Journal of Financial Economics 159 (2024) 103884

Contents lists available at ScienceDirect

Journal of Financial Economics

journal homepage: www.elsevier.com/locate/finec

The short-termism trap: Catering to informed investors with limited horizons[☆]

James Dow[a], Jungsuk Han[b], Francesco Sangiorgi[c,*]

[a] London Business School, Regent's Park, London, NW14SA, United Kingdom
[b] Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul, 08826, Republic of Korea
[c] Frankfurt School of Finance and Management, Adickesallee 32-34, 60322, Frankfurt am Main, Germany

ARTICLE INFO

Dataset link: "The Short-Termism Trap: Catering to Informed Investors with Limited Horizons (Supplementary Data and Code)" (Original data)

JEL classification:
G14
G32
G38

Keywords:
Informational externality
Price informativeness
Myopia
Agency cost
Managerial compensation
Race to the bottom

ABSTRACT

Does the stock market exert short-term pressure on listed firms, do they respond, and is this response value reducing? We show that limited investor horizons indeed have those consequences, as follows. First, informative stock prices increase firm value; in our model, they reduce the agency cost of incentivizing managers. Second, short project maturity improves stock price informativeness by catering to informed investors with short horizons. Third, since informed trading capital is a scarce resource, attracting informed investors cannot increase an individual firm's price informativeness in equilibrium: it simply destroys shareholder value. This "short-termism trap" can potentially destroy up to 100% of the benefits of stock market listing.

1. Introduction

Informative stock prices improve firm value. For example, stock prices can improve managerial contracting (the channel modeled in this paper) or other contracts, guide investment decisions, enable access to finance, and improve governance via activism or acquisitions. So, firms can benefit from going public and having their stock traded by well-informed traders. But traders prefer their positions to make money sooner rather than later: they have short horizons. Under pressure from investor short-termism, firms can make their stock prices more informative by choosing short-term projects that cater to informed traders. However, firms' competition for informed capital can backfire: project choices that are optimal for individual firms can encourage a race to the bottom in which firms all choose projects of excessively short duration. We show that this effect can even be so severe that it destroys 100% of the benefits of going public.

Previous research has established reasons why investors have short horizons (we refer here to hedge funds, pension funds, proprietary traders or any investors that trade based on their own analysis).[1] In our model they may need to liquidate early. Dow et al. (2021) show that investor short-termism emerges endogenously because of capital constraints. More generally, investors may need to demonstrate performance in the short term, they may be subject to margin calls if their trades do not converge, and cost of carry makes long-term

☆ Dimitris Papanikolaou was the editor for this article. We thank the editor and the (anonymous) referee for very helpful comments. We also thank Vikas Agarwal, Laurent Bach, Alvin Chen, Niklas Ekvall, Julian Franks, Mariassunta Giannetti, Denis Gromb, Alexander Guembel, Andrey Malenko, Konstantin Milbradt, Christopher Hennessy, Lin Shen, Günter Strobl, Xavier Vives, and Johan Walden for helpful comments and suggestions. We also thank seminar participants at BI Norwegian Business School, INSEAD, KAIST, London Business School, Stockholm School of Economics, Tilburg University, University of Vienna, Brevan Howard FTG conference, EFA conference, and WFA conference. Han is grateful for the support from the Management Research Institute and the Institute of Finance and Banking at Seoul National University. An earlier version of this paper has been circulated under the title "Stock market efficiency and corporate short-termism".

* Corresponding author.
E-mail addresses: jdow@london.edu (J. Dow), jungsuk.han@snu.ac.kr (J. Han), F.Sangiorgi@fs.de (F. Sangiorgi).

[1] See, for example, Graves and Waddock (1990), Porter (1992), Bushee (1998), Manconi et al. (2012), Cella et al. (2013), Kim et al. (2017), and Von Beschwitz et al. (2022) for relevant discussions and evidence on investor short-termism.

https://doi.org/10.1016/j.jfineco.2024.103884
Received 9 October 2022; Received in revised form 28 May 2024; Accepted 29 May 2024
Available online 14 June 2024

arbitrage uneconomic. Thus, firms whose projects' value is revealed sooner are more attractive to informed investors.

There is also an extensive literature on corporate short-termism. Our paper is different: we do not just demonstrate that firms will take decisions that deliver short-term results by compromising long-term value. Such decisions, after all, are completely natural in contexts where an agent's performance is monitored periodically, and are in general value-creating outcomes given the underlying agency problem. In other words short-term decisions are the equilibrium decisions given a constrained optimal solution to standard formulations of the managerial agency problem. In contrast, in our paper short-termism is dysfunctional because firms' competition (through project selection) for informed trade creates an externality on other firms. Also, our paper features short-termism in the context of publicly-traded companies and stock-based managerial compensation. This is important because much of the public debate on short-termism centres on alleged short-term pressure from the stock market and on stock-based managerial compensation.

To briefly illustrate our point about optimality, consider as an example a firm owner who appoints a manager. If the owner cannot observe managerial effort, it makes sense to sanction the manager if performance targets are not met. Obviously, the manager has an incentive to choose actions that meet the targets by their deadlines, even if other actions are higher NPV but take longer to show positive results. In that sense, the manager is subject to 'short-termist' pressure from the owner. From the owner's perspective, however, imposing performance targets is optimal, even though it distorts managerial decisions. It is second best, i.e., optimal given the information constraint. It is well established in previous literature that short-termism can be second-best (see the literature section of our paper for details). What is less well established, but more important economically, is that there are economic forces causing short-termism to be suboptimal compared to second-best. In this paper, we explain these forces.

We study a model in which firms' shares are traded in a stock market with privately informed investors and uninformed investors. Informed investors have limited capital, modeled by assuming they can only invest one unit. They also have a preference for short-term investments, modeled by assuming they may receive a liquidity shock forcing them to liquidate early. Firms choose projects which are run by managers who are subject to moral hazard. Managers may also need to leave early for exogenous reasons. Stock-based compensation allows firms to implement long-term projects because the stock price in the short term reflects information about the projects' eventual liquidation value.

A firm can make compensation contracts more efficient if it can increase the informativeness of its stock price. Given the project choices made by other firms, an individual firm can do this by reducing its project maturity to attract informed trade. However, informed trading is limited, so the increase in one firm's price informativeness is at the expense of other firms. This externality causes a race to the bottom in which, in equilibrium, project maturity is too short: all firms would have higher value if they coordinated on longer projects. Indeed, in equilibrium, projects may be even shorter duration than if there were no stock-based managerial incentives at all. The race to the bottom in project maturity, and the ensuing loss of value, is what we call the "short-termism trap".

At a high level, our central premise is that informative stock prices are useful to firms. Therefore, firms are under pressure to compete for informed investors, and because informed investors are myopic, firms do this by choosing short-term projects. We model the managerial compensation channel because public debate on short-termism often includes criticism of stock-based managerial incentives. Moreover, market monitoring offers significant value to listed firms. Markets can monitor managers by paying close attention to press conferences, earnings announcements, and financial statements and by conducting their own independent analysis, making share price information a valuable tool for improving managerial incentives.[2] Nevertheless, our analysis is more general in the sense that the short-termism trap can equally arise when informative stock prices add value through other channels, such as managerial learning about project productivity from stock prices.

How quantitatively important is the short-termism trap? Previous literature has established that efficient stock prices add value, which, in our paper, occurs through reducing the cost of the agency problem (the managerial incentive channel). This cost can be large; in general it is much larger than the cost of managerial compensation.[3] In our model the managerial agency problem is turbocharged by the externality in project duration to lead to potentially very large value destruction. We benchmark firm value to the value without a stock market listing and show that the short-termism trap can be so severe that in equilibrium, some firms choose to remain private, while those that choose to list are subject to so much investor pressure that excessively short-term project choice offsets all the value of an informative share price.[4] In other words, while stock market listings can potentially create substantial value through price informativeness, up to 100% of this value can be dissipated by the short-termism trap when investors have sufficiently short horizons (the going-private value creates a floor to firm value, since any firm can opt out of the stock market).

Shocks to the financial system, such as financial crises, can exacerbate investor myopia and hence create substantial value loss. Long-lived investors with limited capital behave as if they have short horizons because of the opportunity cost of holding existing trading positions for long periods instead of reusing capital on new positions (Dow, Han, and Sangiorgi, 2021). This opportunity cost is higher when a shock reduces price efficiency so that trading positions take longer to become profitable. Therefore, shocks that originate in the financial market will, through the short-termism trap, transmit to inefficient real investment. Since Dow et al. (2021) also show that a transitory shock can have long-term effects on efficiency and investor horizons, it follows that via the short-termism trap, the post-financial crisis economy will perform less well than before.

The short-termism trap does not depend on managerial myopia. The cause is investor myopia, but our model also includes the possibility of managerial myopia to allow us to give a richer set of results when comparing project duration to relevant benchmarks. Because investor myopia is the underlying cause of the problem, any collective or regulatory scheme to lengthen managerial horizons (e.g., lengthening option vesting periods) may mitigate, but cannot eliminate the short-termism trap.

We provide several extensions and comparative statics of our model. First, an increase in the number of firms leads to shorter-duration projects because the competition for informed investor capital is more intense. Second, the impact of the agency problem (managers' horizons and cost of effort) is amplified by the externality in project duration. Third, we study the impact of investor horizon. The short-termism trap can be eased when all informed investors exhibit long-term horizons, but this is not the case when investor horizons are diverse. Suppose there are enough investors who never liquidate early. In that case,

[2] There is extensive theoretical literature on the value of market monitoring, pioneered by Holmstrom and Tirole (1993) and discussed in the survey by Bond et al. (2012).

[3] CEO pay is typically small compared to firm value. However, the cost of inducing the manager to take the action that is taken in equilibrium is not a proxy for the cost of the agency problem, except in simple cases such as a binary effort choice by the agent; see Grossman and Hart (1983). In general, the agent's action taken is not the first-best action because that is too expensive or impossible to implement with incentives, so the agency cost of management may be much higher than CEO pay (Holmstrom and Milgrom, 1991).

[4] Of course, in the real world, stock market listings may have other benefits in addition to providing an informative market price (such as adherence to strict disclosure rules). Our point is that the short-termism trap can destroy up to 100% of the value of having a market price.

corporate short-termism is lessened via a clientele equilibrium, where (ex-ante identical) firms divide into two groups: those that opt for short-term projects and attract short-term investors, and those that select long-term projects, thereby drawing long-term investors. By contrast, if long-term investors are below a critical mass, they have no impact on equilibrium short-termism at all. Fourth, a salary cap, often proposed as a mechanism to improve the management of listed companies, may promote short-termism rather than prevent it.

Our baseline model assumes that the value of information is independent of project maturity, but this can be generalized. On the investor side, for example, long-term projects may be more uncertain, so that learning their value could be more valuable. On the firm side, long-term performance metrics may be less informative about managerial effort due to confounding events over the project's lifespan. We explore the impact of some of these effects. Varying the maturity-dependent value of information can either lengthen or shorten project maturity, but there remains an externality in project horizon choice.

Finally, our model also provides some testable empirical predictions. There is ample empirical evidence that stock-based compensation can lead to value-destroying short-termism even though stock prices can improve managerial incentives because they reflect the present value of long-term future cash flows.[5] Our analysis shows that informational externalities in financial markets can change the relation between stock-based compensation and corporate short-termism, and offers several testable implications based on this mechanism.

The paper is organized as follows: In Section 2, we connect our paper to the existing literature. In Section 3, we describe the model setup. In Section 4, we solve for the financial market equilibrium given firms' maturity choices and we solve each firms' optimal managerial compensation and choice of project maturities taking other firms' behavior as given. In Section 5, we describe the equilibrium concept, show existence and uniqueness of equilibrium and we characterize its properties. In Section 6 we study the impact of long-term investors. In Section 7, we study further empirical and policy implications of our model. Section 8 concludes.

2. Literature

There is a large literature on short-termism. This literature identifies two main possible sources of short-termism. First, short-termism could arise because shareholders have short horizons, and want to maximize the share price at the end of their horizon, rather than the value of projects that mature later. This may lead them to encourage managers to choose projects that deliver value quickly, rather than better projects that do not demonstrate their superior value until later.[6] Second, short-termism could arise when managers themselves have short horizons (or higher discount rates) and act in their own interests. If managers own stock or are compensated with a mix of stock and salary, they have an incentive to choose projects that deliver value quickly, rather than better long-term projects (Stein, 1989).[7] In those papers, managerial incentives may not be optimally designed. However, similar outcomes can arise when incentives for managers are designed optimally in response to contracting frictions (Edmans et al., 2012; Varas, 2018). In that case, corporate short-termism is second-best given those contracting constraints.[8] For example, it is easy to see that in many agency problems, optimal incentive schemes will include performance targets and deadlines, specified by the principal, such that the agent must achieve the targets by the deadlines (i.e. failure to do so results in a lower, or even negative, payment to the agent). Such schemes skew the agents choices to achieve short-term performance at the expense of long-term value, but this distortion is by definition optimal given the incentive compatibility constraints of the agency problem. There is no reason to consider this an undesirable outcome, indeed the contrary is true.

Related papers include Bolton et al. (2006) who show that managerial short-termism persists when shareholders optimally induce managers to chase short-term profits to exploit market over-optimism. In Edmans (2009), blockholders' trading on private information causes prices to reflect fundamentals, encouraging managers to invest in valuable long-run projects rather than chasing short-term profits. Thakor (2021) finds that greater noise in performance assessment with long-horizon projects leads to higher agency costs and thus induces a preference for short-termism.

In almost all of this literature on "short termism", however, there is no welfare analysis demonstrating that stock market short-termism is value-reducing. On the contrary, in those papers that permit a welfare analysis, short-termism is second best. There are, however, three exceptions: three papers demonstrate welfare suboptimal short-termism, although via different channels from the stock market. First, Milbradt and Oehmke (2015) study debt financing when long-term projects are more likely to default. In response, firms may shorten project maturity even at the cost of further increasing default risk, initiating a race to the bottom in which firms choose projects of shorter maturities compared to first-best. Second, in Thanassoulis (2013), firms may be willing to tolerate lower value short-term projects in order to reduce the cost of compensating impatient managers. Third, and relatedly, Chemla et al. (2022) study a model where competition among firms to hire managers leads to inefficient overcompensation, and furthermore compensation becomes extremely short due to managerial impatience. Our paper differs from these three papers because we study the role of the stock market in generating inefficiency.

Our paper is also related to the literature on real investment under information asymmetries. Generally, prices in all markets in the economy serve to influence economic decisions, but literature in finance has specifically focused on the feedback effect between an individual firm's investment and its own stock price (e.g., Dow and Rahi, 2003; Bond et al., 2012; Goldstein et al., 2013; Sockin and Xiong, 2015). While producing private information is helpful in guiding investment, the incentives to produce private information are not necessarily optimal. More informative prices may also either help or hinder the allocation of risk (Dow and Rahi, 2003). The market has a strong incentive to concentrate on predicting the payoffs of "no-brainer" projects that are so profitable they will surely be invested in, so the predictions have no social value (Dow et al., 2017). By contrast, our paper studies the real impact of competing firms with endogenous managerial contracting.[9]

[5] See, for example, Bergstresser and Philippon (2006), Gopalan et al. (2014), Asker et al. (2015), and Brochet et al. (2015).

[6] Porter (1992) argues that companies pursue short-term share price appreciation at the expense of the long-term performance due to the pressure from shareholders' short-term interests. For example, Bushee (1998) finds that high ownership by short-horizon investors induces firms' myopic investment. Gaspar et al. (2005) find that firms with short-term shareholders tend to get lower premiums in acquisition bids. Cremers et al. (2020) also find that an increase in ownership by short-horizon investors has an incremental effect on corporate short-termism such as reducing R&D expenses.

[7] For example, empirical evidence shows that shorter CEO horizons reduce investment and lower firm value where horizons are measured by expected tenure (Antia et al., 2010), financial reporting frequency (Kraft et al., 2018), and option vesting periods (Ladika and Sautner, 2020).

[8] This is obvious, in the sense that in any model with just a principal and an agent, the optimal contract is by definition second best.

[9] There are several papers exploring the role of competition with real investment in rather different contexts. In Fishman and Hagerty (1989) prices are useful in improving investment policy so shareholders know they will be able to sell at informative prices, inducing excessive information disclosure as firms' compete for investor attention. Peress (2010) argues that monopolists have more informative prices because their stock prices are sensitive to information, while in competitive industries profits are so low anyway that there are only weak incentives to produce information. Foucault and Frésard

There is a stand of literature following the seminal paper by Holmstrom and Tirole (1993), that studies the effect of stock prices in motivating managers in a model of trading on private information (e.g., Baiman and Verrecchia, 1995; Dow and Gorton, 1997; Kang and Liu, 2010; Strobl, 2014; Lin et al., 2019; Piccolo, 2022). For example, Strobl (2014) shows that shareholders may have an incentive to encourage "overinvestment" (in the first-best sense) in order to make the stock price more informative and improve the managerial agency problem. In Dow and Gorton (1997), prices combine the two roles of guiding investment and motivating managers. In Piccolo (2022), managers choose long- or short-term projects, and the market produces information about the same kind of project; this can lead to multiple equilibria. These papers show the benefits of stock-based compensation. In our paper, we also use an agency framework. Project maturity choice is a key variable, unlike the aforementioned papers, and crucially, we also study the effects of competition among firms for informed trading. This results in socially sub-optimal short-termism, even though each firm's managerial contract and project choice are individually optimal. In other words if there were only one firm in our model, short-termism would be prevented by stock-based compensation. Our model shows that this result is reversed under competition for investors.

3. Setup

Consider a three-period economy ($t = 0, 1, 2$) with a corporate sector and a financial market. The corporate sector consists of firms with a productive technology. Their shares trade in the stock market. The risk-free rate in the economy is normalized to zero.

3.1. Firms

Each firm has risk-neutral shareholders and a risk-averse manager. Initially, we suppose there is a fixed number of listed firms; later, we will endogenize this. Shares of listed firms are traded in the stock market as described in Section 3.2.

There are a total of M firms indexed by $n = 1, \dots, M$, of which a subset of N firms indexed by $n \in \mathcal{N}$ are listed. Shareholders of firm n choose the maturity of its project, $\tau^n \in [0, 1]$, where the project matures early ($t = 1$) with probability $1 - \tau^n$, and late ($t = 2$) with probability τ^n.[10] So if $\tau^n = 0$ the project always matures early, while if $\tau^n = 1$ it always matures late.

When the project matures it generates a payoff which is distributed as a liquidating dividend, given by

$$\begin{aligned} V^n &\equiv f(\tau^n) + R^n \quad \text{where} \\ R^n &= \begin{cases} \Delta V(1+\alpha \mathbf{1}_l) & \text{if the project is successful} \\ 0 & \text{otherwise} \end{cases}, \end{aligned} \tag{1}$$

where $\Delta V > 0, \alpha \geq 0$, and $\mathbf{1}_l$ is an indicator function that equals one if the project pays off late and is equal to zero if the project pays off early. The first component $f(\tau^n)$ is maturity-sensitive and the second component R^n is sensitive to managerial effort (and also to project maturity when $\alpha > 0$). We assume that output rises with longer maturity: $f(\cdot)$ is non-negative, increasing, concave, twice-differentiable with $f'(0) = \infty$ and $f'(1) = 0$.[11]

When $\alpha > 0$, also the volatility of the output increases with project maturity. We initially set $\alpha = 0$ for convenience and discuss the role of this parameter in Section 5.5. Essentially, an $\alpha > 0$ increases the informational advantage of investors with private signals about long-term projects, thereby dampening informed investors' short-term incentives.

