of them have negative expected returns. In other words, over-investment may arise because it improves the effectiveness of the sanitization strategy that selectively reveals favorable outcomes only. We formalize this intuition by showing that the agent never under-invests (relative to the first-best) in equilibrium, and identifying a weak necessary and sufficient condition for over-investment to take place.

By developing a simple and intuitive equilibrium characterization, we investigate a number of factors that affect the equilibrium investment scales. First, as the overinvestment problem is driven by the agent's attempt to manipulate the observer's interim-stage perception, the level of overinvestment is increasing in the agent's concern about his short-term payoff. This finding stands in interesting contrast to the traditional view in the literature that managerial myopia/short-termism lowers long-term investment (Narayanan (1985), Stein (1988, 1989)), and is consistent with empirical findings that managers with a longer horizon devote less on R&D activities (Meulbroek, Mitchell, Mulherin, Netter and Poulsen (1990) and Atanassov (2013)). Second, if the agent becomes more informed in the interim reporting stage, his likelihood of being able to selectively disclose favourable project outcomes increases. At the same time, nondisclosure is viewed more pessimistically by the observer, as it is associated with a higher probability that the agent is concealing bad news. Both effects imply a larger marginal benefit of initiating a project, so the level of overinvestment is increasing in the project's interim-stage observability. Moreover, the two factors above are complementary in driving over-investment. This result could provide an explanation to the empirical finding that public firms, which have a shorter investment horizon, pursue more exploitative and less exploratory innovations, as the former are likely to have quicker realization of results (Bernstein (2015) and Gao, Hsu and Li (2018)). Furthermore, and somewhat surprisingly, we find that it is possible that a decrease in

[1] The same formulation of objective function is adopted in Stein (1989), Bebchuk and Stole (1993) and Ben-Porath, Dekel and Lipman (2018), among others. Stein (1989) offers a detailed account of why a firm manager is concerned about the short-term firm value.

the projects' expected returns leads to a higher level of equilibrium investment. The reason is that with a more pessimistic prior belief about project performances, non-disclosure is viewed more negatively by the observer. This encourages the implementation of extra projects in an attempt to avoid a lack of good news that can be reported.

In equilibrium, all attempts to improve the outlook of the interim-stage portfolio are correctly anticipated by the observer, so she would discount the portfolio's expected value in her evaluation by taking into account the agent's excessive investment. Consequently, the ex-ante expected payoff of the agent coincides with that of the portfolio value in equilibrium, and the agent's investment in projects with negative expected returns ultimately destroys his own (expected) payoff (and hence the social welfare).[2] We show that the overinvestment problem can lead to severe inefficiency, especially if the agent is sufficiently myopic and/or the interim-stage observability of projects is sufficiently high. First, it is possible that the agent is willing to pursue projects that yield losses with probability one. Second, the agent's expected payoff (and hence the social welfare) could be negative in all equilibria, despite the feasibility of abstaining from all projects (and thus getting a zero payoff) or choosing a low investment scale that gives a positive expected return. Furthermore, we provide an example that illustrates the possibility that a reduction in the cost of project implementation could exacerbate the inefficiency due to overinvestment and consequently destroy the equilibrium portfolio value.

Our paper belongs to the large literature on verifiable disclosure, pioneered by Milgrom (1981) and Grossman (1981). They show that if the agent wants to improve the observer's belief about his project's quality and is known to have private information that can be verifiably disclosed, then by an unravelling argument, the unique equilibrium involves the agent fully revealing his private information. Dye (1985) points out that if the agent may be uninformed of the project's quality, then the unravelling argument does not lead to full disclosure, as an agent with only bad news finds it better to feign ignorance than to report it. Shin (2003) investigates the asset pricing implications of the Dye information structure, and finds that an unfavorable interim report is associated with a higher degree of residual uncertainty. We extend his setup by including an ex-ante investment stage, and study the interaction of the disclosure and investment incentives. The recent contribution by Ben-Porath, Dekel and Lipman (2018) shows that if the agent is constrained to choose only one project, the ability to selectively disclose its outcome favors the adoption of a riskier project even with a low expected return. We show that if the agent can implement any number of projects, the ability to selectively disclose any subset of outcomes induces excessive investment. As mentioned in the preceding paragraph, there are cases in which all equilibria involve the agent opting for an investment portfolio that is *first-order stochastically dominated* (as some sure-loss projects are launched). Finally, in a rather different setting, Wen (2013) also studies how disclosure potentially interacts with investment. She points out that the decision to invest in a new project, as well as its disclosed profitability, can be a signal of the quality of other ongoing activities by the firm. Therefore, a firm's investment decision is affected by its implications on the market's perception about the firm's existing projects. We focus on a different consideration, namely, the benefit of starting new projects on the effectiveness of selective disclosure. This consideration is absent in Wen's model because the agent cannot selectively disclose the new project's profitability in the reporting stage: the agent is known to have private and verifiable information, so the standard unravelling argument is applicable.

[2] This aspect of the model has a flavor of the career concern model by Holmstrom (1999). See Section 5.3 for a more detailed discssion on the differences between our work and career-conern models.

The relations of our work and the last two papers are discussed in greater details in Section 5.

The outline of the paper is as follows. We set up the model in Section 2. In Section 3, we characterize the equilibria in which the agent plays the sanitization strategy on the equilibrium path, and discuss the implications on investment inefficiency. We report a number of comparative statics results and their empirical relevance in Section 4. Section 5 provides a more detailed account of how our work are connected to the existing literature. All proofs are relegated to the appendix.

2 Model

The game is played between an agent and an observer. There are infinitely many ex-ante identical projects from which the agent can choose to carry out. The game consists of three stages. In the initial stage, the agent chooses the number of projects to implement. We call this number the choice of *investment scale*. The outcome of each project is either a success or a failure, with the ex-ante probability of success being $r \in (0, 1)$. The realizations of outcomes are independent across projects. A success contributes 1 to the value of the agent's portfolio, whereas a failure contributes 0. The marginal cost of implementing the n-th project is c_n. This marginal cost function satisfies standard properties that $c_1 \geq 0$, c_n is non-decreasing in n, and approaches infinity as $n \to \infty$. Moreover, we assume that there is a large integer $\hat{N}$ such that $c_{\hat{N}} > \hat{N}$. The marginal cost of project implementation is not project-specific. That is, for any collection of n projects, the total cost of implementation is $\sum_{i=1}^{n} c_i$. One interpretation is that while all projects have an identical intrinsic cost, the marginal cost of managing and financing an additional project is increasing in the overall scale of investment pursued by the agent. The observer is not able to see the investment scale chosen in the initial stage.