Firms choose τ^n's simultaneously. Once all firms make their maturity choices, those choices become publicly observable.

We assume that with probability $\delta \in [0, 1]$ each manager exits the economy early ($t = 1$); this includes the special case $\delta = 0$ where managers are long-lived. Managers have limited liability and an outside option which we normalize to zero for simplicity. Managers' effort choice is private information. We denote by e^n the effort level of firm n's manager which is either H ("high effort") or L ("low effort"). Given effort e^n, the project succeeds with probability $\rho(e^n)$, and fails with probability $1-\rho(e^n)$. Success is independent across firms. If the manager exerts high effort, the project is more likely to succeed:

$$\rho(e^n) = \begin{cases} \rho_H & \text{if } e^n = H \\ \rho_L & \text{if } e^n = L \end{cases},$$

where $\Delta\rho \equiv \rho_H - \rho_L > 0$. The manager's utility given wage w^n and effort choice e^n is

$$u(w^n) - \mathbf{1}(e^n = H)K,$$

where K is the manager's effort cost, and u is an increasing, concave, twice continuously-differentiable function with $u(0) = 0$. We further assume that $u'(0) = \infty$ and $\lim_{w\to\infty} u(w) = \infty$ to ensure a unique and interior solution.[12] We restrict the parameter value of K to be less than the upper bound $\bar{K} \equiv \Delta\sigma u\left(\frac{\Delta\rho\Delta V}{\sigma_H}\right)$ where the parameter σ_H is defined in the next subsection.[13]

Shareholder value of firm n is given by

$$V^n - w^n. \tag{2}$$

Shareholders are long-lived and maximize expected shareholder value by choosing whether to be listed, which project to invest in, and which contract to give to the manager. The cost of incentivizing managers, w^n, is borne by shareholders. In contrast, we refer to V^n as "production" or "final payoff". When we refer to "efficiency", we mean with respect to expected shareholder value, henceforth shareholder value for short.

3.2. The financial market

In the financial market, participants trade shares of listed firms. The shares of firm $n \in \mathcal{N}$ are claims on the firm's final payoff V^n when it realizes. There is no constraint on short sales. There are three types of participants: informed traders, noise traders and market makers.

There is a unit mass of risk-neutral informed investors who either consume early ($t = 1$), with probability γ or late ($t = 2$), with probability $1 - \gamma$. We denote by $\mathcal{I}$ the set of informed investors in the economy.

(2019) argue that firms have an incentive to piggyback on information that is produced about other firms, and this induces them to prefer making products that are not differentiated. In Xiong and Jiang (2022), disclosing managerial compensation contracts induces myopic overinvestment.

[10] Project maturity choices are observable, so it makes no difference whether it is shareholders or the manager that choose τ^n. In Appendix I we consider the case where the choice of τ^n is private information. In this scenario, shareholders offer an incentive compatible compensation contract that specifies the maturity τ^n. The main qualitative property of the optimal contract, i.e., that shareholders' wage bill is increasing in τ^n, is robust to this extension.

[11] Throughout the paper, we use the terms "increasing" as synonymous with "strictly increasing", and "concave" (or "convex") as synonymous with "strictly concave" (or "strictly convex"). The assumption that $f'(0) = \infty$ means the marginal benefit of lengthening maturity is infinity for an extremely short-term project (i.e., $\tau^n = 0$). The assumption that $f'(1) = 0$ means that the marginal benefit of lengthening maturity τ^n is zero when it is an extremely long-term project (i.e., $\tau^n = 1$). Concavity together with these two assumptions is assumed for simplicity to ensure a unique interior solution.

[12] The assumption that $u'(0) = \infty$ rules out a corner solution where no compensation is given to managers even when good information arrives. The assumption that $\lim_{w\to\infty} u(w) = \infty$ prevents the situation where it is impossible to incentivize managers because their effort cost K is too high.

[13] If the effort cost is higher than $\bar{K}$, all firms will choose to implement low effort. See the proof of Theorem 1.

Each informed investor can produce private information about one firm in the initial period, $t = 0$. All the informed investors who investigate firm $n \in \mathcal{N}$ receive an identical signal s^n, which is either good (G) or bad (B). High managerial effort results in a higher probability that informed investors receive a good signal. We denote by σ_e the probability that the signal is good given effort $e \in \{H, L\}$; the signal is good with probability $\sigma_H \equiv pr(s^n = G | e^n = H)$ given high effort, and $\sigma_L \equiv pr(s^n = G | e^n = L)$ given low effort where $\Delta\sigma \equiv \sigma_H - \sigma_L > 0$.

We denote by ν_G and ν_B the posterior probability of a high payoff conditioning on a good and a bad signal, respectively. For simplicity, we assume that the signal is a sufficient statistic for the final payoff.[14] Equivalently, we assume

$$\rho_H = \sigma_H \nu_G + (1-\sigma_H)\nu_B; \qquad \rho_L = \sigma_L \nu_G + (1-\sigma_L)\nu_B. \tag{3}$$

There are long-lived, competitive, risk-neutral market makers who set prices to clear the market given aggregate order flows from informed investors and noise traders as in the standard Kyle (1985) model.

The noise traders trade for exogenous reasons such as liquidity needs. As in the case of informed investors, noise traders also consume early or late (with probability γ and $1-\gamma$, respectively). We denote $x_i^n(t)$ the market order of informed investor i in stock $n \in \mathcal{N}$ at time $t = 0, 1$. In the initial period, $t = 0$, noise traders submit order flow z^n in aggregate for each stock n, which follow an i.i.d. uniform distribution on $[-\bar{z}, \bar{z}]$. The parameter $\bar{z}$ captures the intensity of noise in the financial market. Next period, at $t = 1$, those who got liquidity shocks (i.e., γ fraction) reverse their orders. Consequently, they submit $-\gamma z^n$ for each stock n at $t = 1$.

In each period ($t = 0, 1$) market makers observe aggregate order flow for each stock $n \in \mathcal{N}$ such that

$$X^n(t) = \int_{i \in \mathcal{I}} x_i^n(t) di + Z^n(t),$$

where $Z^n(0) = z^n$ and $Z^n(1) = -\gamma z^n$.

In our model, informed trading is a scarce resource in the economy.[15] To this end, we make the following assumptions. First, we assume that $M\bar{z}$ (the total noise trading intensity) is greater than one (the maximum possible size of the informed investors' total order flow). This ensures that the given mass of informed investors cannot fully reveal the signal for every firm.[16]

Second, we assume that each informed investor can hold at most one unit of one stock (either a long or short position).[17] Informed investor i in firm $n \in \mathcal{N}$ can submit a market order $x_i^n(0) \in \{-1, 0, 1\}$ at $t = 0$. If $x_i^n(0) \in \{-1, 1\}$ and firm n liquidates late, informed investor i can reverse their position in $t = 1$, or, if they consume late, hold it until $t = 2$. If $x_i^n(0) = 0$ and firm n liquidates late and informed investor i consumes late, they can submit an order $x_i^n(1) \in \{-1, 0, 1\}$ at $t = 1$.

In addition, we assume that

$$\bar{z} < \frac{1}{\gamma(M-1)}, \tag{4}$$

which ensures that the ratio of noise per unit of informed investors is sufficiently small that for each listed firm, there are enough informed investors that some of them will choose its stock so that it will have positive price informativeness, regardless of other firms' choices (see the proof of Proposition 1). Furthermore, we assume that

$$\left(\frac{1}{\bar{z}} - 1\right)(1-\gamma) \geq 1, \tag{5}$$

which is a sufficient condition for establishing that listed firms' maturity choices are strategic complements (see Proposition 4).[18]

Finally, we assume that all exogenous random variables in our model are jointly independent.

4. Optimal choice

4.1. Investor trades and stock prices

In this subsection, we derive price informativeness of stocks in the financial market by solving informed investors' and market makers' problems. For this, we assume that all managers of listed firms exert effort. In equilibrium, this is true, as firms whose managers exert low effort have nothing to gain from listing.[19]

Because market makers are competitive and risk neutral, the price of each security is its expected liquidation value conditional on market makers' information: the price of stock $n \in \mathcal{N}$ in each period ($t = 0, 1$) is given by

$$P^n(t) = \mathrm{E}\left[V^n \middle| \mathcal{F}(t)\right], \tag{6}$$

where $\mathcal{F}(t)$ is the market makers' information in period t.

Prices are either fully-revealing or non-revealing due to the assumption of uniformly-distributed noise trading. The reason, in brief, is as follows—see, for example, Dow et al. (2021) for a more detailed discussion. If the order flow is large enough (in absolute value, whether buy or sell) then it must imply that both informed investors and noise traders traded in the same direction, so it is fully revealing. But if the absolute value of order flow is smaller than the threshold value at which full revelation occurs, then it could have resulted from either informed investors buying and noise traders selling, or vice versa. Because noise trading is uniformly distributed, any level of the order flow is equally likely regardless of whether arbitrageurs are buying or selling, so it is completely non-revealing.

We denote P_G^n and P_B^n to be the fully-revealing price for good or bad signal, respectively. We also denote $P_\emptyset^n$ to be the non-revealing price. We denote λ^n to be the probability of information revelation for stock n, which we refer to as the price informativeness of stock n.

We can now show the following result:

Lemma 1. *If μ^n mass of informed investors trade on private information on stock $n \in \mathcal{N}$, the price of stock n in the initial period, $t = 0$, is given by*

$$P^n(0) = \begin{cases} P_B^n & if \ -\mu^n - \bar{z} \leq X^n(0) < \mu^n - \bar{z} \\ P_\emptyset^n & if \ \mu^n - \bar{z} \leq X^n(0) \leq -\mu^n + \bar{z} \\ P_G^n & if \ -\mu^n + \bar{z} < X^n(0) \leq \mu^n + \bar{z}, \end{cases} \tag{7}$$

[14] More formally, s^n is a sufficient statistic for (s^n, R^n) if the posterior distribution of e^n conditional on (s^n, R^n) only depends on s^n; see, for example, Chapter 9 in DeGroot (1970). The conditions in Eq. (3) are equivalent to $Pr(R^n|s^n, e^n) = Pr(R^n|s^n)$ because

$$Pr(R^n|e^n) = \sum_{s^n \in \{G,B\}} Pr(R^n|s^n, e^n) Pr(s^n|e^n) = \sum_{s^n \in \{G,B\}} Pr(R^n|s^n) Pr(s^n|e^n).$$

Then, it is immediate that the condition $Pr(R^n|s^n, e^n) = Pr(R^n|s^n)$ is in turn equivalent to the condition that s^n is a sufficient statistic because Bayes' Rule implies

$$Pr(e^n|s^n, R^n) = \frac{Pr(R^n|s^n, e^n) Pr(e^n|s^n)}{Pr(R^n|s^n)} = Pr(e^n|s^n).$$

The sufficient statistic assumption in agency theory is introduced in Holmstrom (1979) or Shavell (1979); for a textbook discussion with discrete signals see Tirole (2006).

[15] While we assume the number of informed traders to be fixed, our main results would go through if the supply of informed trade were elastic, but not perfectly elastic, as discussed in Section 5.

[16] If $M\bar{z}$ is small relative to the mass of informed investors, the economy trivially degenerates to one with fully-revealing prices for every firm.

[17] Because informed investors are risk-neutral, they will choose the maximum amount of trading even though they are allowed to trade less than one unit.

[18] Lemma C.8 in Appendix C shows that a sufficient condition alternative to Eq. (5) is that the manager has CRRA utility with relative risk aversion close to one.

[19] Firms that implement low effort are indifferent between listing and not listing, and we assume they do not list. This choice would be strictly optimal in the presence of any arbitrarily small listing cost.

where

$$P_B^n = f(\tau^n) + \nu_B \Delta V, \quad P_\emptyset^n = f(\tau^n) + \rho_H \Delta V, \quad P_G^n = f(\tau^n) + \nu_G \Delta V,$$

and the probability of information revelation (i.e. the price informativeness) for stock n in the initial period, $t = 0$, is given by[20]

$$\lambda^n(0) = \frac{\mu^n}{\bar{z}}. \tag{8}$$

Proof. See Appendix A. ■

Given informed investor i's choice to produce information on stock n, we can represent the maximization problem as follows:

$$J_0^n \equiv \sigma_H J_0^n(s^n = G) + (1 - \sigma_H) J_0^n(s^n = B), \tag{9}$$

where $J_0^n(s^n)$ is the expected value of trading stock n given signal s^n at $t = 0$:

$$J_0^n(s^n) \equiv \max_{x_i^n(0) \in \{-1,0,1\}} - E[P^n(0)|s^n] x_i^n(0) + \gamma \Gamma^n(s^n) x_i^n(0) + (1-\gamma) \mathrm{E}[J_1^n(x_i^n(0), s^n, P^n(0))|s^n],$$

and $\Gamma^n(s^n)$ is the expected value of an early-liquidated unit of position in stock n conditional on s^n:

$$\Gamma^n(s^n) \equiv (1 - \tau^n)\mathrm{E}[V^n|s^n] + \tau^n \mathrm{E}[P^n(1)|s^n] x_i^n(0),$$

and $J_1^n(x_i^n, s^n, P^n(0))$ is the expected continuation value at $t = 1$ for a late consumer given the position x_i^n in the previous period and conditional on s^n and $P^n(0)$:

$$J_1^n(x_i^n, s^n, P^n(0)) \equiv (1 - \tau^n)\mathrm{E}[V^n|s^n] x_i^n + \tau^n \left\{ \max_{x_i^n(1) \in \{-1,0,1\}, |x_i^n + x_i^n(1)| \le 1} \mathrm{E}\left[V^n(x_i^n + x_i^n(1)) - P^n(1) x_i^n(1) | s^n, P^n(0)\right] \right\}.$$

In case the informed investor waits one period (i.e., $x_i^n(0) = 0$), they will trade in $t = 1$ only if the firm' project pays off late (with probability τ^n) and if $P^n(0)$ is non-revealing. On the other hand, the continuation value of a non-zero position x_i^n in $t = 0$ is simply $\mathrm{E}[V^n|s^n] x_i^n$.[21]

The next lemma shows that the problem can be greatly simplified: first, all informed investors choose to trade at $t = 0$; second, the value function reduces to a much simpler expression; and third, the price at $t = 1$ does not contain additional information because there is no further informed trading.[22]

Lemma 2. *Each informed investor i who receives signal s^n on stock $n \in \mathcal{N}$ always finds it optimal to trade at $t = 0$. The expected value of trading stock n in Eq. (9) is equal to*

$$J_0^n = (1 - \lambda^n(0))(1 - \gamma\tau^n)\Delta P, \tag{10}$$

where ΔP is the expected mispricing wedge such that

$$\Delta P \equiv \left[\sigma_H(\nu_G - \rho_H) + (1 - \sigma_H)(\rho_H - \nu_B)\right] \Delta V.$$

Further, the price next period, $t = 1$, does not reveal further information, i.e., $\lambda^n(1) = 0$.

Proof. See Appendix A. ■

Because the stock market is only informative in the initial period, $t = 0$, we suppress dependence of $\lambda^n(t)$ on period t; henceforth, we denote firm n's price informativeness at $t = 0$ by λ^n instead of $\lambda^n(0)$.[23]

Now, we move on to the choice of information acquisition at $t = 0$. The expected trading gains on each stock, as expressed in Eq. (10), should be equalized across all listed stocks in equilibrium. If they were different, all informed investors would instead gather private information only on those with higher expected trading gains. That is, the indifference condition $J_0^n = J_0^m$ must be satisfied for any pair of stocks $m, n \in \mathcal{N}$, or equivalently,[24]

$$(1 - \lambda^n)(1 - \gamma\tau^n) = (1 - \lambda^m)(1 - \gamma\tau^m), \tag{11}$$

which describes the equilibrium trade-off between mispricing and duration. Informed investors like mispricing but dislike longer duration; so an increase in duration must be compensated for by an increase in mispricing, and vice versa.

Furthermore, because there is one unit mass of informed investors ($\sum_{n\in\mathcal{N}} \mu^n = 1$), we also have the following condition in equilibrium, which we call the informational resource constraint:

$$\sum_{n\in\mathcal{N}} \lambda^n = \frac{1}{\bar{z}}. \tag{12}$$

Using the results so far, we can show that, given maturity choices, there is a unique allocation of information acquisition that satisfies the two constraints.

Proposition 1 (*Financial Market Equilibrium*). *Given $\{\tau^n\}_{n\in\mathcal{N}}$, there exists a unique positive solution $\{\lambda^n\}_{n\in\mathcal{N}}$ that satisfies both the indifference condition Eq. (11) and the informational resource constraint Eq. (12). Furthermore, λ^n is decreasing and concave in τ^n, and is increasing in τ^m for $m \in \mathcal{N} \setminus \{n\}$.*

Proof. See Appendix A. ■

[20] In the general case, the notation for price informativeness should be

$$\lambda^n(0) = \min\left(\frac{\mu^n}{\bar{z}}, 1\right).$$

If $\mu^n \ge \bar{z}$ (the mass of informed investors who have private information on stock n is greater than the intensity of noise trading), $\lambda^n(0)$ is equal to one. But such case never arises in equilibrium because it would be incompatible with informed investors' incentives, as is clear from *Proposition* 1. Therefore, we use the notation in Eq. (8) for convenience.

[21] If the firm' project pays off late and $P^n(0)$ is non-revealing, the informed investor could close the position early in $t = 1$ instead of holding it until $t = 2$. However, the proof of Lemma 2 shows that closing the position early is never optimal.

[22] Because informed investors are constrained and choose to trade at $t = 0$, they are not able to engage in extra informed trading in the subsequent period ($t = 1$); they either already hold maximum positions if information is unrevealed, or do not have any informational advantage otherwise. Consequently, only those with liquidity shocks reverse their positions, thus, prices do not contain additional information at $t = 1$.

[23] In real life, prices may be informative every period adding more information over time, but we shut down the channel of this secondary information revelation for simplicity. Under the setup where prices are informative in each period, higher price efficiency creates two confounding effects. On the one hand, higher price efficiency reduces trading benefits by lowering the chance of acquiring the position at dislocated prices. On the other hand, higher price efficiency increases trading benefits by reducing the maturity of investment due to faster convergence of prices to fundamental value. In our paper, we focus on the former effect by shutting down the latter effect because we are interested in exploring competition for informed trading among firms. See Dow et al. (2021) for the analysis on this trade-off.

[24] This is analogous to the indifference condition for informed investors in Dow et al. (2021), where informed investors' preference for shorter duration arises from the opportunity cost of capital. The difference is that here, informed investors prefer shorter horizons due to the possibility of early liquidation. A similar condition arises in Shleifer and Vishny (1990), but with exogenous duration and in a model without private signals.

The proposition shows that, fixing other listed firms' maturity choices, a listed firm's price informativeness increases as the firm shortens its own maturity due to investors' preference for shorter maturities. Furthermore, there is a spillover effect because a decrease in one firm's maturity decreases other firms' price informativeness. Because the mass of informed investors is limited, firms compete for price informativeness.

4.2. Listed firms' optimal managerial compensation

In this subsection, we derive the optimal managerial compensation contract of each listed firm. In case the price reveals the signal of informed investors, managerial compensation depends only on the signal because it is a sufficient statistic for the final payoff (see, for example, Holmstrom, 1979; Shavell, 1979). In case the price does not reveal the signal, managerial compensation depends on the final payoff whenever possible (either because the manager remains until $t = 2$, or the manager exits at $t = 1$ and the firm's project also matures at $t = 1$).

Hence, there are only five states relevant for the contract: (i) the price reveals the signal to be good ($\omega = G$), (ii) the price reveals the signal to be bad ($\omega = B$), (iii) the price is non-revealing and the manager stays until a successful outcome ($\omega = S$), (iv) the price is non-revealing and the manager stays until an unsuccessful outcome ($\omega = F$), (v) the price is non-revealing and the manager exits before the outcome is realized ($\omega = \emptyset$). A contract will therefore specify non-negative payments corresponding to each of those five states $\left\{ w_G^n, w_B^n, w_S^n, w_F^n, w_\emptyset^n \right\}$ (we will show that three of these payments must optimally be set to zero).

Consider firm $n \in \mathcal{N}$ offering a contract to its manager that induces high managerial effort. We solve the optimal contracting problem taking maturity choice τ^n and price efficiency λ^n as given. The shareholders' wage bill, denoted by $\mathrm{E}\left[w^n\right]$, is given by

$$\begin{aligned} \mathrm{E}\left[w^n\right] = {} & \lambda^n \left(\sigma_H w_G^n + \left(1-\sigma_H\right) w_B^n\right) \\ & + \left(1-\lambda^n\right)\left[\left(1-\delta\tau^n\right)\left(\rho_H w_S^n + \left(1-\rho_H\right) w_F^n\right) + \delta\tau^n w_\emptyset^n\right]. \end{aligned} \tag{13}$$

An optimal contract $\{w_G^{*n}, w_B^{*n}, w_S^{*n}, w_F^{*n}, w_\emptyset^{*n}\}$ solves the following optimization problem that minimizes the shareholders' wage bill:

$$\mathcal{W}^n(\tau^n) \equiv \min_{\{w_G^n, w_B^n, w_S^n, w_F^n, w_\emptyset^n\}} \mathrm{E}\left[w^n\right], \tag{14}$$

subject to (i) the manager's participation constraint (PC):

$$\left\{ \begin{array}{c} \lambda^n[\sigma_H u\left(w_G^n\right) + \left(1-\sigma_H\right) u\left(w_B^n\right)] \\ +\left(1-\lambda^n\right)\left[\left(1-\delta\tau^n\right)\left(\rho_H u\left(w_S^n\right) + \left(1-\rho_H\right) u\left(w_F^n\right)\right) + \delta\tau^n u(w_\emptyset^n)\right] \end{array} \right\} \geq K, \tag{15}$$

and (ii) the manager's incentive compatibility constraint (IC):

$$\lambda^n \Delta\sigma \left(u\left(w_G^n\right) - u\left(w_B^n\right)\right) + \left(1-\lambda^n\right)\left(1-\delta\tau^n\right)\Delta\rho\left(u\left(w_S^n\right) - u\left(w_F^n\right)\right) \geq K, \tag{16}$$

and (iii) the limited liability constraint (LL):

$$w_G^n, w_B^n, w_S^n, w_F^n, w_\emptyset^n \geq 0. \tag{17}$$

The solution to the optimization problem in Eqs. (14)–(17) is described by:

Proposition 2 (*Optimal Managerial Contract for Listed Firms*)**.** *Given τ^n, where $n \in \mathcal{N}$, there exists a unique optimal contract. For this contract, $w_B^{*n} = w_F^{*n} = w_\emptyset^{*n} = 0$ and $w_G^{*n} > w_S^{*n} > 0$ where w_G^{*n} and w_S^{*n} simultaneously solve*

$$\lambda^n \Delta\sigma u\left(w_G^{*n}\right) + \left(1-\lambda^n\right)\left(1-\delta\tau^{*n}\right)\Delta\rho u\left(w_S^{*n}\right) = K \tag{18}$$

$$\sigma_H \Delta\rho u'(w_S^{*n}) = \Delta\sigma\rho_H u'(w_G^{*n}). \tag{19}$$

Furthermore, the shareholders' wage bill $\mathcal{W}^n$ is increasing and convex in τ^n, and its first-order derivative is given by

$$\begin{aligned} \frac{\partial\mathcal{W}^n}{\partial\tau^n} = {} & \frac{\partial\lambda^n}{\partial\tau^n}\left[\sigma_H\Psi(w_G^{*n}) - \rho_H\left(1-\delta\tau^n\right)\Psi(w_S^{*n})\right] \\ & - \left(1-\lambda^n\right)\delta\rho_H\Psi(w_S^{*n}) > 0, \end{aligned} \tag{20}$$

where $\Psi(\cdot)$ is a negative, decreasing, weakly concave function such that

$$\Psi(w) \equiv w - \frac{u(w)}{u'(w)}.$$

Proof. See Appendix B. ■

Together, Propositions 1 and 2 show that firms with shorter maturity anticipate a lower agency cost. The optimal compensation in state $\omega = G$ and $\omega = S$ is determined by Eqs. (18)–(19), where Eq. (18) is the IC constraint, and Eq. (19) is the optimality condition that equates the marginal costs across the two states. The RHS of Eq. (20) represents the marginal effect on the wage bill of increased project maturity. The first term is due to the impact of decreased price informativeness (decreased λ^n from the increase in τ^n due to Proposition 1). This effect is positive because it is more costly for shareholders to provide incentives when the price is less informative. The second term is due to the manager's impatience in case of positive δ. This effect is also positive because it is more costly for shareholders to provide incentives with later payments when the manager may exit early.

4.3. Listed firms' choice of project maturity

In this subsection, we solve each listed firm's maturity choice problem, given endogenous price informativeness, as derived in Section 4.1, and the optimal contract, as derived in Section 4.2.

Recall that each firm's production function is increasing in project maturity (Eq. (1)). In financial market equilibrium, price informativeness increases as the firm shortens its project maturity (Proposition 1); informed investors are willing to accept lower speculative profits at shorter maturities because the possibility of a liquidity shock makes them prefer short-horizon stocks. Also, the optimal managerial contract has a lower wage bill at shorter project maturities (Proposition 2).

By the previous results, we can represent the optimization problem of the firm's shareholders in Eq. (2) as

$$\max_{\tau^n \in [0,1]} \mathcal{V}^n(\tau^n) - \mathcal{W}^n(\tau^n), \tag{21}$$

where $\mathcal{V}^n(\tau^n)$ is the expected value of the final payoff given high managerial effort and maturity choice τ^n as in Eq. (1):

$$\mathcal{V}^n(\tau^n) \equiv f(\tau^n) + \rho_H \Delta V,$$

and $\mathcal{W}^n(\tau^n)$ is the wage bill under the optimal contract given τ^n as defined in Eq. (14).

We can now show that there exists a unique choice of project duration that maximizes shareholder value. This choice is determined by the trade-off between production efficiency and agency costs.

Proposition 3 (*Optimal Maturity Choice*)**.** *Given the choices of other firms' project duration $\{\tau^m\}_{m\in\mathcal{N}\setminus\{n\}}$, there exists a unique interior solution τ^{*n} for each firm's project duration that solves in the optimization problem in Eq. (21). Furthermore, τ^{*n} solves*

$$f'(\tau^{*n}) = \frac{\partial\lambda^n}{\partial\tau^n}\left[\sigma_H\Psi(w_G^{*n}) - \rho_H\left(1-\delta\tau^{*n}\right)\Psi(w_S^{*n})\right] - \left(1-\lambda^n\right)\delta\rho_H\Psi(w_S^{*n}), \tag{22}$$

where w_G^{*n} and w_S^{*n} simultaneously solve:

$$\lambda^n \Delta\sigma u\left(w_G^{*n}\right) + \left(1-\lambda^n\right)\left(1-\delta\tau^{*n}\right)\Delta\rho u\left(w_S^{*n}\right) = K$$

$$\sigma_H \Delta\rho u'(w_S^{*n}) = \Delta\sigma\rho_H u'(w_G^{*n}).$$

The shareholder value for firm $n \in \mathcal{N}$ is given by

$$S^{*n} \equiv f(\tau^{*n}) + \rho_H \Delta V - \left[\lambda^n \sigma_H w_G^{*n} + (1-\lambda^n)\left(1-\delta\tau^{*n}\right)\rho_H w_S^{*n}\right]. \tag{23}$$

Proof. See Appendix C. ■

Eq. (22) is the first-order condition for the optimization problem (derived from Eqs. (1) and (20)), whose LHS is the marginal change in the firm's production, and the RHS is the marginal change in the expected cost of compensation. Note that we suppress dependence of λ^n, w_G^{*n} and w_H^{*n} on τ^{*n} to save on notation.

How does a firm's maturity choice affect other firms? The next proposition provides the answer:

Proposition 4 (*Strategic Complementarity*). *A firm's optimal maturity choice τ^{*n} in Proposition 3 is increasing in other firms' maturity choices, that is,*

$$\frac{\partial \tau^{*n}}{\partial \tau^m} > 0 \quad \text{for all } m \in \mathcal{N} \setminus \{n\}.$$

The proposition establishes that firms' maturity choices are strategic complements:[25] when one firm chooses a shorter maturity project, the other firms want to do the same. Intuitively, when a firm shortens its project maturity, it increases its price informativeness at the expense of other firms' price informativeness (Proposition 1). Thus, other firms' agency cost goes up, increasing their marginal benefit of shortening project maturity to regain price informativeness.

4.4. Unlisted firms and the listing decision

In equilibrium, all managers of unlisted firms exert low effort because a firm that decides to implement high effort can improve value by listing and using the stock price as an informative signal of managerial effort in the compensation contract.

Unlisted firms do not need to provide incentives, so they choose long-term projects ($\tau = 1$) and obtain high value with probability ρ_L. Therefore, shareholder value for unlisted firms, denoted S^U, is

$$S^U \equiv f(1) + \rho_L \Delta V. \tag{24}$$

A firm's listing choice is based on the comparison between S^{*n} in Eq. (23) and S^U in Eq. (24), taking all other firms' choices as given. Thus, listing is optimal for firm $n \in \mathcal{N}$ if $S^{*n} \geq S^U$, and not listing is optimal if $S^U \geq S^{*n}$ (in this case S^{*n} is shareholder value if the firm were to list). This includes the possibility that firms are indifferent. When analyzing this case, we ignore the integer constraint on the number of firms and consider it a continuous variable for analytical simplicity.[26]

5. Equilibrium

This section describes the equilibrium concept, shows equilibrium existence, and characterizes equilibrium properties.

5.1. Definition and existence

We define equilibrium as follows:[27]

Definition 1. An equilibrium consists of a number N of listed firms, project maturity choices $\{\tau^n\}_{n\in\mathcal{N}}$, price informativeness $\{\lambda^n\}_{n\in\mathcal{N}}$, and compensation contracts $\{w^n\}_{n\in\mathcal{N}}$ such that,

1. Given the choices of other firms $\{\tau^m\}_{m\in\mathcal{N}\setminus\{n\}}$, shareholders of each firm $n \in \mathcal{N}$ choose maturity τ^n to maximize the firm value in Eq. (21).
2. Given $\{\tau^n\}_{n\in\mathcal{N}}$, price informativeness $\{\lambda^n\}_{n\in\mathcal{N}}$ satisfies the indifference condition Eq. (11) and the informational resource constraint Eq. (12).
3. Given τ^n and λ^n, shareholders of each firm $n \in \mathcal{N}$ choose contract w^n to minimize the expected cost of managerial compensation in Eq. (14).
4. Firms' listing decisions are optimal as described in Section 4.4.

We focus on pure strategy equilibria for our analysis.[28] In case some firms remain unlisted, consider listed firms only. Because their payoff functions are symmetric and their best responses are increasing in project duration (Proposition 4), any pure strategy equilibrium must feature symmetric maturity choices among listed firms. Then price informativeness should be identical across all listed firms due to the indifference condition Eq. (11); the informational resource constraint Eq. (12) therefore implies that price informativeness should be equal to

$$\lambda^n = \frac{1}{N\bar{z}} \quad \text{for all } n \in \mathcal{N}. \tag{25}$$

If an individual listed firm increases its project maturity, it loses informed investors and its price informativeness decreases, as shown in Proposition 1, i.e., $\partial\lambda^n/\partial\tau^n < 0$ for all $n \in \mathcal{N}$. However, if all listed firms do so by the same quantity, there is no change to informativeness because the total mass of informed investors is fixed (Eq. (25)); attracting informed trade is a zero-sum game.[29]

Consider any individual firm $n \in \mathcal{N}$ choosing its level of maturity τ^n when all other listed firms choose the same maturity τ^*. If $\tau^n = \tau^*$ satisfies the first-order condition in Eq. (22), τ^* is an equilibrium maturity choice. We can show that such an equilibrium τ^* exists, is unique, and is interior.

Theorem 1. *There exists a unique equilibrium. There is a critical value γ^* for investor short-termism such that all firms list if $\gamma \leq \gamma^*$, whereas some firms remain unlisted otherwise. The equilibrium project maturity choice for listed firms is symmetric and interior, and satisfies*

$$f'(\tau^*) = \Theta(\tau^*)\left[\sigma_H \Psi(w_G^*) - \rho_H\left(1-\delta\tau^*\right)\Psi(w_S^*)\right] - \left(1-\frac{1}{N\bar{z}}\right)\delta\rho_H\Psi(w_S^*), \tag{26}$$

where $\Theta(\tau^*)$, the sensitivity of price informativeness to project maturity, is given by

$$\Theta(\tau^*) \equiv -\frac{\gamma(N-1)(N\bar{z}-1)}{N^2\bar{z}(1-\gamma\tau^*)} < 0, \tag{27}$$

and w_G^* and w_S^* simultaneously solve

$$\frac{1}{N\bar{z}}\Delta\sigma u\left(w_G^*\right) + \left(1-\frac{1}{N\bar{z}}\right)\left(1-\delta\tau^*\right)\Delta\rho u\left(w_S^*\right) = K \tag{28}$$

$$\sigma_H \Delta\rho u'(w_S^*) = \Delta\sigma\rho_H u'(w_G^*). \tag{29}$$

Shareholder value for each firm is given by

$$S^* \equiv f(\tau^*) + \rho_H \Delta V - \left[\frac{1}{N\bar{z}}\sigma_H w_G^* + \left(1-\frac{1}{N\bar{z}}\right)\left(1-\delta\tau^*\right)\rho_H w_S^*\right]. \tag{30}$$

---

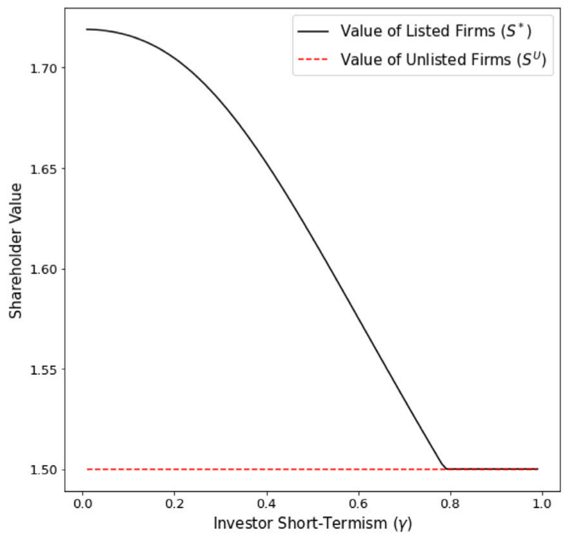
[25] The proof of Proposition 4 shows that the game played by firms at the maturity choice stage is a supermodular game, i.e., a game of strategic complementarities (Topkis, 1998). In a supermodular game, best responses are increasing.

[26] This simplifying assumption is prevalent in the economics literature (e.g., Perry, 1984; Dye, 1993; Harris and Raviv, 2008).

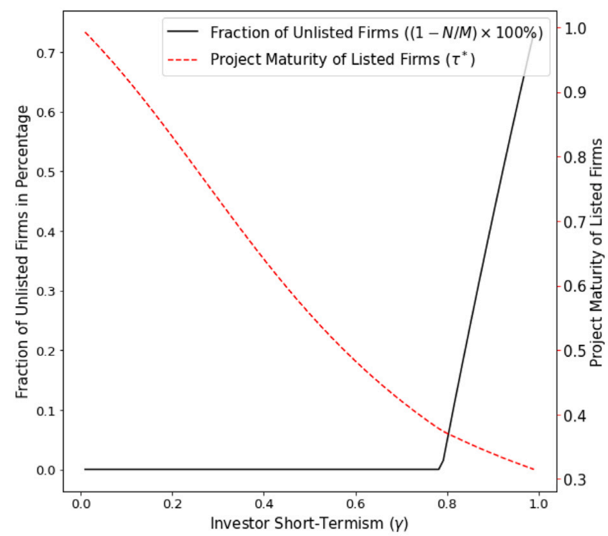
[27] Although they are determined as part of equilibrium, we drop some less important ingredients for brevity in Definition 1. For example, realizations of prices and order flows are not needed because only price informativeness matters for the equilibrium choice of project maturities.

[28] Echenique and Edlin (2004) show that when a game with strategic complementarities has mixed strategy equilibria, these equilibria are unstable. This justifies our focus on pure strategy equilibria.

[29] Strictly speaking, since the payoffs are not fixed in total, the game itself is not zero-sum, but the amount of informed trade is fixed so intuitively, if we regard informed trade as the reward, it is a zero sum game.



(a) Shareholder Value



(b) Project Maturity and Fraction of Unlisted Firms

Fig. 1. The Impact of Investor Short-Termism on Equilibrium Shareholder Value and Listing Decisions. Parameter values: $\rho_H = 0.4; \sigma_H = 0.85; \Delta\rho = 0.35; \Delta\sigma = 0.8; M = 10; \bar{z} = 1/9; K = 1; \delta = 0; \Delta V = 10$. The maturity-sensitive component of a firm's output is $f(\tau) = \sqrt{1-(1-\tau)^2}$, and the utility of a manager given wage w is $u(w) = w^{1-\alpha}$ with $\alpha = 0.8$.