In the interim stage, the outcomes of some (but not necessarily all) projects are realized and privately learned by the agent. The event of outcome realization in this stage is independent across the implemented projects, and is independent of the project outcome. We denote by $\theta \in (0, 1)$ the probability that this happens for an individual project. The agent can disclose some or all of the realized outcomes, by presenting hard and conclusive evidence about these projects. However, he cannot fake evidence; if a project has failed, he cannot show that it is a success. In other words, the agent is not allowed to lie, but he does not have to report the whole truth. It is useful to highlight that we allow the agent to selectively report his information. For instance, if he knows the outcomes of 2 projects, he is free to report that of one project while remain silent on the other project (thus feigning ignorance about the latter). For those projects that do not have their outcomes realized in this stage, including projects that are not implemented, the agent can say nothing about them. Therefore, the agent cannot credibly reveal the actual number of projects pursued, other than the obvious fact that at least n projects were pursued if n outcomes are revealed. The observer relies only on the information disclosed by the agent to form belief about the performance of his investment portfolio.

In the final stage, all project outcomes realize and become public knowledge. The agent is risk neutral and his payoff is determined by the observer's beliefs about the portfolio value in the interim and the final stages. Specifically, if the observer's expected value of the portfolio are b_1 and b_2 in the interim and the final stages respectively, then the agent's payoff is $(1 - \alpha) b_1 + \alpha b_2$ for some $\alpha \in [0, 1]$. The observer's role in the game is simply forming beliefs, and she does not derive any payoff.

We use the solution concept of weak perfect Bayesian Nash equilibrium, and focus on equilibria in which the agent plays a pure strategy. Moreover, following Shin (2003), we focus on equilibria in which, on the equilibrium path, the agent adopts the sanitization strategy, i.e., he conceals all the failures and discloses all the successes that he knows. In determining the portfolio value in the interim stage, the observer has to form a belief about the number of projects pursued, as well as the performance of projects that are not revealed. In the off-the-equilibrium-path event in which the agent is found to pursue an investment scale exceeding the equilibrium value, the observer holds the pessimistic belief that more than $\hat{N}$ projects have been pursued. It will become clear later that this pessimistic belief discourages upward deviations in the initial investment stage. Consequently, imposing this off-path belief is without loss, as our objective is characterizing the set of all (pure-strategy) equilibrium outcomes.

3 Equilibrium and Inefficiency

We begin our analysis by characterizing the first-best outcomes. Let N^+ be the efficient investment scale, i.e., $N^+ = \max\{n \in \mathbb{N} : c_n \leq r\}$ if $c_1 \leq r$, and $N^+ = 0$ otherwise. If the agent can commit to implementing N^+ projects, the ex-ante expected portfolio value is $rN^+ - \sum_{i=1}^{N^+} c_i$, and by the law of iterated expectation, regardless of what reporting strategy is used in the interim stage, the interim expected value coincide with the ex-ante expected value in equilibrium. The agent would therefore collect an expected payoff of $rN^+ - \sum_{i=1}^{N^+} c_i$. Below, we will show that if the agent chooses the number of projects privately (as in our model), the first-best investment scale N^+ cannot, in general, be supported in any equilibrium.

Below, we identify conditions for a pure-strategy equilibrium in which the agent plays the sanitization strategy on the equilibrium path. Suppose the observer believes that the agent implements $\tilde{N}$ projects in the initial investment stage. Suppose also that in the interim stage, the agent reports s successful projects and f failed projects such that $s + f \leq \tilde{N}$, then the expected portfolio value according to the observer is

$$s + \left(\tilde{N} - s - f\right) \frac{r\,(1-\theta)}{1-\theta r} - \sum_{i=1}^{\tilde{N}} c_i. \tag{1}$$

To understand the expression above, for a project that is believed to have been pursued but its outcome is not revealed, either the agent has observed a bad outcome (which happens with probability $\theta\,(1-r)$), or the agent did not observe anything (which happens with probability $1-\theta$). The conditional probability that the unrevealed project is a success is therefore $r\,(1-\theta)\,/\,(1-\theta r)$.

Suppose the agent's report shows that at least N' projects have been pursued, i.e., $N' \equiv s + f$, and $N' > \tilde{N}$. As mentioned above, in this case, we impose the observer's belief that the agent has pursued $\max\left\{N', \hat{N}\right\}$, where $\hat{N}$ is such that $c_{\hat{N}} > \hat{N}$. Under this belief, the agent never finds it optimal to make such a report. Intuitively, over-reporting the number of outcomes beyond $\tilde{N}$ leads to a substantial increase in the perceived cost of the portfolio that exceeds the maximum possible benefit of doing so.

Lemma 1 *Suppose the observer holds the following belief: $\tilde{N}$ projects have been implemented if the number of revealed outcomes N' is no more than $\tilde{N}$; and $\max\left\{N', \hat{N}\right\}$ projects have been implemented if the number of revealed outcomes N' exceeds $\tilde{N}$. Given this belief, the agent never finds it optimal to report more than $\tilde{N}$ outcomes.*

Lemma 1, together with the expected-value formula (1), implies that given the observer's belief, the sequentially optimal reporting strategy in the interim stage is almost-sanitization. Specifically, under all circumstances, the agent does not voluntarily disclose any failure. Moreover, he discloses as many successful outcomes as possible, so long as the total number of revealed outcomes does not exceed $\tilde{N}$. This reporting strategy is exactly sanitization on the equilibrium path.

In our subsequent analysis, we impose the belief described in Lemma 1 on the observer's evaluation of the interim-stage portfolio value. This belief allows us to obtain the largest possible set of equilibrium investment scales, i.e., if $\tilde{N}$ cannot be supported as an equilibrium investment scale under this belief, there is no other belief under which $\tilde{N}$ can be supported. The reason is that any alternative belief would weakly increase the agent's payoff of upward deviation, while leaving the payoff of downward deviation unaffected.

Now we investigate the agent's incentives in the initial investment stage. Given that the almost-sanitization strategy is played in the interim stage, if the observer's expectation of the investment scale is $\tilde{N}$, then the agent's payoff of choosing N projects is

$$\begin{aligned} U\left(N;\tilde{N}\right) \equiv\ & (1-\alpha)\underbrace{\left(\sum_{s=0}^{N}\binom{N}{s}(r\theta)^{s}(1-r\theta)^{N-s}\left(\min\left\{s,\tilde{N}\right\}+\frac{r(1-\theta)}{1-r\theta}\left(\tilde{N}-\min\left\{s,\tilde{N}\right\}\right)\right)-\sum_{i=1}^{\tilde{N}}c_i\right)}_{\text{expected observer's belief in the interim stage}} \\ & +\alpha\underbrace{\left(rN-\sum_{i=1}^{N}c_i\right)}_{\text{expected observer's belief in the final stage}}. \end{aligned}$$

As the number of observed successes in the interim stage is a binomial-$(N, r\theta)$ random variable, an increase in N shifts its distribution in a first-order stochastic dominant manner. Therefore, an increase in N always raises the agent's interim-stage payoff. Implementing an additional project, however, can adversely affect the agent's final payoff if a large number of projects is already in place. We define the marginal benefit of implementing the N-th project to the agent, conditional on $\tilde{N}$ projects being expected, by

$$\begin{aligned} MB\left(N;\tilde{N}\right) &\equiv U\left(N;\tilde{N}\right)-U\left(N-1;\tilde{N}\right) \\ &= (1-\alpha)\left[\sum_{s=0}^{\min\left\{\tilde{N},N\right\}-1}\binom{N-1}{s}(r\theta)^{s}(1-r\theta)^{N-1-s}\left(r\theta\frac{1-r}{1-r\theta}\right)\right]+\alpha\left(r-c_N\right). \end{aligned}$$

The bracketed term represents the expected magnitude of the interim-stage gain due to the N-th project; this gain exists whenever the first $N-1$ projects does not yield more than $\min\left\{\tilde{N},N\right\}-1$ observed successes. In this case, carrying out one more project allows the agent to report an additional success in the interim stage with probability $r\theta$, in which case the perceived portfolio value increases by $1-r(1-\theta)/(1-\theta r)$. The last term in the expression of $MB\left(N;\tilde{N}\right)$ captures the net return of the marginal project realized in the final stage.

An immediate observation is that any $\tilde{N}<N^{+}$ cannot be supported in equilibrium because the marginal benefit of the $\tilde{N}+1$-th project, $MB\left(\tilde{N}+1;\tilde{N}\right)$, is positive and a profitable deviation exists. The following proposition states how this marginal cost function characterizes the equilibria.

Proposition 1 *There exists a pure-strategy equilibrium in which the agent plays the sanitization strategy on the equilibrium path. Within this class of equilibria,* $N^* > 0$ *is an equilibrium investment scale if and only if* $MB(N^*; N^*) \geq 0$ *and* $MB(N^* + 1; N^*) \leq 0$*. Moreover, the unique equilibrium investment scale is* 0 *if and only if* $MB(1; 1) < 0$.

The characterization in Proposition 1 is very intuitive: if $MB(N; N) \geq 0$ and $MB(N + 1; N) \leq 0$, then under the belief that N projects are implemented, the agent finds it profitable to carry out the marginal project but not more. Note also that $r < c_1$ is not enough to guarantee $MB(1; 1) < 0$ whenever $\alpha < 1$, i.e., if the agent cares about the observer's interim-stage perception. Therefore, it is possible that some projects are implemented even if none of them are ex-ante profitable. Below, we discuss in greater detail the inefficiency that ensues from the agent's concerns about the observer's belief, and his ability in selective reporting of interim outcomes.

As mentioned above, the agent never underinvests in equilibrium. However, inefficiency in the form of overinvestment can easily occur in our model. In fact, from the perspective of maximizing his interim-stage payoff, the agent should pursue as many projects as possible. This is because the observer does not know the actual investment scale until the final stage, so her evaluation of the portfolio cost in the interim stage is based only on her understanding of the equilibrium strategy. Consequently, the agent could find it tempting to engage in all possible projects to maximize the probability that he can report full successes in the interim stage. The only force that reins in the agent is the realized returns in the final stage; the pursuit of projects with negative returns is eventually costly to the agent. In equilibrium, the agent tradeoffs the gain in his interim-stage payoff with the loss in his final-stage payoff in determining the extent of overinvestment. The corollary below states the precise condition under which the aforementioned consideration results in an inefficient investment scale.

Corollary 1 *The efficient number of projects* N^+ *cannot be supported as an equilibrium outcome if and only if* $MB(N^+ + 1; N^+) > 0$*. This arises whenever* α *is sufficiently small.*

The proof can be found in the appendix. In fact, as long as the marginal cost function does not exhibit a large jump at the efficient value N^+, i.e., $c_{N^+ + 1} - r$ is relatively small, the agent would find it tempting to marginally expand the investment scale beyond N^+.

The inefficiency outlined above can be very severe, especially when the agent cares a lot about the observer's interim belief. In some cases, there are equilibria that involve the agent pursuing projects that contribute negatively to the portfolio value with probability one. Moreover, he may end up with a negative equilibrium payoff, even if the first-best payoff is positive and a zero investment scale is always feasible.

Corollary 2 *(i) Suppose* $\alpha < r\theta$ *and there are some projects with marginal costs* $c_n \in \left(1, r\left(1 + \frac{1-\alpha}{\alpha}\frac{(1-r)\theta}{1-r\theta}\right)\right)$*. Then there is an equilibrium in which these sure-loss projects are pursued.*

(ii) There exists an $\hat{\alpha} \in (0, 1)$ *such that for all* $\alpha < \hat{\alpha}$*, the agent's payoff, and hence the social welfare, is negative in all equilibria.*

The scenarios described in the corollary above highlight how the agent's short-termism lead to extreme distortion in his investment decisions. As mentioned above, this distortion arises from the agent's attempt to manipulate the observer's belief through selective disclosure of positive news in the interim stage. However, as his strategy is correctly anticipated by the observer in equilibrium, the agent's ex-ante expected payoff must coincide with the ex-ante expected portfolio value in equilibrium. Therefore, it is the agent himself who ultimately suffers from these manipulations. In the scenario described in part (ii) of Corollary 2, the agent's equilibrium payoff can be so low that he would be better off if he could commit not to pursue any project, even if a positive investment scale is profitable (i.e., $c_n < r$ for some $n \in \mathbb{N}$).