Proof. See Appendix D. ■

Whether firms list depends on the value of market monitoring that comes from an informative share price. For $\gamma \leq \gamma^*$, all firms opt for listing, and the equilibrium shareholder value S^* exceeds S^U (the value of unlisted firms in Eq. (24)). Fig. 1 provides an illustration. The incremental value $S^* - S^U$, resulting from listing, illustrates the benefits of market monitoring: informative stock prices enable firms to provide better incentives and implement the high level of managerial effort, thereby increasing firm value.[30]

However, the short-termism trap can destroy this value. As investor short-termism intensifies (γ increases), S^* falls due to heightened competition among firms for price informativeness, as illustrated in the left panel of Fig. 1 . Once investor short-termism exceeds γ^*, as illustrated in the right panel of Fig. 1, some firms choose to remain unlisted; in equilibrium firms are indifferent between listing or not, so equilibrium shareholder value equals S^U. In other words, when $\gamma > \gamma^*$, the short-termism trap completely nullifies the value of market monitoring. This is because listed firms are subjected to such intense investor pressure that they choose excessively short-term projects to an extent that offsets all the incentive benefits of an informative share price.

Intuitively, the critical value for investor short-termism γ^* depends on the intensity of the agency problem which, fixing other parameters, can be quantified through the managerial effort cost K. γ^* is less than one only if K is sufficiently large.[31]

[30] More generally, we can define the value of market monitoring as the difference between S^* and the greater out of the unlisted value (low effort), and the value if firms were forced to implement high effort without relying on an informative share price, which we define in Section 5.2.1 and denote S^{EP} (Eq. (33)). Thus, the value of market monitoring equals $S^* - \max\{S^U, S^{EP}\}$. For the parameter values in Fig. 1, market monitoring is necessary to implement the high level of managerial effort, that is, $S^U > S^{EP}$.

[31] In the proof of the theorem, we establish two values K_1, K_2, such that $0 < K_1 < K_2 < \bar{K}$. If K is less than or equal to K_1, $\gamma^* = 1$ and all firms decide to list. For K between K_1 and K_2, $\gamma^* \in (0,1)$ and, therefore, some firms opt to stay unlisted at sufficiently high γ values. If K exceeds K_2, some firms remain unlisted for all γ values.

5.2. Benchmark cases

We study two benchmark cases: (i) firms must induce high effort without stock market prices, (ii) a coordinated benchmark where listed firms coordinate their project maturity choices. To have a more interesting comparison, we focus on parameter values where managers are impatient ($\delta > 0$).[32] Existence and uniqueness of equilibrium as well as the equilibrium characteristics can be trivially proven as special cases of Theorem 1.

5.2.1. High effort without price

Suppose that firms could only use the final payoff to incentivize managers to exert high effort, without using the share price. We call this the "effort without price" benchmark. Note that this is not an equilibrium of our model and differs from the unlisted value in equilibrium, in case some firms choose to remain unlisted, because firms only choose to remain unlisted if they decide not to induce high effort.

In this benchmark, each firm's maturity choice τ^{EP} should satisfy the first-order condition in Eq. (22) assuming $\lambda^n = 0$ and $\partial\lambda^n/\partial\tau^n = 0$, which is equivalent to

$$f'(\tau^{EP}) = -\delta\rho_H \Psi(w_S^{EP}), \tag{31}$$

where w_S^{EP} solves

$$(1 - \delta\tau^{EP})\Delta\rho u\left(w_S^{EP}\right) = K. \tag{32}$$

The shareholder value for each firm is given by

$$S^{EP} \equiv f(\tau^{EP}) + \rho_H \Delta V - \left(1 - \delta\tau^{EP}\right)\rho_H w_S^{EP}. \tag{33}$$

To understand how this benchmark differs from the situation where some firms choose to remain unlisted in equilibrium, consider the following comparison. If effort cost is low enough, all firms will choose to

[32] Without impatience ($\delta = 0$), in the cases of both benchmarks, firms will choose the maximal maturity $\tau^n = 1$ because reducing τ to provide early compensation does not improve the manager's utility, hence does not reduce the wage bill. Note that our main message, that there is a race to the bottom in project duration, remains robust when managers are long-lived; however, the comparison to the benchmarks is not as rich.

list in equilibrium, and the effort without price benchmark corresponds to forcing firms to remain unlisted, in which case they would want to induce effort anyway using only the final payoff. If effort cost is higher, the effort without price benchmark corresponds to forcing firms to be unlisted and induce high effort (even though, given that they cannot list, they would prefer to implement low effort).[33]

5.2.2. Coordinated project maturity choice benchmark

We also consider a benchmark where listed firms coordinate their project maturity choices. This internalizes the externality of project maturity on other firms and, in this sense, provides a natural constrained-efficient benchmark.[34] In this benchmark, project maturity is chosen uniformly across listed firms to maximize their aggregate shareholder value in Eq. (21):

$$\max_{\tau\in[0,1]} \sum_{n=1}^{N} \left[\mathcal{V}^n(\tau) - \mathcal{W}^n(\tau)\right], \tag{34}$$

Because project maturity varies simultaneously for all listed firms in this expression, there is no reallocation of informed trading across firms, i.e., the sensitivity of informed trading is zero and price informativeness is equal across all stocks as given by Eq. (25). Then, the optimal project duration, denoted τ^{CB}, satisfies the first-order condition

$$f'(\tau^{CB}) = -\left(1 - \frac{1}{N\bar{z}}\right)\delta\rho_H \Psi(w_S^{CB}), \tag{35}$$

and w_G^{CB} and w_S^{CB} simultaneously solve

$$\frac{1}{N\bar{z}}\Delta\sigma u\left(w_G^{CB}\right) + \left(1 - \frac{1}{N\bar{z}}\right)\left(1 - \delta\tau^{CB}\right)\Delta\rho u\left(w_S^{CB}\right) = K \tag{36}$$

$$\sigma_H \Delta\rho u'(w_S^{CB}) = \Delta\sigma\rho_H u'(w_G^{CB}). \tag{37}$$

Each firm's shareholder value is given by

$$S^{CB} \equiv f(\tau^{CB}) + \rho_H \Delta V - \left[\frac{1}{N\bar{z}}\sigma_H w_G^{CB} + \left(1 - \frac{1}{N\bar{z}}\right)\left(1 - \delta\tau^{CB}\right)\rho_H w_S^{CB}\right]. \tag{38}$$

This coordinated project maturity choice benchmark (henceforth coordinated benchmark) also has two alternative interpretations. First, it is the equilibrium that would arise if informed investors were not mobile across firms, so were allocated equally across all listed firms, resulting in $\lambda^n = 1/(N\bar{z})$ being fixed and $\partial\lambda^n/\partial\tau^n = 0$ in the first-order condition of Eq. (22). Second, it is as if investors had long horizons ($\gamma = 0$), making $\Theta(\tau^*)$ equal to zero in Eq. (27).

5.3. Excessive short-termism

We now compare equilibrium to these benchmarks (Section 5.2.2).[35] In the following discussion, when we refer to equilibrium project maturity, we mean project maturity of listed firms. The comparison illustrates the interaction among different economic forces. First, using stock prices allows a firm to incentivize the manager more efficiently, thereby increasing firm value. Second, price informativeness reacts to project maturity: shorter maturity is advantageous to an individual firm because it attracts informed investors, fixing other firms' maturity choices. Third, other firms also have an incentive to shorten their own project maturity. But, this just leads to a race to the bottom where there are no winners: firms have inefficiently short maturities, but still have exactly the same price informativeness as they would have without competition for informed trade.

The first-order conditions (Eqs. (26), (31) and (35)) describe the trade-off between production efficiency and agency cost in the three different cases. In each equation, the LHS captures the marginal change in production with respect to a change in project maturity and the RHS captures the marginal change in agency cost with respect to a change in project maturity.

In the effort without price benchmark, the RHS in Eq. (31) shows that pursuing a longer-term project increases the agency cost when the manager is impatient ($\delta > 0$). In the coordinated benchmark, price informativeness dampens this effect. This is illustrated by the coefficient $(1 - 1/(N\bar{z}))$ in the RHS of Eq. (35). With probability $\lambda^n = 1/(N\bar{z})$ the price is informative, allowing the manager to be rewarded in the short term even if the project has not matured.

This allows the firm to pursue longer term projects without impairing incentives, thereby enhancing value. We call this the "price information effect". It is an example of the effect that has been highlighted in previous literature (e.g., Holmstrom and Tirole, 1993): stock prices are useful for monitoring managers.

On the other hand, in equilibrium, the first term on the RHS of Eq. (26) captures the impact on agency costs of competition among firms. Individually, a firm can enhance value by shortening project maturity to attract informed trade and thereby reduce agency costs (Eq. (22) and Proposition 3). However, this creates a negative spillover effect to other firms, and does not result in any benefit in equilibrium once others' reactions are endogenized. That is, price informativeness is still at the same level $\lambda^n = 1/(N\bar{z})$ for all $n \in \mathcal{N}$, but project maturities are overly shortened as a result of competition.[36] This leads to a loss in value. We call this the "competition for informativeness effect".

The following theorem summarizes the result.

Theorem 2 (*Excessive Short-Termism*). *The coordinated benchmark has the longest maturity, i.e.,*

$$\tau^{CB} > \max\left(\tau^*, \tau^{EP}\right).$$

Furthermore, equilibrium has shorter maturity than the effort without price benchmark ($\tau^{EP} > \tau^*$) if and only if the competition for informativeness effect dominates the price information effect, i.e.,

$$\Theta(\tau^*)\left[\sigma_H \Psi(w_G^*) - \rho_H\left(1 - \delta\tau^*\right)\Psi(w_S^*)\right] > \delta\rho_H\left[\left(1 - \frac{1}{N\bar{z}}\right)\Psi(w_S^*) - \Psi(w_S^{EP})\right]. \tag{39}$$

Proof. See Appendix E. ■

The coordinated benchmark has a longer maturity than the effort without price benchmark because of the price information effect: shareholders can lengthen project maturity using stock prices while still giving good managerial incentives. However, informed traders can switch between firms and are attracted to shorter-term projects. Recognizing this, firms can make their stock prices more informative by choosing projects that are more likely to mature early (the competition for informativeness effect). This offsetting effect may be strong enough that firms choose maturities that are even shorter than if they had no stock market listing at all. The LHS of Eq. (39) reflects the competition

[33] More formally, it can easily be shown there exists a critical value K_0 for the effort cost such that $S^U < S^{EP}$ if and only if $K < K_0$, where S^U and S^{EP} as defined in Eqs. (24) and (33) respectively. Since $K_0 < K_1$ (see Footnote 31), all firms choose to list for $K \le K_0$.

[34] Equivalently, we can think of a social planner who chooses listed firms' project maturities to maximize their aggregate shareholder value taking asset price informativeness in Eqs. (11)–(12) as given. The planner also faces the same agency problem faced by firms.

[35] To be clear, the number of listed firms in the coordinated benchmark is taken to be the equilibrium number of listed firms from Theorem 1.

[36] If the number of informed traders was endogenous, as opposed to fixed as in our model, informed trading would increase when maturity was reduced. However, as long as informed traders' entry was not perfectly elastic there would remain a spillover effect, causing a larger marginal benefit to the individual firm from reducing maturity compared to the marginal change in the total value of all firms (as in Eq. (34)). Thus, our results on excessive short-termism would remain robust.

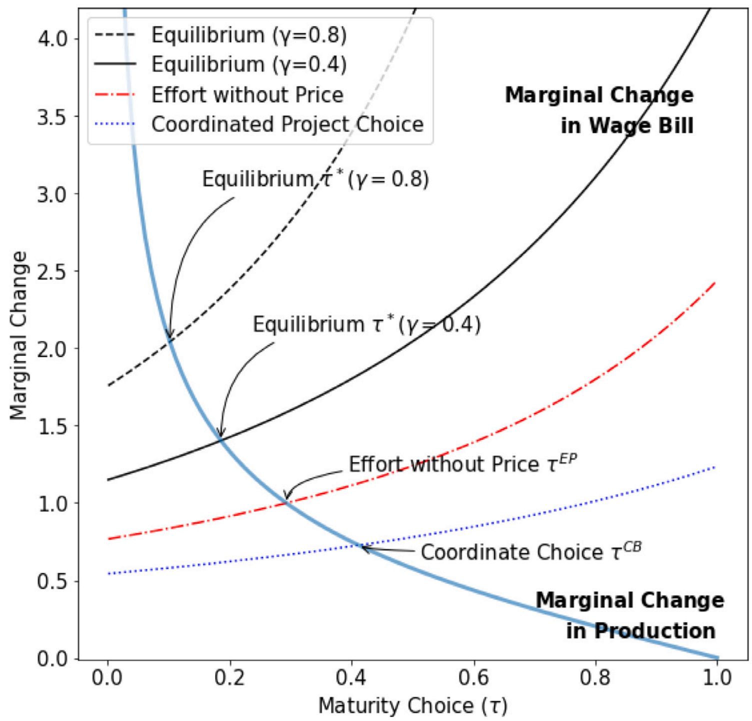


Fig. 2. Equilibrium Maturity Choice vs. Maturity Choices under Different Benchmarks. Parameter values: $\rho_H = .4, \sigma_H = .85, \Delta\rho = .35, \Delta\sigma = .8, K = 1, N = 10, z = 1, \delta = .5, \Delta V = 10$. The maturity-sensitive component of a firm's output is $f(\tau) = \sqrt{1-(1-\tau)^2}$, and the utility of a manager given wage w is $u(w) = w^{1-\alpha}$ with $\alpha = .4$. The dashed (solid) line shows the marginal change in wage bill under $\gamma = .8$ ($\gamma = .4$). The maturity choice is determined where the marginal change in the wage bill equals that in production. The equilibrium maturity choice τ^* becomes shorter with shorter investor horizons ($\gamma = .8$).

effect (the first term in Eq. (26)), and the RHS reflects the price information effect (differentials between Eq. (31) and the second term in Eq. (26)). Fig. 2 shows examples under different values of γ.

Shorter term projects in our model have lower final payoffs because $f(\tau)$ is increasing in τ. Therefore, we have $f(\tau^{CB}) > f(\tau^{EP}) > f(\tau^*)$ in case $\tau^{CB} > \tau^{EP} > \tau^*$; equilibrium has the smallest production of output compared to the two benchmarks. To address overall efficiency, the next theorem nets off managerial compensation.

Theorem 3 (*Constrained Inefficiency*). *Shareholder value for each firm across different cases is ranked as*

$$S^{EP} < S^* < S^{CB}.$$

Proof. See Appendix E. ■

The theorem shows that firms would improve shareholder value if they lengthened their maturities in a coordinated manner. In this sense, equilibrium is constrained inefficient, and shareholder value is suboptimally low due to firms competing for a fixed amount of informed trading by choosing short-term projects. This is parallel with the classical idea of the "tragedy of the commons" (e.g., Hardin, 1968; Levhari and Mirman, 1980) where individuals, who have access to a common pool of resource but do not internalize their externalities, end up with a tragic overexploitation of resource (such as fisheries, irrigation systems). In our model, informed trading is the common resource which can be used for more informative managerial compensation schemes.

The theorem also shows that, despite the short-termism trap, equilibrium shareholder value exceeds that in the effort without price benchmark. This is immediate because listed firms always have the option to disregard price information in their compensation contracts.

5.4. Comparative statics

5.4.1. The impact of increased competition

According to conventional wisdom, competition makes firms leaner, in other words, more efficient and more profitable (e.g., Porter, 1990). In the literature on optimal contracting, however, it has been noted that increased competition may not always lead to an improvement. More competition in product markets may increase agency costs (e.g., Nalebuff and Stiglitz, 1983; Scharfstein, 1988; Hermalin, 1992; Schmidt, 1997; Raith, 2003). We also use an agency framework, but we study a different channel for competition. In a highly competitive industry, not only are firms desperate to attract buyers, they are also desperate to attract investors. Firms compete for informed investors who have industry-specific knowledge and limited trading capital.

We can show analytically that more intense competition leads to increased short-termism. In our comparative statics, we consider the case where all firms list (i.e., $N = M$) and fix the product $M\bar{z}$ to be a constant to keep the quantity of informed trade per firm (relative to noise trade) at the same level.[37] Because an increase in M is compensated by a decrease in $\bar{z}$, the equilibrium price informativeness is unchanged regardless of the level of M, thus, equals that in Eq. (25).

Proposition 5 (*Competition*). *Consider the case where all firms list. Fixing $M\bar{z}$, higher competition induces more short-termism and lower share-*

[37] The result in Proposition 5 on equilibrium short-termism is unchanged if we vary M with $\bar{z}$ fixed and consider both cases where all firms list and some firms remain unlisted. In this general case, τ^* and S^* decrease in M in case all firms list, and are unaffected by M when some firms remain unlisted. See the proof of Proposition 5.

holder value, i.e., τ^* and S^* decrease in M. By contrast, the coordinated benchmark has no change in τ^{CB} and S^{CB}.

Proof. See Appendix F. ■

Our prediction is broadly consistent with empirical findings in the literature. There is some evidence that product market competition can induce short-term pressure (e.g., Aghion et al., 2013; Acharya and Xu, 2017).

5.4.2. The impact of shorter investor horizons

The comparative statics of the equilibrium with respect to investor horizons are particularly important because they tell us about the effects of shocks that may perturb investor horizons.

Proposition 6 (*Investor Short-Termism*)**.** *A shift in investor preferences toward early consumption induces more short-termism and weakly lower shareholder value, i.e., τ^* is decreasing in γ, and S^* is weakly decreasing in γ. By contrast, the coordinated benchmark has no change in τ^{CB} and S^{CB}.*

Proof. See Appendix F. ■

When investors become more short-term oriented, they become more responsive to a firm's decrease in project maturity. As a result, the sensitivity of price informativeness $\Theta(\tau^*)$ in Eq. (27) becomes more negative as γ increases. That is, the competition for informativeness effect becomes more pronounced, resulting in more excessive corporate short-termism. As equilibrium project maturity decreases further compared to the coordinated benchmark value, shareholder value decreases. Fig. 1 provides an illustration.

Dow et al. (2021) show that investor short-termism emerges endogenously because of capital constraints. A shock that reduces price efficiency increases the opportunity cost of investing in long-term assets. This makes long-lived but capital-constrained informed investors behave as if they were more short-term oriented (i.e., as if γ was larger). Therefore, we can interpret the comparative statics in Proposition 6 as a change in market conditions: shocks that originate in the financial market can propagate to the real economy when firms compete for informed trading. So a shock that reduces investor capital, which is then manifested as increased investor myopia, can lead to more short-termism in project selection as we show in this paper. Since Dow et al. (2021) also show that a transitory shock can have long-term effects on efficiency and investor horizons, it follows that via the short-termism trap, the post-financial crisis economy will perform less well than before.

5.4.3. The impact of more severe agency problems

Managerial effort cost and impatience aggravate the managerial agency problem even with a single firm, and this effect is multiplied by the externality in project duration.