4 Comparative Statics

In this section, we investigate how the set of equilibrium investment scales could be affected by the model's parameters. These comparative statics highlight the effects of the agent's selective disclosure on his equilibrium investment choices.

While there are, in general, multiple equilibria, the set of equilibrium outcomes takes a very simple form if the marginal cost function c_n is convex. In this case, $MB\,(N+1;N)$ is concave in N and so intersects the horizontal axis at most twice if $r \leq c_1$ and at most once if $r > c_1$. Consequently, the equilibrium number of projects are given by at most two intervals. This interval characterization of equilibria is convenient and allows us to conduct neat comparative statics in the subsequent analysis.

Corollary 3 *Suppose c_n is weakly convex and $MB\,(1;1) > 0$.*

(i) If $r > c_1$, then N^* is an equilibrium investment scale if and only if $N^* \in \left[\underline{N}^*, \bar{N}^*\right]$, where $\bar{N}^*$ and $\underline{N}^*$ are the unique solutions to $MB\,(N;N) = 0$ and $MB\,(N+1;N) = 0$ respectively.

(ii) Suppose $r \leq c_1$. If $MB\,(N+1;N) \leq 0$ for all $N \geq 1$, then N^* is an equilibrium investment scale if and only if $N^* \in \left[0, \bar{N}^*\right]$. If $MB\,(N+1;N) > 0$ for some $N \geq 1$, then N^* is an equilibrium investment scale if and only if $N^* \in [0, \underline{N}_0^*] \cup \left[\underline{N}_1^*, \bar{N}^*\right]$, where $\underline{N}_0^*$ and $\underline{N}_1^*$ are the smaller and larger root of $MB\,(N+1;N) = 0$ respectively.

An increase in the project transparency θ has two effects on the agent's investment incentives. First, for each project, there is a greater likelihood that he is able to disclose its outcome in the interim stage, provided that he learns that it is a success. Second, as the agent is more informed in the interim stage, the observer correctly believes that an undisclosed project is more likely to have an unfavorable outcome realized already. Consequently, the gain of disclosing a good outcome in the interim stage goes up. Both effects encourage the agent to increase the investment scale in the initial stage.

Proposition 2 *If c_n is weakly convex and $r > c_1$, then an increase in project transparency θ weakly shifts up the interval of equilibrium investment scales (in strong set order).*

The project transparency parameter θ can be interpreted as a measure of the agent's ability to engage in selective disclosure: a small (large) value of θ means that it is unlikely (likely) that the agent can learn and disclose a project's outcome at the interim stage. An implication of Proposition 2 is therefore that investment scale goes down as the agent has less room in selective disclosure. This result is consistent with the empirical finding of Aggarwal and Hsu (2013) that IPO lowers the level of innovation activities as measured by patent counts. They provide evidence that an important channel for their finding is an information confidentiality mechanism: going public entails stricter disclosure requirement, which discourages innovative activities.

Next, we show that the overinvestment problem in our setting is exacerbated if the agent becomes more myopic, modelled by a decrease in α. By implementing an additional inefficient project (i.e., $r < c_n$), the agent enjoys the benefit of a higher interim-stage payoff at the cost of a lower final-stage payoff. Therefore, if α goes down, the net marginal benefit of an additional project increases, thus shifting up the equilibrium investment scales.

Proposition 3 *If c_n is weakly convex and $r > c_1$, then an increase in the agent's myopia (i.e., a decrease in α) weakly shifts up the interval of equilibrium investment scales (in strong set order).*

This finding, while quite straightforward in our setting, contrasts interestingly to those in the corporate finance literature about the effect of managerial short-termism on investment distortion. Stein (1989) points out that a manager concerned about the firm's short-term stock prices has incentives to underinvest in projects that are not observable to the market but nonetheless generate long-term values.[3] In a similar vein, Bebchuk and Stole (1993) show that if the market cannot observe the investment scale, a myopic manager would underinvest in order to "pull in" future cash flows to the present. On the other hand, if investment is observable by the market and the manager has superior information concerning the profitability of a project, he may overinvest in order to send a positive signal to the market, thus boosting his near-term payoff. Therefore, the direction of investment distortion due to short-termism depends on whether the manager is plagued with a moral hazard problem (underinvestment) or an adverse selection problem (overinvestment). Our setting is closer to a moral hazard setting as the observer cannot see the investment scale until the final stage, and the agent does not possess superior information when making his investment decision. Nonetheless, we find that short-termism can cause the agent to overinvest because of his ability to selectively disclose favourable information in an interim stage.

Our result that managerial short-termism can exacerbate overinvestment is consistent with empirical findings. Meulbroek, Mitchell, Mulherin, Netter and Poulsen (1990) find that the introduction of antitakover provisions (which reduces managerial myopia according to Stein (1998)) lowers firms' R&D expenditures. Relatedly, Atanassov (2013) identifies a significant reduction in firms' patents and citations per patent for firms incorporated in states that pass antitakeover laws.

Proposition 2 and 3 consider, respectively, the equilibrium effect of an increase in project transparency and the agent's short-termism. The corollary below shows that these two effects are complementary in inducing overinvestment.

Corollary 4 *If c_n is weakly convex and $r > c_1$, then an increase in project transparency and an increase in the agent's myopia are complementary in shifting upwards the equilibrium investment scales.*

This result echoes the recent empirical findings due to Gao, Hsu and Li (2018) and Bernstein (2015). Gao, Hsu and Li (2018) find that the shorter investment horizon of public firms (due to the CEO's short vested equity

[3] Bolton, Scheinkman and Xiong (2006) point out that the optimal managerial compensation could over-emphasize the short-term stock performance at the expense of long-term firm value, as an incentive to induce managers to pursue actions which increase the speculative component in the stock price.

portfolios, the threat of takeovers, and presence of the transient institutional investors) make them pursue less exploratory and more exploitative innovation strategies. According to their definitions, exploratory innovation "requires new knowledge or a departure from existing knowledge, and its payoffs take longer to realize and are of higher uncertainty", whereas exploitative innovation "builds on existing knowledge, and its payoffs are realized faster with less uncertainty". In the language of our model, exploitative innovation has a larger value of θ than exploratory innovation due to its relatively quick realization. Corollary 4 thus suggests that exploitative innovation are favored by firms with a short horizon, as found in Gao, Hsu and Li (2018). Bernstein (2015) has a similar finding that going public causes a substantial 40% decline in innovation novelty as measured by patent citations.

Next, consider the effect of an increase in the projects' profitability r. While it is immediate that, from the perspective of improving the portfolio's ex-ante expected value, a higher investment return calls for a larger investment scale, its effect on the agent's interim-stage payoff is more subtle. On one hand, a larger value of r means that for each project, it is more likely that a favorable outcome can be revealed in the interim stage, thus further raising the benefit of investment. On the other hand, it implies that an undisclosed project outcome is treated more favorably by the observer. Consequently, the relative gain of disclosing a good outcome in the interim stage decreases, thus lowering the benefit of investment. The latter effect is particularly strong when α is small and the value of r is already high.

Proposition 4 *Suppose c_n is weakly convex and $r > c_1$. If α is sufficiently small, then there exists a $\hat{r} \in (0, 1)$ such that if $r' > r \geq \hat{r}$, the interval of equilibrium investment scales is weakly lower (in strong set order) with r' than with r.*

We would like to remark that the effect identified here is not special to the case of binary project outcomes. To illustrate, let $[\underline{x}, \bar{x}]$ be the set of possible project outcomes. It is a standard result that in equilibrium the agent reveals an interim outcome learned if and only if it exceeds some cutoff $x^* \in [\underline{x}, \bar{x}]$. A first-order stochastic improvement in the distribution of project outcomes raises this equilibrium cutoff, as well as the expected outcome conditional on no interim disclosure. Therefore, conditional on an interim realization of outcome $x > x^*$, the gain associated with its revelation (relative to no-reporting), given by $x - \{(1-\theta) E[x] + \theta E[x|x \leq x^*]\}$ goes down, thus lowering the benefit of investment.

We conclude this section by discussing the equilibrium effect of a change in the project costs. As noted at the beginning of Section 3, the inefficiency in our setting can be attributed to a commitment problem: if the agent can commit to the investment scale in the initial stage, he would always choose the first-best level of N^+. His attempt to manipulate the observer's interim belief by selective disclosure, however, creates incentives to overinvest. This commitment problem can get more severe as the project costs c_n go down, leading to a reduction in the equilibrium (expected) portfolio value. To illustrate this, compare the following two marginal cost functions $\{c_n^1\}$ and $\{c_n^2\}$. The first one $\{c_n^1\}$ has $c_1^1 > r + \left(\frac{1-\alpha}{\alpha}\right) r\theta \frac{1-r}{1-r\theta}$, so $MB(1;1) < 0$ and the unique equilibrium investment scale is 0. The second one $\{c_n^2\}$ coincides with the first for all $n \geq 2$ except that $c_1^2 \in \left(r, r + \left(\frac{1-\alpha}{\alpha}\right) r\theta \frac{1-r}{1-r\theta}\right)$. It follows from the equilibrium characterization in Proposition 1 that the unique equilibrium investment scale under marginal cost function $\{c_n^2\}$ is 1, and the agent's ex-ante expected payoff is $r - c_1^2 < 0$. This example illustrates that a downward shift of the marginal cost function, while definitely improves the first-best portfolio value, may exacerbate the agent's commitment problem and destroy the portfolio value in equilibrium.

5 Connection to the Literature

5.1 Relation with Ben-Porath, Dekel and Lipman (2017)

In Ben-Porath, Dekel and Lipman (2017), the agent chooses a single project out of a set of feasible projects, and their main result is that the agent's project choice is titled towards risky projects even though they have low expected returns. The intuition for this inefficiency is that, in equilibrium, the agent's payoff as a function of his interim reports is convex, giving rise to an endogenous preference for risky projects. They also identify a tight lower bound on the ratio of the agent's equilibrium payoff to his first-best payoff. Our setting differs from theirs in that we allow the agent to adopt multiple projects, and to reveal the outcomes of any subset of implemented projects that are realized in the interim stage. Therefore, the agent in our model has more flexibility in making his disclosure: in Ben-Porath, Dekel and Lipman (2017), the agent, effectively, can only either fully disclose or report complete ignorance about its portfolio (which consists of a single project) in the interim stage.

Our analysis suggests that the extra flexibility in the interim reporting stage modelled here *encourages excessive investment, rather than excessive risk-taking*, and it leads to a number of novel consequences. First, as shown in part (i) of Corollary 2, it is possible that the agent chooses an investment scale so high that its return distribution is first-order stochastically dominated (by another feasible investment scale). This result is impossible in the single-project choice framework of Ben-Porath, Dekel and Lipman (2017).[4] Second, the magnitude of the inefficiency resulting from the overinvestment identified in our model can be much more severe. As shown in part (ii) of Corollary 2, the agent's equilibrium payoff could be negative even if the first-best payoff is positive. This is again impossible in the single-project choice framework of Ben-Porath, Dekel and Lipman (2017) as the agent can secure at least half of the first-best payoff.[5] Finally, according to Proposition 2, the effect of selective disclosure on overinvestment is most severe in our setting if the agent learns the project outcomes in the interim stage with almost certainty (i.e., $\theta \to 1$). This result stands in interesting contrast to Ben-Porath, Dekel and Lipman (2017) which find that inefficiency vanishes with $\theta = 1$: in the single-project choice setting, if the agent knows the project outcome for certain, a standard unravelling argument is applicable and there is no room for manipulating the observer's belief by selective disclosure.[6] In contrast, in our setting of multiple projects, even if the observer knows that the agent has full information about the project outcomes in the interim stage, she does not directly observe the number of projects implemented. Consequently, non-disclosure of an individual project outcome may not be interpreted as a failure, as long as a certain number of other projects' outcomes are revealed. As a result, the agent is still tempted to manipulate the observer's interim belief by trying a lot of projects in the investment stage, thus increasing the expected number of successes that can be reported. This incentive is particularly strong when θ is large, as the observer treats disclosure profiles with the number of reported outcomes below the equilibrium investment scale

[4] Intuitively, while selective reporting convexifies the agent's payoff as a function of interim reports, the resulting function is still weakly increasing.