Proposition 7 (*Amplification of the Agency Problem*)**.** *Consider the case where all firms list. An increase in managers' impatience or effort cost induces more short-termism and lower shareholder value in equilibrium, i.e., τ^* and S^* decrease in δ and K. This effect is larger than the corresponding effect in the coordinated benchmark.*

Proof. See Appendix F. ■

As the agency problem becomes more severe, equilibrium becomes more short-term. In contrast to the comparative statics results in Propositions 5 and 6 that leave the coordinated benchmark unaffected, a more severe agency problem decreases project maturity in the coordinated benchmark also. However, because firms' project maturity choices are strategic complements (Proposition 4), there is an amplification effect in equilibrium that is absent in the coordinated benchmark. That is, equilibrium short-termism is more sensitive to agency cost parameters compared to the coordinated benchmark.[38]

By the same token, lengthening the horizon of all investors mitigates the short-termism trap and raises shareholder value. However, this may not be the case if only some investors have long horizons, since Proposition 7 relies on all investors having identical horizons.

5.5. Value of information at different horizons

Our baseline model assumes that the value of information is independent of project maturity. More generally however, one can readily think of various reasons why the production of information could be more or less valuable at longer horizons. On the investor side, for example, long-term projects may be more uncertain, so that learning their value could be more valuable. Additionally, the cost (or opportunity cost) to produce information, and the precision of that information may vary with the horizon. On the firm side, long-term performance metrics may be less informative about managerial effort due to confounding events over the project's lifespan: if long-term profits are subject to many exogenous shocks as well as reflecting managerial effort, early price signals are more valuable for measuring and rewarding managerial performance.

In this subsection, we explore the impact of some of these effects on the short-termism trap. Our analysis shows that varying the maturity-dependent value of information can either lengthen or shorten project maturity, but suggests that it is unlikely to reverse our main findings. In particular, there will still be an externality in project horizon choice that biases project horizon away from the coordinated benchmark. However, we show that in extreme cases, for example where long term information is a lot more valuable but has the same opportunity cost of production, the direction of this externality could be reversed: projects could be excessively long term compared to the coordinated benchmark. On balance, we consider the short-term case to be the more relevant one empirically.

Finally, we conclude this subsection with a discussion of the inverse relationship between project maturity and price informativeness, which is a key mechanism in our model.

5.5.1. Long-term information more valuable to investors

First, we consider the parameter α introduced in Section 3.1. Thus far we have set $\alpha = 0$ and we now consider the case $\alpha > 0$. Recall that $\alpha > 0$ means that the volatility of output increases with project maturity. This increases the informational advantage of privately-informed investors for long-term projects.[39] It will therefore dampen the short term preference of informed investors: ex-ante, and incorporating the probability that informed investors may leave early, we show in Appendix J that the indifference condition Eq. (11) becomes

$$(1-\lambda^n)(1-\tau^n\hat{\gamma}) = (1-\lambda^m)(1-\tau^m\hat{\gamma}) \tag{40}$$

for any pair of stocks $m, n \in \mathcal{N}$, where we define investors *effective short-termism* as

$$\hat{\gamma} \equiv \gamma - \alpha(1-\gamma). \tag{41}$$

[38] When some firms remain unlisted, τ^* and N must adjust to an increase in δ or K so that firms are indifferent between listing and not listing. In this case, the proof of Proposition 7 shows that an increase in δ or K reduces the number of listed firms N so that shareholder value does not change with δ or K, but the effect on listed firms' project duration is ambiguous.

[39] Formally, Eqs. (1) and (3) imply $\mathrm{E}\left[|\mathrm{E}(V^n|s^n) - \mathrm{E}(V^n)|\right] = 2\sigma_H(1-\sigma_H)(v_G - v_B)\Delta V(1+\tau^n\alpha)$, i.e., the gap between the value of the project conditional on private information vs. prior information scales up with project maturity.

Whether investors have a preference for long-term or short-term firms depends on the combined effect of their limited horizons (γ) and the informational advantage of long-term projects (α). Eq. (41) gives the interaction between these effects: investors prefer short-term projects if $\hat{\gamma} > 0$ and prefer long-term projects if $\hat{\gamma} < 0$. $\hat{\gamma}$ is increasing in γ and decreasing in α. Effective short-termism is strictly positive so long as γ is large enough. On the other hand, for any $\gamma < 1$, effective short-termism will become negative at sufficiently high values of α.

Since α affects the firm's problem only indirectly via $\hat{\gamma}$, the model solution with $\alpha > 0$ is the same as our benchmark model with γ replaced by $\hat{\gamma}$.[40] Higher values of α decrease $\hat{\gamma}$ and therefore mitigate the inefficiencies associated with investor short-termism (Proposition 6) but do not eliminate the short-termism trap provided that $\hat{\gamma} > 0$. If α is so high that $\hat{\gamma} < 0$, the model leads to excessive long-termism. The externality is still present, but its direction is reversed. However, we consider this scenario to be unrealistic given the extensive evidence on investor short-term biases (such as the evidence cited in Footnote 1).

The parameter α scales the uncertainty of long-term projects, but variation in the value of information at different horizons could arise through different channels such as varying the cost and precision of information (see, for example, Han and Sangiorgi, 2018). We explore this in Appendix K, where we provide an alternative extension of the model that scales informed trading profits by a factor $\chi(\tau^n)$, where $0 < \chi(\tau^n) \leq 1$, that is a function of project maturity τ^n. Our interpretation of χ being increasing in τ^n is that long-term information is cheaper to produce or more precise (and vice versa if χ is decreasing).

In that analysis, the indifference condition for informed investors in Eq. (11) is adjusted to this scaling factor, in a way that is analogous to Eq. (40). The resulting outcomes are similar to the effects of α: the short-termism trap remains unless the scaling factor strongly favors long-term information production. The short-termism trap also remains, for a given scaling factor, so long as investor short-termism is sufficiently strong.

To summarize the conclusions of this subsection, so long as the net effect of the different economic forces still leaves investors with a preference for short-term projects, firms will cater to investor preferences and choose project durations that are too short relative to the coordinated benchmark. On the other hand, if the net effect is to create an investor preference for long-term projects, there will still be a suboptimal choice of project duration, but they will be too long-term, although in our judgement this case is less relevant in practice.

5.5.2. Long-term information more valuable to firms

Not only investors, but also firms may have preferences for information that depend on project maturity. It is plausible that the information in short term stock prices (period 0 in our model) is more valuable when the firm chooses a long term project, *ceteris paribus*. The reason is that project payoffs are affected by factors that are unconnected with managerial performance such as macroeconomic shocks, geopolitical shocks, industry-wide technological advances, etc. Over a long time period, more of these shocks arrive. This implies that outcomes for long-term projects are less informative about managerial effort compared to short-term projects. In this case, an early price signal about managerial effort is more valuable to the firm as project maturity increases.

We implement this idea in the model assuming an additional layer of randomization if the project realizes late, whereby the probability of success becomes $\rho_e(1-\beta)$ for some $\beta \in [0, 1)$ for $e \in \{H, L\}$. The probability of success when the project realizes early is unchanged compared to our benchmark model and equal to ρ_e for $e \in \{H, L\}$. For simplicity, we further assume that if the project pays off late, its risky component in case of success equals $\Delta V/(1-\beta)$.[41]

We show in Appendix J that in this framework the optimal contract is identical to the one in Proposition 2,[42] with the managerial impatience parameter δ replaced by

$$\hat{\delta} = \delta + \beta(1-\delta). \tag{42}$$

By Eq. (42), $\hat{\delta}$ is increasing in both δ and β. Therefore, the effect of noisier long-term performance measures is equivalent to worsening the agency problem, that is, an increase in β has the same effect as an increase in δ. This worsens the short-termism trap, as shown in Proposition 7. So if, as seems plausible, short term price signals are more important for long term projects, the short termism trap is worsened.

5.5.3. Inverse relationship between price informativeness and project horizon

Our model emphasizes that short-term projects allow firms to provide superior incentives due to their superior informativeness. While stock prices are only informative in the initial period in our model (Section 4.1), we acknowledge that stock prices may provide repeated informative signals for long-term projects in more complex dynamic settings: during the lifespan of a long-term project, there is a longer time series of price data, hence, more signals.

First note that these additional signals in general need not have the same relevance for assessing managerial efforts compared to early price signals. In line with the discussion in Section 5.5.2, the early signals are more relevant in the case when later, investors learn about exogenous shocks affecting long-term performance that are unrelated to managerial effort.

Second, the presence of small frictions may cause the prices of long-term assets to be informative only in periods close to the asset's maturity, as in Dow and Gorton (1994). They show that if there is a small cost of carry, informed traders with short horizons will optimally ignore their information signals until a threshold time period that may be close to the asset's maturity. It follows that if informed traders can choose which signals to receive (i.e. there is cost or opportunity cost of information production), they will choose stocks that are close to liquidation (for a stock that pays a single liquidating dividend; more generally, they will choose to receive signals about information that will likely become public soon). So if the manager exits before the price is informative, the stock price cannot be used to incentivize managerial effort for long-term projects.

Third, even if stock prices are equally informative about managerial effort in each period, price signals from a long-term project do not automatically equate to better incentive schemes. Dow et al. (2021) develop a stationary dynamic framework with short and long-term assets, and show that long-term assets (unlike short-term assets) may get "stuck" in a regime with low price informativeness. In this regime, traders can buy long-term assets that are mispriced based on their private information, but cannot sell them soon afterwards at prices reflecting that information, and may be unable to profit unless they hold the assets to maturity. This disincentivizes traders from producing information about long-term assets. This effect can be so severe that long-term assets may have lower total informativeness even aggregating per-period price informativeness over all periods. In this case, short-term assets provide more overall price information and better incentives. In

[40] More precisely, since the ex-ante value of the firm under high effort changes to

$$\mathrm{E}(V^n) = f(\tau^n) + \rho_H \Delta V(1 + \alpha\tau^n),$$

the firm's first-order condition with respect to τ^n has the additional constant term $\rho_H \Delta V \alpha$. This, however, is immaterial for our results.

[41] This assumption keeps investor trading incentives and the value of high effort to the firm unchanged with respect to the parameter β. Thus, β exclusively affects how the value of price informativeness to firms interacts with project duration.

[42] The contract allows for different payments conditional on early and late success, but these are the same under the optimal contract.

addition, managers' impatience or short horizon diminishes the value of repeated signals from long-term projects as only a fraction of those signals can be used for managerial compensation.

6. Extension: Introducing a fraction of long-term investors

A recent trend among some investment managers is to pursue long-term value, often as part of an ESG commitment. For example, in a joint statement in March 2020, large public investors including Japan's GPIF (Government Pension Investment Fund), CALSTRS (California State Teachers' Retirement System) and the UK's USS Investment Management, wrote "asset managers that only focus on short-term, explicitly financial measures, and ignore longer-term sustainability-related risks and opportunities are not attractive partners for us".[43] From our results above (Proposition 7), we know that if *all* investors have longer horizons, the short-termism trap will be mitigated. But what if only a subset of investors commit to long horizons?

Our results in this section are that long-term investing has no impact on project maturity until it exceeds a critical mass. Even though long-term investors shun short-termist firms, other investors can simply fill that void. This is in line with recent empirical findings that the impact of ESG investing on firms' cost of capital is too small to have any meaningful impact (Berk and van Binsbergen, 2021). On the other hand, if the mass of long-term investors is sufficiently large that they are marginal investors for all firms, project maturity reverts to the coordinated benchmark and the short-termism trap disappears. In between, there is an intermediate case. When the mass of long-term investors is in this intermediate range, firms choose different project maturities to cater to different investor clienteles. In this case, some firms choose fairly long-term projects and are held by long-term investors, while other choose shorter-term projects and are held by short-term investors. This is only a partial solution to the liquidity trap however, in the sense that even the longer term projects are shorter than those in the coordinated benchmark, and shareholder value is not as high.

Suppose that a fraction μ of "long-term investors" stay in the economy until $t = 2$ (i.e., until all projects pay off). The remaining fraction $1 - \mu$ are "short-term investors" who may exit the economy in $t = 1$ with probability γ, as in our original model. For simplicity, we focus on parameter values such that all firms list in the original model.

We first investigate parameter values for which the equilibrium is symmetric. Denoting the equilibrium project maturity by τ^{μ}, we have

Proposition 8 (*Symmetric Equilibrium with Long-Term Investors*). *(i) There exists $\mu^* \in (0, 1/N)$ such that (a) for $\mu \le \mu^*$, there is a unique symmetric equilibrium and $\tau^{\mu} = \tau^*$ (i.e., equilibrium is identical to the one without long-term investors in Theorem 1); (b) For $\mu \in (\mu^*, 1/N)$, if a symmetric equilibrium exists, the equilibrium project maturity is $\tau^{\mu} = \tau^*$. (ii) For $\mu \ge 1 - 1/N$, there is a unique symmetric equilibrium and $\tau^{\mu} = \tau^{CB}$, i.e., equilibrium project maturity is the same as in the coordinated benchmark. (iii) For $\mu \in [1/N, 1 - 1/N)$, there is no symmetric equilibrium.*

Proof. See Appendix G. ■

Proposition 8-(i) shows that long-term investors have no impact on project duration if their mass is smaller than the threshold $1 - 1/N$. Intuitively, when the mass of long-term investors is sufficiently small, short-term investors are marginal for all firms. Each firm's price informativeness is determined by short-term investors' indifference condition as in Eq. (11). Hence, the project maturity in a symmetric equilibrium is the same as in the case without long-term investors.

Proposition 8-(ii) shows that when the mass of long-term investors is larger than the threshold, they eliminates the race to the bottom in project duration. Intuitively, when the mass of long-term investors is sufficiently large, they become the marginal investors. Because long-term investors' trading profits do not depend on project maturity, a firm's project maturity has no impact on its price informativeness. As a result, equilibrium project maturity with a sufficiently large mass of long-term investors is the same as in the coordinated benchmark, and therefore the equilibrium is constrained efficient (Section 5.3).

The intuition for Proposition 8-(iii) is as follows. Consider a candidate symmetric equilibrium τ^{μ}. For intermediate values of μ, if firm n deviates to a longer project maturity, there are enough long-term investors to step in and sustain the same level of price informativeness as in all other firms, even though short-term investors no longer invest in firm n. Therefore, for all $\tau^{\mu} < \tau^{CB}$, a firm can profitably lengthen its project maturity without a reduction in price informativeness. At the same time, if firm n deviates to a shorter project maturity, there are enough short-term investors to sustain higher price informativeness for firm n even though long-term investors do not invest in this firm. Therefore, for all $\tau^{\mu} > \tau^*$, a firm can increase its value by shortening its project maturity and increasing its price informativeness. Because $\tau^* < \tau^{CB}$ (Theorem 2), there is no symmetric equilibrium in the intermediate region for μ.

When the mass of long-term investors is in an intermediate range, however, we can show that there is a "clientele equilibrium" in which firms choose different maturities (i.e., some choose short-term whereas others choose long-term). The following proposition summarizes this result:

Proposition 9 (*Clientele Equilibrium*). *For $1 - (N-1)\bar{z} < \mu < 1 - 1/N$, there exists a clientele equilibrium in which a fraction α_S of firms choose maturity τ_S and a fraction $1 - \alpha_S$ of firms choose maturity τ_L where $0 < \alpha_S < 1$ and $\tau^* < \tau_S < \tau_L < \tau^{CB}$. In this equilibrium, short-term investors invest in short-term firms whereas long-term investors invest in long-term firms. Price efficiency for short- and long-term firms satisfies $\lambda_L < 1/(N\bar{z}) < \lambda_S$. Equilibrium shareholder value, S^{Cl}, satisfies $S^* < S^{Cl} < S^{CB}$.*

Proof. See Appendix G. ■

For analytical simplicity, the proof of Proposition 9 ignores the integer constraint on the number of firms in each group. The clientele equilibrium in Proposition 9 has the following important features.

First, ex-ante identical firms choose different project maturities to cater to different investor clienteles. Hence, firms become ex-post heterogeneous in equilibrium: long-term firms become more productive than short-term firms, but attract less investor attention. Thus, long-term firms have less informative prices and face higher agency cost compared to short-term firms.

Second, long-term firms choose shorter project maturities and have lower price efficiency compared to the coordinated benchmark, while short-term firms choose longer project maturities and have higher price efficiency compared to the equilibrium in the absence of long-term investors. Each firm must have no incentive to deviate to the other type. For this to happen, long-term firms must be sufficiently less valuable than in the coordinated benchmark, and short-term firms must be sufficiently more valuable than in the absence of long-term investors.

7. Empirical and policy implications

7.1. Salary caps

It has been suggested that short-termism goes hand in hand with excessive incentive compensation for CEOs (see, for example, Porter, 1992). Limits to CEO compensation have been proposed as a mechanism to improve the management of listed companies. For example, in

[43] "Joint statement on the importance of long-term, sustainable growth"at https://www.gpif.go.jp/en/investment/Our_Partnership_for_Sustainable_Capital_Markets_Signatories.pdf

1993 the Clinton administration introduced a salary cap on CEO compensation in the form of $1 million deductibility cap (see Murphy, 2013 for further details). Can a salary cap promote shareholder value by mitigating excessive short-termism? Since the level of salary is not directly related to project duration, a salary cap does not necessarily lengthen project duration. Indeed, in our model the effect of a salary cap, at the margin, is to reduce project duration. More broadly, although high salaries and short-termism are often considered problematic, they are two different phenomena and addressing one does not solve the other.

We use the same setup of our model as in Section 3, except we assume an upper bound $\bar{w}$ on managerial compensation in each state. In that case, the optimal contracting problem defined in Eqs. (13)–(17) needs to be augmented by an extra constraint:

$$w_G^n, w_B^n, w_S^n, w_F^n, w_\emptyset^n \leq \bar{w}. \tag{43}$$

We focus on values of the salary cap $\bar{w}$ that ensures that the IC constraint with effort holds. For notational convenience, we use a double asterisk notation ($**$) for the optimal solution under the salary cap, and use a single asterisk notation ($*$) for the optimal solution without the salary cap.

Proposition 10. *Suppose that the equilibrium contract is given by w_G^*, w_S^* without a salary cap. Then, given the number of listed firms N, the equilibrium contract under salary cap is given by*

$$w_G^{**} = \min(w_G^*, \bar{w}),$$

$$w_S^{**} = \begin{cases} w_S^* & \text{if } w_G^* < \bar{w} \\ u^{-1}\left(\dfrac{K - \frac{1}{N\bar{z}}\Delta\sigma u(\bar{w})}{\left(1-\frac{1}{N\bar{z}}\right)(1-\delta\tau^{**})\Delta\rho}\right) & \text{otherwise,} \end{cases}$$

where τ^{**} solves the following first-order condition of each firm's maturity choice problem under salary cap:

$$f'(\tau^{**}) = \Theta(\tau^{**})\left[\sigma_H\left(w_G^{**} - \frac{\Delta\sigma\rho_H}{\sigma_H\Delta\rho}\frac{u(w_G^{**})}{u'(w_S^{**})}\right) - \rho_H\left(1-\delta\tau^{**}\right)\Psi(w_S^{**})\right] - \left(1-\frac{1}{N\bar{z}}\right)\delta\rho_H\Psi(w_S^{**}). \tag{44}$$

Maturity becomes shorter (i.e., $\tau^{**} < \tau^*$) when the salary cap starts binding, and shareholder value is reduced.