[5] See Theorem 2 of Ben-Porath, Dekel and Lipman (2017).

[6] See Theorem 2 of Ben-Porath, Dekel and Lipman (2017), and its subsequent discussion.

very unfavorably.

5.2 Relation with Wen (2013)

In Wen (2013), a firm, endowed with an ongoing activity, privately learns in the initial stage whether there is a new project available, and if so, its profitability. It then decides whether to invest in this project, after which the investment decision is publicly revealed. If and only if it invests, the firm has the option of revealing the project's profitability in the interim stage. Similar to our model, the firm makes its investment and disclosure decision with the objective of maximizing a weighted average of the perceived firm values (sum of the cash flows generated by the ongoing activity and the new project) in the interim stage and the expost stage. Moreover, the firm can disclose the project's profitability only if it has invested in it. There are, however, a number of key modelling differences from ours. First, the firm's investment decision is binary (invest in the new project or not). Second, the firm is informed of the project's profitability at the investment stage, whereas the agent in our model has no such private information when deciding his investment scale. Third, the new project's profitability is positively correlated with that of an ongoing activity, whereas the agent in our model has no endowed projects and that all available projects have independent returns. Fourth, the firm's investment decision is public, whereas the agent's investment decision in our model is private until the final expost stage.

The main determinant in the firm's investment decision in Wen's model is as follows. On top of the obvious consideration about the new project's profitability, the firm also takes into account the effect of revealing the new project's profitability on the market's perception of its ongoing activity, due to their positive correlation. If the market's prior belief about the new project's profitability is relatively low, which is associated with an unfavorable perception about its ongoing activity (because of their positive correlation), the firm is willing to implement the new project, even if it has a small negative return. The reason is that by doing so, it gives the firm an option to disclose the new project's profitability, which helps boost the market's perception about its ongoing activity. It is important to note that because the investment decision is public in her model, the standard unravelling argument applies, so the firm necessarily fully discloses the new project's profitability, provided that it is pursued. Consequently, *the option of disclosure could discourage investment*, as the firm must reveal its profitability once it is pursued. In fact, Wen finds that if the market's prior belief about the new project's profitability is relatively high, the firm may refrain from investing the new project even though it has a positive expected return. In sum, the firm's investment decision is distorted (upwards or downwards) by its value of signalling about its pre-existing activity.

In our model, the agent has very different economic considerations in his investment decisions. First, as the agent has no private information about the new projects' profitability, and the market's perception of the portfolio value is unrelated to any ongoing activity, these factors are not taken into account in the investment stage. Second, as the investment decision is private (until the final stage), the unravelling argument does not (fully) apply, and the agent understands that he does not have to fully reveal all project outcomes in the reporting stage. In our model, this ability to selectively disclose interim information, as well as its associated benefits, constitute the main determinants of the agent's investment scale. This consideration, however, is markedly absent in Wen's model: in the unique equilibrium of her model, the firm makes full disclosure whenever it invests in the new project.

Consequently, the firm's investment decision is unaffected even if full disclosure about all ongoing activities is mandated. These significant differences in economic considerations lead us to very different implications about investment distortions. In particular, whereas the signalling aspect of Wen's model could imply either over- or under-investment depending on the market's perception, we show that the benefit of selective disclosure always induces over-investment.

5.3 Relation with Holmstrom (1999)

In the career concerns literature pioneered by Holmstrom (1999), an agent is motivated to exert effort to improve his observable performance from which the market draws inference about his hidden ability. Effort is typically distorted from the first-best because it is determined, not by its actual productivity, but rather by the sensitivity of the market's evaluation of the agent's ability to the observed output. There are two main modelling differences between our work and this line of literature. First, we allow the agent to directly control the information revelation in the reporting stage, whereas the agent in a career-concerns model can influence the signal indirectly and imperfectly through effort exertion only. Second, in our model, there is no ex-ante uncertainty about the intrinsic productivity of the agent and the values of the projects, whereas the agent in a career-concerns model has an intrinsic ability that the market is interested in learning.

According to Holmstrom (1999), whether an agent concerned about his career prospect over- or under-exert effort (relative to the first-best) depends on whether the market's perception of his intrinsic ability is too sensitive or too insensitive to his performance. This distortion exists even if the signal generation process of the agent's production is exogenous. In contrast, the agent's investment decision in our model is not driven by his attempt to impress the market about his innate productivity. Instead, the reason for his overinvestment is to increase the expected number of successes that can be reported. As the sources of distortion are markedly different, we arrive at very distinct implications. First, the freedom of selective disclosure always induces overinvestment, whereas career concerns may lead to either upward or downward distortion of effort depending on the market's sensitivity. Second, the over-exertion of effort in a career-concerns model is more severe if the agent has a long horizon ahead, whereas the over-investment problem in our model is more severe if the agent is myopic (recall Proposition 3). Third, in a career-concerns model, an improvement in production transparency by having a less noisy performance measure encourages effort exertion. On the other hand, in our model, an improvement in the portfolio's transparency limits the agent's ability to manipulate his interim-stage disclosure, thus lowering the incentives for over-investment.[7] Finally, an increase in the productivity of effort in a career-concerns model typically raises the equilibrium level of effort.[8] On the other hand, as shown in Proposition 4, an increase in the projects' return may lower the gain due to selective disclosure and thus the equilibrium investment scale.

[7]Recall the discussion following Proposition 2 that a reduction in θ can be interpreted as a decrease in the agent's ability to selectively disclose. According to Proposition 2, this lowers the equilibrium investment scale. Alternatively, we could modify the model by assuming that with a certain probability $q \in [0, 1]$, the portfolio's interim performance is perfectly revealed to the observer. It is clear that an increase in transparency q lowers the equilibrium investment scales.

[8]This is because it makes the market's perception of the agent's ability more responsive to the observed performance.

Appendix

Proof of Lemma 1

First consider the case that $\tilde{N} < N' \leq \hat{N}$. By lowering the number of revealed outcomes from N' to $\tilde{N}$, the change in the expected portfolio value is at least $-\left(N' - \tilde{N}\right) + \sum_{i=\tilde{N}+1}^{\hat{N}} c_i$, which is no less than $-\hat{N} + c_{\hat{N}} > 0$.

Next consider the case that $\max\left\{\tilde{N}, \hat{N}\right\} < N'$. By lowering the number of revealed outcomes from N' to $\max\left\{\tilde{N}, \hat{N}\right\}$, the change in the expected portfolio value is at least $-\left(N' - \max\left\{\tilde{N}, \hat{N}\right\}\right) + \sum_{i=\max\left\{\tilde{N},\hat{N}\right\}+1}^{N'} c_i$, which is no less than $\left(c_{\hat{N}} - 1\right)\left(N' - \max\left\{\tilde{N}, \hat{N}\right\}\right) > 0$.

Proof of Proposition 1

First, we establish that $MB\left(N; \tilde{N}\right)$ is nonincreasing in N. This fact is obvious if $\tilde{N} = 0$, so suppose $\tilde{N} > 0$. As c_N is nondecreasing, it suffices to show that $b\left(N; \tilde{N}\right) \equiv \sum_{s=0}^{\min\left\{\tilde{N},N\right\}-1} \binom{N-1}{s} (r\theta)^s (1 - r\theta)^{N-1-s}$ is nonincreasing in N. If $\min\left\{\tilde{N}, N+1\right\} = N+1$, then $b\left(N+1; \tilde{N}\right) = b\left(N; \tilde{N}\right) = 1$. If $\min\left\{\tilde{N}, N+1\right\} = \tilde{N} \in (0, N+1)$, then

$$
\begin{aligned}
& b\left(N+1; \tilde{N}\right) - b\left(N; \tilde{N}\right) \\
= & \left[-\binom{N-1}{\tilde{N}-1} (r\theta)^{\tilde{N}} (1 - r\theta)^{N-\tilde{N}} + \sum_{s=0}^{\tilde{N}-1} \binom{N-1}{s} (r\theta)^{s+1} (1 - r\theta)^{N-s-1} + \sum_{s=0}^{\tilde{N}-1} \binom{N-1}{s} (r\theta)^s (1 - r\theta)^{N-s}\right] \\
& - \sum_{s=0}^{\tilde{N}-1} \binom{N-1}{s} (r\theta)^s (1 - r\theta)^{N-1-s} \\
= & -\binom{N-1}{\tilde{N}-1} (r\theta)^{\tilde{N}} (1 - r\theta)^{N-\tilde{N}} + \sum_{s=0}^{\tilde{N}-1} \binom{N-1}{s} (r\theta)^s (1 - r\theta)^{N-s-1} (r\theta + (1 - r\theta) - 1) \\
= & -\binom{N-1}{\tilde{N}-1} (r\theta)^{\tilde{N}} (1 - r\theta)^{N-\tilde{N}} < 0.
\end{aligned}
$$

Now take an integer N^* such that $MB(N^*; N^*) \geq 0$ and $MB(N^*+1; N^*) \leq 0$. As $MB(\cdot; N^*)$ is nonincreasing, $MB(N; N^*) \geq MB(N^*; N^*) \geq 0$ for all $N \leq N^*$. Thus, each of the first N^* projects are profitable to implement. Moreover, $MB(N; N^*) \leq MB(N^*+1; N^*) \leq 0$ for all $N \geq N^*+1$. Thus, it is optimal to implement N^* projects only. Conversely, if N' is such that $MB(N'; N') < 0$, then the agent does not find it optimal to carry out the N'-th project, under the belief that N' projects were implemented. Similarly, if N' is such that $MB(N'+1; N') > 0$, then the agent finds it profitable to pursue at least one more project, under the belief that $N'+1$ projects were implemented. In both cases above, N' cannot be supported in equilibrium.

Next, by definition of the marginal cost functions, we have

$$
\begin{aligned}
MB(N; N) &= (1 - \alpha)\left(r\theta \frac{1-r}{1-r\theta}\right) + \alpha(r - c_N); \text{ and} \qquad (2) \\
MB(N+1; N) &= (1 - \alpha)\left(r\theta \frac{1-r}{1-r\theta}\right)\left(1 - (r\theta)^N\right) + \alpha(r - c_{N+1}). \qquad (3)
\end{aligned}
$$

Therefore, it is clear that $MB(N; N)$ is nonincreasing in N, and that $MB(N; N) > MB(N+1; N)$ for all N. If $MB(1, 1) < 0$, then $MB(N; N) < 0$ for all N and the only equilibrium investment scale is thus 0.

Finally, if $MB(1,1) \geq 0$, there is at least one integer satisfying $MB(N;N) \geq 0$ and $MB(N+1;N) \leq 0$. To see this, let N' be the largest integer satisfying $MB(N;N) \geq 0$. Then we must have $MB(N'+1;N') < 0$, for otherwise, $MB(N'+1;N'+1) \geq MB(N'+1;N') \geq 0$, violating the definition of N'.

Proof of Corollary 1

As $MB(N^+;N^+) > 0$, the first part of the corollary follows immediately from Proposition 1. It also follows from straightforward algebra that $MB(N^+ + 1;N^+) > 0$ holds if and only if

$$\alpha < \left(1 + \frac{c_{N^+ + 1} - r}{\left(r\theta \frac{1-r}{1-r\theta}\right)\left(1 - (r\theta)^{N^+}\right)}\right)^{-1},$$

which is positive as $c_{N^+ + 1} > r$ by the definition of N^+.

Proof of Corollary 2

(i) Let N' be the largest integer satisfying $MB(N;N) \geq 0$. Let N'' be such that $c_{N''} \in \left(1, r\left(1 + \frac{1-\alpha}{\alpha}\frac{(1-r)\theta}{1-r\theta}\right)\right)$. As $MB(N'';N'') \geq 0$, we have $N' \geq N''$, so $c_{N'}$ is also in the interval $\left(1, r\left(1 + \frac{1-\alpha}{\alpha}\frac{(1-r)\theta}{1-r\theta}\right)\right)$. As $MB(N'+1;N') \leq MB(N'+1;N'+1) < 0$, by Proposition 1, there is an equilibrium in which N' projects are pursued. In this equilibrium, the marginal project N' is a sure loss as $c_{N'} > 1$.