Proof. See Appendix H. ■

Thus, Proposition 10 shows that the marginal impact of a salary cap does not prevent short-termism but rather promotes it. This is because a binding salary cap reduces stock price-based compensation and induces firms to increase compensation conditional on successful project outcome (a smaller payment) instead. Eq. (H.10) shows that this increases firms' incentives to gain price informativeness by shortening project maturity. The overall effect in equilibrium is to reduce project duration and shareholder value.

7.2. Further testable implications

In this section, we discuss the empirical implications of our model. There is a large empirical literature showing that stock-based compensation can lead to value-destroying short-termism (e.g., Bergstresser and Philippon, 2006; Gopalan et al., 2014; Asker et al., 2015; Brochet et al., 2015). On a broad level, our paper investigates this well-documented connection between stock-based compensation and corporate short-termism through the lens of imperfect information in financial markets. The main idea of our model is that short-termism is an optimal response of firms to minimize their agency cost when prices are informative, but those individually optimal responses lead to an aggregate inefficiency through informational externalities. This mechanism sheds light on some empirical regularities that are not fully explained, and furthermore offers several testable implications.

First, higher competition can exacerbate short-termism through the channel of price informativeness (Proposition 5). Furthermore, this link between competitive pressure and short-termism should be present only in the presence of informational externalities. Proposition 5 highlights an important aspect of our prediction that firm value is destroyed due to short-termism even when price informativeness stays the same. As is discussed in Section 5.4.1, however, there has been a long debate whether competitive pressure improves firm value or destroys firm value. On the one hand, competition among firms can make firms more efficient (e.g., Porter, 1990). On the other hand, competition among firms can sometimes lead to a negative consequence such as reduced innovations (e.g., Aghion et al., 2005). In particular, competitive pressure can make firms focus on short-term performance, destroying their long-term value (e.g., Pathan et al., 2021; Keum, 2021).

One of the distinct predictions of our model is that firms' maturities are endogenously determined given the degree of informational externalities. A shock that shortens the duration of one firm's cash flows should increase that firm's price informativeness at the expense of other firms; the intensity of this reaction measures the strength of information externalities. Although such measure may be difficult to construct empirically, the degree of informational externalities can be associated with the magnitude of price sensitivities to new information, which can be measured, for example, by "earnings response coefficient" (Ball and Brown, 1968; Dhaliwal et al., 1991). Our model predicts that short-termism will be more severe when the sensitivity is higher. Such a measure will allow us to distinguish between different mechanisms; the relation between competition and short-termism will be positive only when there are informational externalities. Our prediction is broadly consistent with Asker et al. (2015) who empirically find that short-termist pressure is more severe for public firms in which stock prices are most sensitive to earnings news (i.e., high earnings response coefficients).

Second, more severe investor short-termism can lead to greater corporate short-termism (Proposition 6). Furthermore, this effect should be more severe in the presence of informational externalities. Although it is often argued that investor myopia is responsible for corporate short-termism, empirical evidence seems to be mixed. On the one hand, short-horizoned institutional investors force managers into value-destroying short-horizoned decision making (e.g., Jacobs, 1991; Latham and Braun, 2010; Callen and Fang, 2013; Agarwal et al., 2018; Kim et al., 2019). For example, Bushee (1998) finds that a large proportion of ownership with high turnover and momentum trading increases the probability that managers will reduce R&D investment to reverse an earnings decline. On the other hand, short-horizoned institutional investors offer better disciplining as well as useful information (e.g., Hansen and Hill, 1991; Yan and Zhang, 2009; Giannetti and Yu, 2021). Our model provides one way to resolve such mixed observations: investor myopia would not directly translate into corporate short-termism unless informational externalities are present. That is, our model predicts that the relation between investor short-termism and corporate short-termism will be positive only when there are informational externalities. Our prediction is consistent with evidence by Agarwal et al. (2018) who show that frequent portfolio disclosures can induce increased short-term focus of fund managers, which in turn creates pressure on managers of investee firms to behave myopically.

Third, more severe managerial myopia can lead to greater corporate short-termism (Proposition 7). Furthermore, this effect should be more severe in the presence of informational externalities. Empirical evidence indeed shows that short-horizoned CEOs tend to avoid value-enhancing long-term investments (e.g., Dechow and Sloan, 1991; Gopalan et al., 2014; Lee et al., 2018; Lundstrum, 2002). As is shown in Section 5.2.1, managerial myopia can still affect corporate short-termism regardless informational externalities. But informational externalities amplify the effect of managerial myopia because firms compete for the benefit of informed trading. This mechanism is broadly consistent with empirical findings that stock-based CEO compensation is more tightly connected to corporate short-termism when prices are more sensitive to news (Asker et al., 2015).

Fourth, a decrease in informed trading can lead to more severe short-termism (see the discussion after Proposition 6). There is a vast literature on the impact of business cycles on financial markets. In particular, a downturn in business cycles can reduce the participation of sophisticated institutional investors by tightening their funding constraints (e.g., Brunnermeier and Pedersen, 2009), thus reduce informed trading (e.g., Dow and Han, 2018; Dow et al., 2021). Based on such observations, our model suggests that, during economic downturns, it is likely that short-termism is exacerbated by firms' competition to accommodate more informed trading. This is in line with empirical findings which show that long-term value creation is often more difficult to implement during economic downturns (e.g., Nanda and Nicholas, 2014).

Finally, it is often argued that the stock market imposes an excessive focus on short-term financial outcomes for publicly traded companies. Therefore, the argument asserts that going private enables firms to escape the short-termist pressure imposed by the stock market and attain greater freedom to concentrate on long-term growth and innovation.[44] In support of this, Asker et al. (2015) find that private firms are less subject to short-termist pressure than public firms. As a result, private firms tend to invest more and also produce more distinctive innovations than equivalent public firms (e.g., Davies et al., 2014; Bernstein, 2015). Our model provides a theoretical perspective supporting these arguments. Theorem 1 shows investor short-termism fosters a race-to-the-bottom among firms, where the associated costs can outweigh the benefits of price informativeness. Consequently, some firms opt to remain private.

8. Conclusion

In this paper, we explore whether managerial stock-price based compensation leads to excessive short-termism. In previous models, firms' and managers' prioritizing of short-term results as an individually rational response to short-term pressure from the stock market is also collectively rational, in other words it is efficient given the informational constraints that govern managerial incentives and project selection.

In contrast, we study short-termism that is individually rational, but collectively suboptimal. We study an economy with a stock market where informed investors have short-horizons. Regardless of investors' horizons, stock-based compensation can improve shareholder value of an individual firm by reducing agency cost because stock prices are informative about future cash flows. This allows the firm to pursue longer term projects without impairing incentives.

Because price informativeness is endogenous, however, competition for informed trading can destroy shareholder value as a result of negative externalities to price informativeness of other firms. Firms compete for informed investors by reducing project maturities because informed investors are short-horizoned. Negative spillover effects arise but firms do not internalize such adverse effects to other firms. Therefore, a short-termism trap arises in equilibrium; firms reduce their maturity excessively, thereby reducing shareholder value.

This is similar to the "race to the bottom" described by U.S. Supreme Court Justice Louis Brandeis, in which states designed regulations to compete for firms, which were attracted to incorporate in "states where the cost was lowest and the laws least restrictive ... The race was one not of diligence, but of laxity". (Liggett Co. v. Lee, 288 U.S. 517, 558–59 (1933), dissenting opinion). It has been used to describe competition among stock exchanges by choice of listing regulations (Chemmanur and Fulghieri, 2006), and competition among jurisdictions by choice of tax rates (Mast, 2020).

This paper is part of a broader research project exploring the impact of limited informed investor capital on stock market performance (Dow and Han, 2018; Dow et al., 2021). Informed trading helps stock markets to perform their economic functions, and shortages of informed capital can disrupt those functions.

CRediT authorship contribution statement

James Dow: Writing – original draft. **Jungsuk Han:** Writing – original draft. **Francesco Sangiorgi:** Writing – original draft.

Declaration of competing interest

The authors declare that they have not received any financial support for the research described in this paper, and they also have no relevant or material financial interests that relate to the research described in this paper.

Data availability

"The Short-Termism Trap: Catering to Informed Investors with L imited Horizons (Supplementary Data and Code)" (Original data) (Mendeley Data)

Appendix A

Proof of Lemma 1.

In our model, because all stock payoffs and signals are jointly independent, there is no learning across stocks in the market. Therefore, we can analyze market makers' learning informed investors' private information for each stock $n \in \mathcal{N}$ separately.

Let $g(z^n)$ be the probability density function of noise trading z^n. Because z^n is uniformly distributed on $[-\bar{z}, \bar{z}]$, we have $g(z^n) = 1/(2\bar{z})$ for $z^n \in [-\bar{z}, \bar{z}]$ and $g(z^n) = 0$ otherwise. By Bayes' Rule, market makers' posterior belief that $s^n = G$ conditional on aggregate order flow $X^n(0)$ is given by[45]

$$Pr(s^n = G|X^n(0)) = \frac{\sigma_H g(X^n(0) - \mu^n)}{\sigma_H g(X^n(0) - \mu^n) + (1 - \sigma_H) g(X^n(0) + \mu^n)}. \tag{A.1}$$

From Eq. (A.1), it is immediate that

$$Pr(s^n = G|X^n(0)) = \begin{cases} 0 & \text{if } -\mu^n - \bar{z} \le X^n(0) < \mu^n - \bar{z} \\ \sigma_H & \text{if } \mu^n - \bar{z} \le X^n(0) \le -\mu^n + \bar{z} \\ 1 & \text{if } -\mu^n + \bar{z} < X^n(0) \le \mu^n + \bar{z}. \end{cases} \tag{A.2}$$

[44] For example, in a letter to Tesla employees in August 7, 2018, Tesla CEO Elon Musk motivated the intention to take Tesla private on the basis that " As a public company, we are subject to wild swings in our stock price that can be a major distraction for everyone working at Tesla, all of whom are shareholders. Being public also subjects us to the quarterly earnings cycle that puts enormous pressure on Tesla to make decisions that may be right for a given quarter, but not necessarily right for the long-term". He further added " Basically, I'm trying to accomplish an outcome where Tesla can operate at its best, free from as much distraction and short-term thinking as possible". https://www.tesla.com/blog/taking-tesla-private

[45] See, for example, Lemma 1 in Dow et al. (2021) for a similar analysis with uniformly-distributed noise trading, and also Lemma 4 in Dow and Han (2018) for an analysis with noise trading under general distributions.

Given τ^n (firm n's maturity choice) the posterior belief about the liquidation value conditional on private information s^n is

$$\mathrm{E}\left[V^n|X^n(0)\right] = f(\tau^n) + \sum_{s^n\in\{G,B\}} Pr(R=\Delta V|s^n)Pr(s^n|X^n(0))\Delta V,$$

which implies,[46]

$$\mathrm{E}\left[V^n|X^n(0)\right] = \begin{cases} f(\tau^n)+\nu_B\Delta V & \text{if } -\mu^n-\bar{z}\le X^n(0)<\mu^n-\bar{z} \\ f(\tau^n)+\rho_H\Delta V & \text{if } \mu^n-\bar{z}\le X^n(0)\le -\mu^n+\bar{z} \\ f(\tau^n)+\nu_G\Delta V & \text{if } -\mu^n+\bar{z}< X^n(0)\le \mu^n+\bar{z}. \end{cases} \tag{A.3}$$

Now, we derive the price informativeness for stock n. From Eq. (A.2), it is clear that prices are informative except when $\mu^n-\bar{z}\le X^n(0)\le -\mu^n+\bar{z}$. In case $s^n=H$, we have $X^n(0)=\mu^n+z^n$. Then, prices are uninformative if $-\bar{z}\le z^n\le -2\mu^n+\bar{z}$, which occurs with probability $1-\mu^n/\bar{z}$. In case $s^n=L$, we have $X^n(0)=\mu^n+z^n$. Then, prices are uninformative if $2\mu^n-\bar{z}\le z^n\le\bar{z}$, which occurs with probability $1-\mu^n/\bar{z}$. Therefore, prices are informative with probability $\mu^n/\bar{z}$ regardless of signals. ∎

Proof of Lemma 2. We rewrite the value function $J_0^n(s^n)$ given s^n in Eq. (9) in a more general form as follows:

$$J_0^n \equiv \sigma_H J_0^n(s^n=G)+(1-\sigma_H)J_0^n(s^n=B), \tag{A.4}$$

where

$$\begin{aligned} J_0^n(s^n) \equiv \max_{x_i^n(0)\in\{-1,0,1\}} & -E[P^n(0)|s^n]x_i^n(0)+\gamma\Gamma^n(s^n)x_i^n(0) \\ & +(1-\gamma)\mathrm{E}[J_1^n(x_i^n(0),s^n,P^n(0))|s^n], \end{aligned}$$

and

$$\Gamma^n(s^n)\equiv(1-\tau^n)\mathrm{E}[V^n|s^n]+\tau^n\mathrm{E}[P^n(1)|s^n],$$

and

$$\begin{aligned} J_1^n(0,s^n,P^n(0)) &\equiv \max_{x_i^n(1)\in\{-1,0,1\}} \tau^n\mathrm{E}[(V^n-P^n(1))|s^n,P^n(0)]x_i^n(1); \\ J_1^n(1,s^n,P^n(0)) &\equiv (1-\tau^n)\mathrm{E}[V^n|s^n] \\ &\quad +\tau^n\max\{E[V^n|s^n],E[P^n(1)|s^n,P^n(0)]\}; \\ J_1^n(-1,s^n,P^n(0)) &\equiv -(1-\tau^n)\mathrm{E}[V^n|s^n] \\ &\quad -\tau^n\min\{E[V^n|s^n],E[P^n(1)|s^n,P^n(0)]\} \end{aligned}$$

In this formulation, the value $J_1^n(x_i^n,s^n,P^n(0))$ accounts for the possibility that a late-consumer with a non-zero position in $t=0$ may reverse the position in $t=1$ instead of holing the position until $t=2$.

First, we show that a long position conditional on a good signal dominates a long position conditional on a bad signal. This is obvious in $t=1$ since, conditional on $P^n(0)$ being non-revealing, the expected payoff from a long position given a good signal is

$$\begin{aligned} \mathrm{E}[V^n-P^n(1)|s^n=G,P^n(0)] &= (1-\lambda^n(1))E[V^n-P_\emptyset^n|s^n=G] \\ &= (1-\lambda^n(1))(\nu_G-\rho(e^n))\Delta V>0, \end{aligned}$$

where the inequality is due to Eq. (3). Likewise, the expected payoff from a long position given a bad signal is

$$\begin{aligned} \mathrm{E}[V^n-P^n(1)|s^n=G,P^n(0)] &= (1-\lambda^n(1))E[V^n-P_\emptyset^n|s^n=B] \\ &= (1-\lambda^n(1))(\nu_B-\rho(e^n))\Delta V<0. \end{aligned}$$

In $t=0$, the expected value from a buy order conditional on $s^n=G$ is

$$(1-\lambda^n(0))(1-\gamma\tau^n(1-\lambda^n(1)))E[V^n-P_\emptyset^n|s^n=G], \tag{A.5}$$

whereas the expected value from a buy order conditional on $s^n=B$ is

$$(1-\lambda^n(0))\left[1-\gamma\tau^n(1-\lambda^n(1))-(1-\lambda^n(1))(1-\gamma)\right]E[V^n-P_\emptyset^n|s^n=B]. \tag{A.6}$$

Subtracting (A.6) from (A.5) gives

$$\begin{aligned} &(1-\lambda^n(0))\,(1-\gamma\tau^n(1-\lambda^n(1)))\,(E[V^n|s^n=G]-E[V^n|s^n=B]) \\ &-(1-\lambda^n(0))(1-\lambda^n(1))(1-\gamma)E[P_\emptyset^n-V^n|s^n=B], \end{aligned}$$

which is strictly positive since $E[V^n|s^n=G]>P_\emptyset^n$ and $(1-\gamma\tau^n(1-\lambda^n(1)))>(1-\lambda^n(1))(1-\gamma)$. A similar argument shows that a short position conditional on a bad signal dominates a short position conditional on a good signal.

Since informed investors always trade in the direction of their signal, an informed investor with a long position in $t=0$ must have received a good signal. If this investor consumes late and $P^n(0)$ is non-revealing, it is strictly optimal to hold the position until $t=2$ because $E[V^n|s^n=G]>E[P^n(1)|s^n=G,P^n(0)]$. Therefore, $J_1^n(1,s^n=G,P^n(0))=E[V^n|s^n=G]$. A similar argument shows that $J_1^n(-1,s^n=B,P^n(0))=-E[V^n|s^n=B]$. This shows that if the firm' project pays off late and $P^n(0)$ is non-revealing, late-consumers hold the position until $t=2$.

Next, we prove that an informed investor prefers trading early. Consider the expected value from a long position at $t=0$ conditional on a good signal. Using Lemma 1 and Eq. (9) and simplifying, we can write this value, $\hat{J}_0^n$ say, as

$$\hat{J}_0^n(G)=(1-\lambda^n(0))(1-\gamma\tau^n(1-\lambda^n(1)))(E[V^n|s^n=G]-P_\emptyset^n).$$

On the other hand, consider the expected value at $t=0$ of trading at $t=1$ conditional on a good signal. Using Lemma 1 and Eq. (9) and simplifying, we can write this value, $\hat{J}_1^n(G)$ say, as

$$\hat{J}_1^n(G)=(1-\lambda^n(0))(1-\gamma)\tau^n(1-\lambda^n(1))(E[V^n|s^n=G]-P_\emptyset^n).$$

Therefore, we have

$$\hat{J}_0^n(G)-\hat{J}_1^n(G)=(1-\lambda^n(0))(1-\tau^n(1-\lambda^n(1)))(E[V^n|s^n=G]-P_\emptyset^n),$$

which implies that $\hat{J}_0^n(G)\ge\hat{J}_1^n(G)$, with a strict inequality if $\tau^n(1-\lambda^n(1))<1$. Likewise, the results are identical because the difference of values of trading at $t=0$ and trading at $t=1$ conditional on a bad signal is given by

$$\hat{J}_0^n(B)-\hat{J}_1^n(B)=(1-\lambda^n(0))(1-\tau^n(1-\lambda^n(1)))(P_\emptyset^n-E[V^n|s^n=B]),$$

which implies that $\hat{J}_0^n(B)\ge\hat{J}_1^n(B)$, with a strict inequality if $\tau^n(1-\lambda^n(1))<1$.