(ii) It suffices to show that if α is sufficiently small, $MB(N+1;N) > 0$ for all $N \leq \hat{N}$ (recall $c_{\hat{N}} > \hat{N}$). In this case, all equilibria would have an investment scale exceeding $\hat{N}$, and the agent's equilibrium payoff is no more than $\hat{N} - c_{\hat{N}} < 0$. Now it follows from straightforward algebra that $MB(N+1;N) > 0$ if and only if $\alpha < \left(\frac{c_{N+1} - r}{\frac{r(1-r)\theta}{1-r\theta}\left(1-(r\theta)^N\right)} + 1\right)^{-1}$. As c_n is nondecreasing and $\hat{N} \geq 1$, to ensure that the last inequality holds for all $N \leq \hat{N}$, it suffices to have $\alpha < \left(\frac{c_{\hat{N}+1} - r}{r(1-r)\theta} + 1\right)^{-1}$.

Proof of Corollary 3

(i) As $MB(1;1) > 0$, and $MB(N;N)$ is nonincreasing and weakly concave, $MB(N;N)$ has a unique root in N. Moreover, the weak convexity of c_n implies that $MB(N+1;N)$ is strictly concave in N, so it has a unique root in N whenever $MB(1;0) = \alpha(r - c_1) > 0$.

(ii) If $r - c_1 \leq 0$, then $MB(1;0) \leq 0$. The strict concavity of $MB(N+1;N)$ implies that it has either 0 or 2 roots. The corollary statement follows immediately from Proposition 1.

Proof of Proposition 2

It follows from straightforward calculations that $MB(N;N)$ and $MB(N+1;N)$ are both increasing in θ. Using (2) and (3),

$$\begin{aligned}
\frac{\partial MB(N;N)}{\partial\theta} &= \frac{(1-\alpha)\, r\,(1-r)}{(1-r\theta)^2}, \text{ and} \\
\frac{\partial MB(N+1;N)}{\partial\theta} &= \frac{(1-\alpha)\, r\,(1-r)}{(1-r\theta)^2}\left[1 - (1 + (1-r\theta)\,N)\,(r\theta)^N\right],
\end{aligned}$$

where the bracketed term in the last expression is positive because it is no less than $1-(1+(1-1)N)(1)^N = 0$. The upward shift of the equilibrium interval following an increase in θ is an obvious consequence of the characterization in Corollary 3.

Proof of Proposition 3

Let $\bar{N}^*_\alpha$ and $\underline{N}^*_\alpha$ be respectively the largest and the smallest equilibrium investment scales, given the weight on the final-stage payoff being α. Using part (i) of Corollary 3 as well as (2) and (3),

$$\begin{aligned} c_{\bar{N}^*_\alpha} &\leq r + \left(\frac{1-\alpha}{\alpha}\right)\left(r\theta\frac{1-r}{1-r\theta}\right) < c_{\bar{N}^*_\alpha+1} \text{ and} \\ c_{\underline{N}^*_\alpha} &< r + \left(\frac{1-\alpha}{\alpha}\right)\left(r\theta\frac{1-r}{1-r\theta}\right)\left(1-(r\theta)^{\underline{N}^*_\alpha}\right) \leq c_{\underline{N}^*_\alpha+1}. \end{aligned} \tag{4}$$

It is apparent from that an increase in α weakly lowers $\bar{N}^*_\alpha$ (by the first inequality above) and $\underline{N}^*_\alpha$ (by the second inequality above).

Proof of Corollary 4

Recall that the set of equilibrium investment scales are determined by the inequalities of (4). It follows from immediate computation that

$$\begin{aligned} \frac{\partial^2}{\partial\alpha\partial\theta}\left(r + \left(\frac{1-\alpha}{\alpha}\right)\left(r\theta\frac{1-r}{1-r\theta}\right)\right) &= \frac{-r(1-r)}{\alpha^2(r\theta-1)^2}, \text{ and} \\ \frac{\partial^2}{\partial\alpha\partial\theta}\left(r + \left(\frac{1-\alpha}{\alpha}\right)\left(r\theta\frac{1-r}{1-r\theta}\right)\left(1-(r\theta)^N\right)\right) &= \frac{-r(1-r)}{\alpha^2(1-r\theta)^2}\left[1-(1+(1-r\theta)N)(r\theta)^N\right]. \end{aligned}$$

While the first partial derivative above is clearly negative, the second one is also negative because of the reason pointed out in the proof of Proposition 2. Consequently, the effects of an increase in θ and a decrease in α are complementary in raising both the upper and the lower bounds of the equilibrium investment levels.

Proof of Proposition 4

Observe first that $r > c_1$ implies that the equilibrium investment scale is always positive. Next, using (2) and (3), direct computation gives

$$\begin{aligned} \frac{\partial MB(N;N)}{\partial r} &= 1-(1-\alpha)\frac{1-\theta}{(1-r\theta)^2}, \text{ and} \\ \frac{\partial MB(N+1;N)}{\partial r} &= 1-(1-\alpha)\frac{1-\theta}{(1-r\theta)^2} - (1-\alpha)\frac{\theta(r\theta)^N}{(1-r\theta)^2}\left(N(1-r)(1-r\theta)+\theta r^2-2r+1\right). \end{aligned}$$

To prove the proposition, it suffices to show that for $N \geq 1$, both $MB(N;N)$ and $MB(N+1;N)$ are decreasing in r, provided that $\alpha < \theta/(1+\theta)$ and r is sufficiently large. Consider first $\partial MB(N;N)/\partial r$. It is nonpositive if and only if $r \geq \left(1-\sqrt{(1-\alpha)(1-\theta)}\right)/\theta$. The last expression is less than 1 if and only if $\alpha < \theta$. Consider next $\partial MB(N+1;N)/\partial r$. As $N \geq 1$, it is no more than $1-\left(1-r\theta^2\right)(1-\alpha)(1-\theta)/(1-r\theta)^2$. As $\alpha < \theta/(1+\theta)$, the last expression is nonpositive if and only if $r \geq \left(2-\theta(1-\alpha)(1-\theta)-(1-\theta)\sqrt{(1-\alpha)\left(4+\theta^2(1-\alpha)\right)}\right)/2\theta \equiv \hat{r}$. It is straightforward to verify that $\hat{r}$ is less than 1 provided that $\alpha < \theta/(1+\theta)$. In sum, both $\partial MB(N;N)/\partial r$ and $\partial MB(N+1;N)/\partial r$ are nonpositive for all $N \geq 1$ provided that $r \geq \hat{r}$.

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