Since it is optimal for informed investors to buy (sell) at $t=0$ conditional on a good (bad) signal, there is an equilibrium in which all informed investors trade at $t=0$. In this equilibrium, the aggregate order flow at $t=1$ is proportional to order flow in the previous period, i.e., $X^n(1)=-\gamma X^n(0)$. Because $X^n(0)$ is already known to market makers, there is no new information for market makers in $X^n(1)$. Therefore, the price is uninformative at $t=1$, that is, $\lambda^n(1)=0$. In this equilibrium, the value of trading stock n given a good signal is

$$\hat{J}_0^n(G)=(1-\lambda^n(0))(1-\gamma\tau^n)\Delta P_G,$$

where ΔP_G is the mispricing wedge given $s^n=G$ such that

$$\Delta P_G\equiv P_G^n-P_\emptyset^n=(\nu_G-\rho_H)\Delta V,$$

and the value of trading stock n given a bad signal is

$$\hat{J}_0^n(B)=(1-\lambda^n(0))(1-\gamma\tau^n)\Delta P_B,$$

where ΔP_B is the mispricing wedge given $s^n=B$ such that

$$\Delta P_B\equiv P_\emptyset^n-P_B^n=(\rho_H-\nu_B)\Delta V.$$

Therefore, the value of trading stock n before acquiring a signal is equal to

$$J_0^n=\sigma_H\hat{J}_0^n(G)+(1-\sigma_H)\hat{J}_0^n(B)=(1-\lambda^n(0))(1-\gamma\tau^n)\Delta P,$$

[46] To see this, $Pr(R=\Delta V|s^n=G)\times 0+Pr(R=\Delta V|s^n=B)\times 1=\nu_B$, $Pr(R=\Delta V|s^n=G)\times\sigma_H+Pr(R=\Delta V|s^n=B)\times(1-\sigma_H)=\rho_H$ due to the first equation in Eq. (3) and finally $Pr(R=\Delta V|s^n=G)\times 1+Pr(R=\Delta V|s^n=B)\times 0=\nu_G$.

where ΔP is a constant such that

$$\Delta P \equiv \sigma_H \Delta P_G + (1-\sigma_H)\Delta P_B = \left[\sigma_H(v_G-\rho_H) + (1-\sigma_H)(\rho_H - v_B)\right]\Delta V$$

Finally, we prove this is the only trading equilibrium. Consider a candidate equilibrium in which a mass $\eta^n > 0$ of informed investors does not trade at $t=0$ and waits to trade in $t=1$. For this trading behavior to be optimal, it must be $\hat{J}_0^n(s^n) \le \hat{J}_1^n(s^n)$, which requires $\tau^n(1-\lambda^n(1)) = 1$ and therefore $\lambda^n(1) = 0$. However, when a mass $\eta^n(1-\gamma) > 0$ of informed investors trades at $t=1$, the order flow at $t=1$ must be informative, which implies $\lambda^n(1) > 0$, a contradiction. ■

Proof of Proposition 1. Let $\Lambda > 0$ be

$$\Lambda = (1-\lambda^n)(1-\gamma\tau^n) = (1-\lambda^m)(1-\gamma\tau^m),$$

for all $n, m \in \mathcal{N}$ (see Eq. (11)). Then, we can write each λ^n as

$$\lambda^n = 1 - \frac{\Lambda}{1-\gamma\tau^n}. \tag{A.7}$$

By adding Eq. (A.7) for all $n \in \mathcal{N}$ and using the informational resource constraint Eq. (12), we can obtain

$$\Lambda = \frac{\frac{N\bar{z}-1}{\bar{z}}}{\sum_{n=1}^{N}\frac{1}{1-\gamma\tau^n}}. \tag{A.8}$$

Therefore, there exists a unique solution for each λ^n for all $n \in \mathcal{N}$ given $\{\tau^n\}_{n\in\mathcal{N}}$ from Eqs. (A.7)–(A.8).

Now, we prove that, fixing $\{\tau^m\}_{m\in\mathcal{N}\setminus\{n\}}$, λ^n is decreasing and concave in τ^n, where the notation $B \setminus A$ is the set difference, defined as $B\setminus A = \{x \in B | x \notin A\}$. For notational convenience, we represent Eqs. (A.7)–(A.8) as follows:

$$\lambda^n(\tau^n) = 1 - \frac{\frac{N\bar{z}-1}{\bar{z}}x(\tau^n)}{\sum_{m\in\mathcal{N}} x(\tau^m)},$$

where $x(\cdot)$ is a positive function such that

$$x(\tau) \equiv \frac{1}{1-\gamma\tau},$$

which is increasing in τ because

$$\frac{\partial x(\tau)}{\partial\tau} = \frac{\gamma}{(1-\gamma\tau)^2} = \gamma\,[x(\tau)]^2 > 0. \tag{A.9}$$

Because $x(\tau)$ is increasing in τ, $\lambda^n(\tau^n)$ becomes the smallest when $\tau^n = 1$ and $\tau^m = 0$, in which case we have

$$\lambda^n(1) = 1 - \frac{\frac{N\bar{z}-1}{\bar{z}}\frac{1}{1-\gamma}}{\frac{1}{1-\gamma}+N-1} = 1 - \frac{N-\frac{1}{\bar{z}}}{\gamma+(1-\gamma)N}.$$

Therefore, Eq. (4) is sufficient to guarantee that $\lambda^n(1)$ is positive.

The first-order derivative of λ^n with respect to τ^n is given by

$$\frac{\partial\lambda^n(\tau^n)}{\partial\tau^n} = -A \times \frac{\gamma\,[x(\tau^n)]^2}{\left(x(\tau^n) + \sum_{m\in\mathcal{N}\setminus\{n\}} x(\tau^m)\right)^2} < 0, \tag{A.10}$$

where A is a positive constant such that

$$A \equiv \left(\frac{N\bar{z}-1}{\bar{z}}\right)\sum_{m\in\mathcal{N}\setminus\{n\}} x(\tau^m).$$

which proves that λ^n is decreasing in τ^n.

Likewise, the second-order derivative of λ^n with respect to τ^n is

$$\frac{\partial^2\lambda^n(\tau^n)}{(\partial\tau^n)^2} = -A\left[\frac{2\gamma^2[x(\tau^n)]^3\left(x(\tau^n)+\sum_{m\in\mathcal{N}\setminus\{n\}}x(\tau^m)\right) - 2\gamma^2[x(\tau^n)]^4}{\left(x(\tau^n)+\sum_{m\in\mathcal{N}\setminus\{n\}}x(\tau^m)\right)^3}\right]$$
$$= -A\left[\frac{2\gamma^2[x(\tau^n)]^3\sum_{m\in\mathcal{N}\setminus\{n\}}x(\tau^m)}{\left(x(\tau^n)+\sum_{m\in\mathcal{N}\setminus\{n\}}x(\tau^m)\right)^3}\right] < 0,$$

which proves that λ^n is concave in τ^n.

Finally, we obtain

$$\frac{\partial\lambda^n(\tau^n)}{\partial\tau^m} = \left(\frac{N\bar{z}-1}{\bar{z}}\right)\frac{x(\tau^n)\gamma\,[x(\tau^m)]^2}{\left[\sum_m x(\tau^m)\right]^2} > 0. \tag{A.11}$$

■

Appendix B

We begin with a preliminary lemma.

Lemma B.3 (*Implicit Function*)**.** *Let the real-valued function $F(x,y)$ defined on the interval $I \subseteq [\underline{x},\bar{x}]\times[\underline{y},\bar{y}]$ be continuous, increasing in x and decreasing (respectively, increasing) in y. Furthermore, assume that for any x there is a unique y such that $F(x,y)=0$. Then, $F(x,y)=0$ uniquely defines a continuous, increasing (respectively, decreasing) function $f(x)$ such that $F(x,f(x))=0$.*

Proof. The fact that for any x there is a unique y such that $F(x,y)=0$ implies the existence of a unique mapping $f : [\underline{x},\bar{x}] \to [\underline{y},\bar{y}]$ such that $F(x,f(x))=0$.

Consider the case where F is decreasing in y. We show by contradiction that f is increasing. Assume not. Then, for some $x, x' \in [\underline{x},\bar{x}]$ such that $x' > x$ we have $f(x) \ge f(x')$ and therefore

$$0 = F(x', f(x')) \ge F(x', f(x)) > F(x, f(x)) = 0$$

where the weak inequality follows because F is decreasing in y, the strict inequality follows because F is increasing in x, and the equalities follow by definition of f. Hence, we have a contradiction. The case where F is increasing in y is identical.

Next, we show by contradiction that f is continuous on the interior of I. Assume not. Then there exist a point x_0, a value $\epsilon > 0$ and a sequence $\{h_n\}$ converging to zero as $n \to \infty$ such that $|f(x_0+h_n) - f(x_0)| \ge \epsilon$ for every $n \in \mathbb{N}$. By construction, the sequence $\{f(x_0+h_n)\}$ is bounded in $[\underline{y},\bar{y}]$. By the Bolzano–Weierstrass theorem, a sequence bounded by an interval has a subsequence converging in that interval. Thus, there is a subsequence $\{h_{n_k}\}$ and a value $\alpha \in [\underline{y},\bar{y}]$ such that $f(x_0+h_{n_k}) \to \alpha$ as $k\to\infty$. Since $|f(x_0+h_{n_k}) - f(x_0)| \ge \epsilon$ for every $k \in \mathbb{N}$, then $\alpha \ne f(x_0)$. Since and $(x_0+h_{n_k}, f(x_0+h_{n_k})) \to (x_0,\alpha)$ as $k\to\infty$ and F is continuous, we have $F(x_0+h_{n_k}, f(x_0+h_{n_k})) \to F(x_0,\alpha)$ as $k\to\infty$. Since $F(x_0+h_{n_k}, f(x_0+h_{n_k})) = 0$ for every $k\in\mathbb{N}$ and F is continuous, it must be that $F(x_0,\alpha)=0$. Since for each x there exists a unique value y solving $F(x,y)=0$, it must be that $\alpha = f(x_0)$, a contradiction. Right continuity at $\underline{x}$ and left continuity at $\bar{x}$ can be shown in the same way, and the proof is omitted. ■

Proof of Proposition 2. Given the LL constraint in Eq. (17), the PC constraint in Eq. (15) must not bind if the IC constraint in Eq. (16) is satisfied. Thus, it must be $w_B^{*n} = w_F^{*n} = w_\emptyset^{*n} = 0$ (i.e., the LL constraint binds for these states) and the IC constraint must bind, for otherwise shareholders could reduce the wage bill without violating the IC constraint. Hence, an optimal contract solves

$$\min_{\{w_G^n, w_S^n\}\in\mathbb{R}_+^2} \lambda^n\sigma_H w_G^n + (1-\lambda^n)(1-\delta\tau^n)\rho_H w_S^n \tag{B.1}$$

such that the IC constraint (16) binds,

$$\lambda^n\Delta\sigma u\left(w_G^n\right) + (1-\lambda^n)(1-\delta\tau^n)\Delta\rho u\left(w_S^n\right) = K. \tag{B.2}$$

Now, we prove the following lemmas to finish the proof.

Lemma B.4. *Eq. (3) implies $\Delta\sigma > \Delta\rho$, $v_G > v_B$, and $\rho_H/\Delta\rho > \sigma_H/\Delta\sigma$.*

Proof. By taking the difference of two equations in Eq. (3), we have

$$\Delta\rho = \Delta\sigma(v_G - v_B), \tag{B.3}$$

which implies $\Delta\sigma > \Delta\rho$, and $v_G > v_B$. Furthermore, Eq. (3) also implies that

$$\frac{\rho_H}{\Delta\rho} = \frac{\sigma_H(v_G - v_B)}{\Delta\rho} + \frac{v_B}{\Delta\rho}$$

which in turn together with Eq. (B.3) implies

$$\frac{\rho_H}{\Delta\rho} = \frac{\sigma_H}{\Delta\sigma} + \frac{v_B}{\Delta\rho} > \frac{\sigma_H}{\Delta\sigma}. \quad \square$$

Lemma B.5. *There exists a unique solution for the optimization problem in Eq. (B.1) such that $w_G^{*n} > w_S^{*n} > 0$ where w_G^{*n} and w_S^{*n} simultaneously solve*

$$\begin{aligned} \lambda^n \Delta\sigma u\left(w_G^{*n}\right) + (1-\lambda^n)\left(1-\delta\tau^{*n}\right)\Delta\rho u\left(w_S^{*n}\right) = K \\ \sigma_H \Delta\rho u'(w_S^{*n}) = \Delta\sigma\rho_H u'(w_G^{*n}). \end{aligned} \tag{B.4}$$

Furthermore, both w_G^{*n} and w_S^{*n} are continuously differentiable and increasing in τ^n, K, δ and decreasing in λ^n.

Proof. Because of the assumption that $u'(0) = \infty$, we can rule out any corner solution such that either $w_G^{*n} = 0$ or $w_S^{*n} = 0$. Therefore, we can drop non-negativity constraints for w_G^n, w_S^n. Then, the Lagrangian is given by

$$\mathcal{L} = \lambda^n \sigma_H w_G^n + (1-\lambda^n)(1-\delta\tau^n)\rho_H w_S^n + \psi\left[\begin{array}{c} K - \lambda^n\Delta\sigma u\left(w_G^n\right) \\ -(1-\lambda^n)(1-\delta\tau^n)\Delta\rho u\left(w_S^n\right)\end{array}\right],$$

where ψ is the Lagrangian multiplier. The first-order conditions with respect to w_G^n and w_S^n are given by

$$\sigma_H - \psi\Delta\sigma u'\left(w_G^{*n}\right) = 0, \quad \rho_H - \psi\Delta\rho u'\left(w_S^{*n}\right) = 0, \tag{B.5}$$

which implies

$$\frac{\sigma_H}{\rho_H} = \frac{\Delta\sigma}{\Delta\rho}\frac{u'(w_G^{*n})}{u'(w_S^{*n})}. \tag{B.6}$$

Therefore, we have $w_G^{*n} > w_S^{*n}$ because $u'(\cdot)$ is positive and decreasing (i.e., $u'(\cdot) > 0, u''(\cdot) < 0$), and also $\rho_H/\Delta\rho > \sigma_H/\Delta\sigma$ from Lemma B.4.

Using continuous differentiability and strict monotonicity of $u'(\cdot)$, we can obtain w_S^{*n} as a continuously differentiable function of w_G^{*n} using Eq. (B.6):

$$w_S^{*n} = \tilde{W}(w_G^{*n}) \equiv u'^{-1}\left(\frac{\rho_H}{\sigma_H}\frac{\Delta\sigma}{\Delta\rho}u'(w_G^{*n})\right), \tag{B.7}$$

which implies w_S^{*n} is increasing in w_G^{*n} because both $u'(\cdot)$ and $u'^{-1}(\cdot)$ are decreasing:[47]

$$\frac{\partial w_S^{*n}}{\partial w_G^{*n}} = \frac{\rho_H}{\sigma_H}\frac{\Delta\sigma}{\Delta\rho}\frac{u''(w_G^{*n})}{u''\left(w_S^{*n}\right)}. \tag{B.8}$$

The RHS in Eq. (B.7) is not defined for $w_G^{*n} = 0$. However, we note that $w_G^{*n} = 0$ if and only if $K = 0$, in which case also $w_S^{*n} = 0$. Therefore, we define the function $W(\cdot)$ to equal $\tilde{W}(\cdot)$ for $w_G^{*n} > 0$ and $W(0) = 0$. Since $0 < \tilde{W}(w_G^{*n}) < w_G^{*n}$ for any $w_G^{*n} > 0$, we have $\lim_{w_G^{*n}\to 0^+}\tilde{W}(w_G^{*n}) = 0$. Thus, $W(\cdot)$ is right-continuous at zero.

We can represent the IC constraint as

$$\lambda^n\Delta\sigma u\left(w_G^{*n}\right) + (1-\lambda^n)(1-\delta\tau^n)\Delta\rho u\left(W(w_G^{*n})\right) = K. \tag{B.9}$$

The LHS of Eq. (B.9) at $w_G^{*n} = 0$ is zero because $u(0) = 0$ and $W(0) = 0$. The LHS is greater than K as $w_G^{*n} \to \infty$ because $\lim_{w\to\infty} u(w) = \infty$. Because the LHS is an increasing continuous function of w_G^{*n}, the intermediate value theorem implies that for all $\tau^n, \delta, \lambda^n, K$ there exists a unique w_S^{*n} solving Eq. (B.9), which in turn implies the same for w_S^{*n} by Eq. (B.7). Furthermore, w_G^{*n} and w_S^{*n} simultaneously solve Eqs. (B.4) by construction.

For a given value of w_S^{*n}, the LHS of Eq. (B.9) is decreasing in δ and the RHS of Eq. (B.9) is increasing in K. Therefore, by Lemma B.3, w_G^{*n} is an increasing and continuous function of δ and K; since $W(\cdot)$ is increasing and continuous, so is w_S^{*n}. Similarly, the LHS of Eq. (B.9) is increasing in λ^n because $w_G^{*n} > W(w_G^{*n})$ and $\Delta\sigma > \Delta\rho$ (Lemma B.4). Therefore, by Lemma B.3, w_G^{*n} is a decreasing and continuous function of λ^n; since $W(\cdot)$ is increasing and continuous, so is w_S^{*n}.

Next, we prove that both w_G^{*n} and w_S^{*n} increase in τ^n. Note that τ^n enters Eq. (B.9) directly but also indirectly through λ^n. For the direct effect, the LHS of Eq. (B.9) is decreasing in τ^n at any level of w_G^{*n} (because $u(\cdot)$ is positive), whereas the RHS is a constant. For the indirect effect, Proposition 1 implies that $\frac{\partial\lambda^n(\tau^n)}{\partial\tau^n} < 0$, and we previously established that the LHS of Eq. (B.9) is increasing in λ^n. Therefore, the LHS of Eq. (B.9) is decreasing in τ^n. Therefore, by Lemma B.3, w_G^{*n} is an increasing and continuous function of λ^n; since $W(\cdot)$ is increasing and continuous, so is w_S^{*n}.

Continuous differentiability of w_G^{*n}, w_S^{*n} follows from continuous differentiability of $u(\cdot), W(\cdot), \lambda^n$ and the Implicit Function Theorem. ■

Lemma B.6. *Under the optimal contract, $\mathcal{W}^n$ is increasing in τ^n.*

Proof. At optimum, the following should be true:

$$\begin{aligned}\mathcal{W}^n = &\lambda^n\sigma_H w_G^{*n} + (1-\lambda^n)(1-\delta\tau^n)\rho_H w_S^{*n} \\ &+ \psi\left[K - \lambda^n\Delta\sigma u\left(w_G^{*n}\right) - (1-\lambda^n)(1-\delta\tau^n)\Delta\rho u\left(w_S^{*n}\right)\right].\end{aligned}$$

Then, the Envelope theorem implies

$$\begin{aligned}\frac{\partial\mathcal{W}^n}{\partial\tau^n} = &\frac{\partial\lambda^n}{\partial\tau^n}\sigma_H w_G^{*n} - \left(\frac{\partial\lambda^n}{\partial\tau^n}(1-\delta\tau^n) + (1-\lambda^n)\delta\right)\rho_H w_S^{*n} \\ &- \psi\frac{\partial\lambda^n}{\partial\tau^n}\Delta\sigma u\left(w_G^{*n}\right) + \psi\left(\frac{\partial\lambda^n}{\partial\tau^n}(1-\delta\tau^n) + (1-\lambda^n)\delta\right)\Delta\rho u\left(w_S^{*n}\right).\end{aligned} \tag{B.10}$$

Substituting the first-order conditions in Eq. (B.5) into Eq. (B.10), we have

$$\begin{aligned}\frac{\partial\mathcal{W}^n}{\partial\tau^n} &= \frac{\partial\lambda^n}{\partial\tau^n}\sigma_H\Psi(w_G^{*n}) - \left(\frac{\partial\lambda^n}{\partial\tau^n}(1-\delta\tau^n) + (1-\lambda^n)\delta\right)\rho_H\Psi(w_S^{*n}) \\ &= \frac{\partial\lambda^n}{\partial\tau^n}\left[\sigma_H\Psi(w_G^{*n}) - \rho_H(1-\delta\tau^n)\Psi(w_S^{*n})\right] - (1-\lambda^n)\delta\rho_H\Psi(w_S^{*n})\end{aligned} \tag{B.11}$$

where

$$\Psi(w) \equiv w - \frac{u(w)}{u'(w)} < 0, \tag{B.12}$$

which is a decreasing function because of the concavity of $u(\cdot)$:

$$\Psi'(w) = 1 - \frac{\left(u'(w)\right)^2 - u(w)u''(w)}{(u'(w))^2} = \frac{u(w)u''(w)}{(u'(w))^2} < 0. \tag{B.13}$$

Because $\Psi(\cdot) < 0, \Psi'(\cdot) < 0$ and $w_G^{*n} > w_S^{*n}$ (Lemma B.5), we have $\Psi(w_G^{*n}) < \Psi(w_S^{*n}) < 0$.

We now claim that

$$\frac{u'(w_S^{*n})}{u'(w_G^{*n})} < \frac{\Psi(w_G^{*n})}{\Psi(w_S^{*n})}. \tag{B.14}$$

To see this, note that Eq. (B.14) is equivalent to

$$u'(w_S^{*n})\Psi(w_S^{*n}) > u'(w_G^{*n})\Psi(w_G^{*n}),$$

which is always true because $w_G^{*n} > w_S^{*n}$ (Lemma B.5) and $u'(w)\Psi(w)$ is decreasing in w due to the concavity of $u(\cdot)$, i.e.,

$$\left[u'(w)\Psi(w)\right]' = u''(w)\Psi(w) + u'(w)\Psi'(w) = wu''(w) < 0. \tag{B.15}$$

[47] Due to strict concavity of $u(\cdot)$, it is immediate that $u'(\cdot)$ is decreasing. For Likewise, $u'^{-1}(\cdot)$ is decreasing because

$$\frac{\partial u'^{-1}(y)}{\partial y} = \frac{1}{u''(u'^{-1}(y))} < 0.$$

Furthermore, Eq. (B.6), together with $\Delta\sigma > \Delta\rho$ (Lemma B.4), implies that

$$\frac{\rho_H}{\sigma_H} < \frac{u'(w_S^{*n})}{u'(w_G^{*n})}. \tag{B.16}$$

Therefore, Eqs. (B.14) and (B.16) imply that

$$\frac{\rho_H}{\sigma_H} < \frac{u'(w_S^{*n})}{u'(w_G^{*n})} < \frac{\Psi(w_G^{*n})}{\Psi(w_S^{*n})},$$

which in turn proves that

$$\sigma_H \Psi(w_G^{*n}) - \rho_H (1-\delta\tau^n)\Psi(w_S^{*n}) < \sigma_H \Psi(w_G^{*n}) - \rho_H \Psi(w_S^{*n}) < 0. \tag{B.17}$$

Because $\partial\lambda^n/\partial\tau^n$ is negative (Proposition 1), Eq. (B.17) implies that the first term in Eq. (B.11) is positive. Because $\Psi(\cdot)$ is negative (Eq. (B.12)), the second term in Eq. (B.11) is also positive. Therefore $\partial\mathcal{W}^n/\partial\tau^n$ is positive, which proves that $\mathcal{W}^n$ is increasing in τ^n. ■

Lemma B.7. *Under the optimal contract, $\mathcal{W}^n$ is convex in τ^n.*

Proof. From Eq. (B.11), we can obtain the second-order derivative of $\mathcal{W}^n$ with respect to τ^n as follows:

$$\begin{aligned}\frac{\partial^2\mathcal{W}^n}{(\partial\tau^n)^2} =& \frac{\partial^2\lambda^n}{(\partial\tau^n)^2}\left[\sigma_H\Psi(w_G^{*n}) - (1-\delta\tau^n)\rho_H\Psi(w_S^{*n})\right] \\ &+ \frac{\partial\lambda^n}{\partial\tau^n}\delta\rho_H\Psi(w_S^{*n}) - (1-\lambda^n)\delta\rho_H\Psi'(w_S^{*n})\frac{\partial w_S^{*n}}{\partial\tau^n} \\ &+ \frac{\partial\lambda^n}{\partial\tau^n}\left[\sigma_H\Psi'(w_G^{*n})\frac{\partial w_G^{*n}}{\partial\tau^n} - (1-\delta\tau^n)\rho_H\Psi'(w_S^{*n})\frac{\partial w_S^{*n}}{\partial\tau^n}\right].\end{aligned} \tag{B.18}$$

Because $\partial^2\lambda^n/(\partial\tau^n)^2$ is negative (Proposition 1), Eq. (B.17) implies that the first term in Eq. (B.18) is positive. Because $\partial\lambda^n/\partial\tau^n$ is negative (Proposition 1), and $\Psi(\cdot)$ is negative (Eq. (B.12)), the second term in Eq. (B.18) is also positive. Because $\Psi'(\cdot)$ is negative (Eq. (B.13)) and $\partial w_S^{*n}/\partial\tau^n$ is positive (Lemma B.5), the third term is also positive.

Now, we prove that the fourth term in Eq. (B.18) is also positive. Using Eq. (B.8) we obtain

$$\frac{\partial w_S^{*n}}{\partial\tau^n} = \frac{\rho_H}{\sigma_H}\frac{\Delta\sigma}{\Delta\rho}\frac{u''(w_G^{*n})}{u''\left(w_S^{*n}\right)}\frac{\partial w_G^{*n}}{\partial\tau^n}. \tag{B.19}$$

Then, we have

$$\begin{aligned}&\sigma_H\Psi'(w_G^{*n})\frac{\partial w_G^{*n}}{\partial\tau^n} - (1-\delta\tau^n)\rho_H\Psi'(w_S^{*n})\frac{\partial w_S^{*n}}{\partial\tau^n} \\ &= \frac{\partial w_G^{*n}}{\partial\tau^n}\left[\sigma_H\Psi'(w_G^{*n}) - (1-\delta\tau^n)\rho_H\Psi'(w_S^{*n})\left(\frac{\rho_H}{\sigma_H}\frac{\Delta\sigma}{\Delta\rho}\right)\frac{u''(w_G^{*n})}{u''\left(w_S^{*n}\right)}\right] \\ &= \sigma_H\frac{u''(w_G^{*n})}{\left(u'(w_G^{*n})\right)^2}\frac{\partial w_G^{*n}}{\partial\tau^n}\left[u(w_G^{*n}) - (1-\delta\tau^n)\left(\frac{\rho_H^2}{\sigma_H^2}\frac{\Delta\sigma}{\Delta\rho}\right)u(w_S^{*n})\left(\frac{u'(w_G^{*n})}{u'(w_S^{*n})}\right)^2\right] \\ &= \sigma_H\frac{u''(w_G^{*n})}{\left(u'(w_G^{*n})\right)^2}\frac{\partial w_G^{*n}}{\partial\tau^n}\left[u(w_G^{*n}) - (1-\delta\tau^n)\left(\frac{\Delta\rho}{\Delta\sigma}\right)u(w_S^{*n})\right] < 0,\end{aligned} \tag{B.20}$$

where the first equality is due to Eq. (B.19), the second equality is due to Eq. (B.12), and the third equality is due to Eq. (B.6). Because $u(w_G^{*n}) > u(w_S^{*n})$ (Lemma B.5) and $\Delta\rho/\Delta\sigma < 1$ (Lemma B.4), we have

$$u(w_G^{*n}) - (1-\delta\tau^n)\left(\frac{\Delta\rho}{\Delta\sigma}\right)u(w_S^{*n}) > 0. \tag{B.21}$$

Then, the last inequality in Eq. (B.20) holds because $u'' < 0$ and $w_S^{*n}/\partial\tau^n$ is positive (Lemma B.5).

Finally, because $\partial\lambda^n/\partial\tau^n$ is negative (Proposition 1), Eq. (B.20) implies that the fourth term in Eq. (B.18) is positive.

Because all four terms in Eq. (B.18) are positive, the second-order derivative of $\mathcal{W}^n$ with respect to τ^n is positive, which finishes the proof of strict convexity of $\mathcal{W}^n$. ■

Appendix C

Proof of Proposition 3. We define a mapping $\Upsilon^n : [0,1] \to \mathbb{R}$ as follows:

$$\Upsilon^n(\tau^n) \equiv \frac{\partial\mathcal{V}^n(\tau^n)}{\partial\tau^n} - \frac{\partial\mathcal{W}^n(\tau^n)}{\partial\tau^n} = f'(\tau^n) - \frac{\partial\mathcal{W}^n(\tau^n)}{\partial\tau^n}.$$

Then, $\Upsilon^n(\tau^n) = 0$ is equivalent to the first-order condition in Eq. (22) for the optimization problem in Eq. (21). Because f is concave and $\mathcal{W}^n$ is convex in τ^n (Proposition 2), $\Upsilon^n(\tau^n)$ is decreasing in τ^n, i.e.,

$$\frac{\partial\Upsilon^n(\tau^n)}{\partial\tau^n} = f''(\tau^{*n}) - \frac{\partial^2\mathcal{W}^n}{(\partial\tau^n)^2} < 0.$$

Furthermore, we have

$$\Upsilon^n(0) = f'(0) - \left.\frac{\partial\mathcal{W}^n}{\partial\tau^n}\right|_{\tau^n=0} < 0, \quad\text{and}\quad \Upsilon^n(1) = f'(1) - \left.\frac{\partial\mathcal{W}^n}{\partial\tau^n}\right|_{\tau^n=1} > 0.$$

because $f'(0) = \infty$ and $f'(1) = 0$, and $\partial\mathcal{W}^n/\partial\tau^n$ is positive (Lemma B.6) and finite for all $\tau^n \in [0,1]$.[48]

Therefore the intermediate value theorem implies that the first-order condition is satisfied (i.e., $\Upsilon^n(\tau^n) = 0$) at an interior point $\tau^n \in (0,1)$.

Proof of Proposition 4. We prove the proposition with a corollary of the following lemma:

Lemma C.8 (*Supermodularity*). *Consider the simultaneous move game played by the N firms when choosing the project maturity. Each firm chooses $\tau^n \in [0,1]$ to maximize $\mathcal{V}^n(\tau^n) - \mathcal{W}^n(\tau^n)$, where $\mathcal{V}^n(\tau^n)$ is defined in the text and $\mathcal{W}^n(\tau^n)$ is the wage bill under the optimal contract given τ^n in Eq. (14). This game is supermodular if either (i) $(N-1)(1-\gamma) \geq 1$, or if (ii) the manager has CRRA utility, $u(x) = \frac{x^{1-\alpha}}{1-\alpha}$, and $\alpha \in (\bar{\alpha}, 1)$, for some $\bar{\alpha} \in (0,1)$.*

Proof. By the maximum theorem, $\mathcal{W}^n(\tau^n)$ is continuous in τ^n and in τ^m for all $m \in \mathcal{N} \setminus \{n\}$, and so are firms' objective functions. The strategy space is compact since $\tau^n \in [0,1]$. Therefore, the game is supermodular if each firm's objective function has increasing differences in maturity choices, that is, for all n and $m \in \mathcal{N} \setminus \{n\}$,

$$\frac{\partial^2\left(\mathcal{V}^n(\tau^n) - \mathcal{W}^n(\tau^n)\right)}{\partial\tau^n\partial\tau^m} \geq 0. \tag{C.1}$$

Since $\mathcal{V}^n(\tau^n)$ is not a function of τ^m for all $m \in \mathcal{N} \setminus \{n\}$, (C.1) is equivalent to

$$\frac{\partial^2\mathcal{W}^n(\tau^n)}{\partial\tau^n\partial\tau^m} \leq 0. \tag{C.2}$$

By Eq. (B.11), we have:

$$\begin{aligned}\frac{\partial^2\mathcal{W}^n}{\partial\tau^n\partial\tau^m} =& \frac{\partial^2\lambda^n}{\partial\tau^n\partial\tau^m}\left[\sigma_G\Psi(w_G^{*n}) - \rho_H(1-\delta\tau^n)\Psi(w_S^{*n})\right] \\ &+ \frac{\partial\lambda^n}{\partial\tau^n}\left(\sigma_G\Psi'(w_G^{*n}) - \rho_H(1-\delta\tau^n)\Psi'(w_S^{*n})\frac{\partial w_S^{*n}}{\partial w_G^{*n}}\right)\frac{\partial w_G^{*n}}{\partial\lambda^n}\frac{\partial\lambda^n}{\partial\tau^m} \\ &+ \frac{\partial\lambda^n}{\partial\tau^m}\delta\rho_H\left[\Psi(w_S^{*n}) - (1-\lambda^n)\Psi'(w_S^{*n})\frac{\partial w_S^{*n}}{\partial w_G^{*n}}\frac{\partial w_G^{*n}}{\partial\lambda^n}\right].\end{aligned} \tag{C.3}$$

Using Eq. (B.6) we obtain

$$\frac{\partial w_S^{*n}}{\partial w_G^{*n}} = \frac{u''\left(w_G^{*n}\right)}{u''\left(w_S^{*n}\right)}\frac{\rho_H\Delta\sigma}{\sigma_H\Delta\rho}. \tag{C.4}$$

[48] Because the amounts of optimal compensation w_G^{*n} and w_S^{*n} are finite, it is immediate that $\partial\mathcal{W}^n/\partial\tau^n$ is finite from Eqs. (A.10) and (B.11).

Using Eqs. (B.6) and implicit differentiation of Eq. (B.9) to compute $\frac{\partial w_G^{*n}}{\partial \lambda^n}$, after some straightforward manipulation we obtain

$$\left(\sigma_G \Psi'(w_G^{*n}) - \rho_H (1-\delta\tau^n)\Psi'(w_S^{*n})\frac{\partial w_S^{*n}}{\partial w_G^{*n}}\right)\frac{\partial w_G^{*n}}{\partial \lambda^n} = \Gamma$$

where we define

$$\Gamma \equiv \frac{\left(\sigma_G \frac{u\left(w_G^{*n}\right)}{u'\left(w_G^{*n}\right)} - \rho_H (1-\delta\tau^n)\frac{u\left(w_S^{*n}\right)}{u'\left(w_S^{*n}\right)}\right)^2}{\lambda^n \sigma_H w_G^{*n} R\left(w_G^{*n}\right)^{-1} + (1-\lambda^n)\rho_H(1-\delta\tau^n)w_S^{*n} R\left(w_S^{*n}\right)^{-1}} > 0.$$

Since $\frac{\partial \lambda^n}{\partial \tau^m} > 0, \Psi(w_S^{*n}) < 0, \Psi'(w_S^{*n}) < 0, \frac{\partial w_S^{*n}}{\partial w_G^{*n}} > 0$ (Eq. (C.4)) and $\frac{\partial w_G^{*n}}{\partial \lambda^n} < 0$ (Lemma B.5), the third line in Eq. (C.3) is negative. Therefore, for (C.2) to hold it is sufficient to show that

$$\frac{\partial^2 \lambda^n}{\partial \tau^n \partial \tau^m}\left[\sigma_G \Psi(w_G^{*n}) - \rho_H (1-\delta\tau^n)\Psi(w_S^{*n})\right] + \frac{\partial \lambda^n}{\partial \tau^n}\frac{\partial \lambda^n}{\partial \tau^m}\Gamma \le 0. \tag{C.5}$$

Since $\frac{\partial \lambda^n}{\partial \tau^n} < 0$, $\frac{\partial \lambda^n}{\partial \tau^m} > 0, \Gamma > 0$, and $\left[\sigma_G \Psi(w_G^{*n}) - \rho_H (1-\delta\tau^n)\Psi(w_S^{*n})\right] < 0$ (Eq. (B.17)), a sufficient condition for (C.5) is that $\frac{\partial^2 \lambda^n}{\partial \tau^n \partial \tau^n} \ge 0$. Using the expression for λ^n in the proof of Proposition 1, we obtain

$$\frac{\partial^2 \lambda^n}{\partial \tau^n \partial \tau^m} = \left(\frac{N\bar{z}-1}{\bar{z}}\right)\frac{\gamma^2 [x(\tau^n)]^2 [x(\tau^m)]^2 \left(\sum_{m\in\mathcal{N}\setminus\{n\}} x(\tau^m) - x(\tau^n)\right)}{\left(\sum_{m\in\mathcal{N}} x(\tau^m)\right)^3}. \tag{C.6}$$

Therefore

$$sign\left(\frac{\partial^2 \lambda^n}{\partial \tau^n \partial \tau^m}\right) = sign\left(\sum_{m\in\mathcal{N}\setminus\{n\}} x(\tau^m) - x(\tau^n)\right).$$

Because $x(\tau)$ is increasing, we have that $\sum_{m\in\mathcal{N}\setminus\{n\}} x(\tau^m) - x(\tau^n) \ge 0$ if $(N-1)\,x(0) \ge x(1)$, which is equivalent to

$$(N-1)(1-\gamma) \ge 1. \tag{C.7}$$

In the proof of Theorem 1, we show that the number of listed firms in equilibrium must be such that $1/(N\bar{z}) < 1$, for otherwise listed firms' shareholder value exceeds that of unlisted firms. Hence, Eq. (C.7) is satisfied for $\left(\frac{1}{\bar{z}} - 1\right)(1-\gamma) \ge 1$, as stated in Eq. (5) in the main text.

As an alternative sufficient condition that does not depend on investor preferences or the number of firms, we consider the case where the manager has CRRA utility as stated in the lemma. With this assumption, (C.5) can be rewritten as

$$\frac{w_G^{*n}\eta}{1-\alpha}\left(\frac{\partial^2 \lambda^n}{\partial \tau^n \partial \tau^n} + \frac{\partial \lambda^n}{\partial \tau^n}\frac{\partial \lambda^n}{\partial \tau^m}\frac{\eta}{(1-\alpha)\left(\lambda^n \sigma_H + (1-\lambda^n)\rho_H(1-\delta\tau^n)\xi\right)}\right) \le 0, \tag{C.8}$$

where we define

$$\xi = \left(\frac{\Delta\sigma\rho_H}{\Delta\rho\sigma_H}\right)^{-\frac{1}{\alpha}}$$
$$\eta = \sigma_H - \rho_H(1-\delta\tau^n)\xi.$$

We find that

$$\lim_{\alpha\longrightarrow 1^-}\frac{\eta}{(1-\alpha)\left(\lambda^n \sigma_H + (1-\lambda^n)\rho_H(1-\delta\tau^n)\xi\right)} = \infty.$$

Since $\frac{\partial \lambda^n}{\partial \tau^n}\frac{\partial \lambda^n}{\partial \tau^m} < 0$ and $\frac{\partial \lambda^n}{\partial \tau^n}, \frac{\partial \lambda^n}{\partial \tau^m}$, and $\frac{\partial^2 \lambda^n}{\partial \tau^n \partial \tau^n}$ do not depend on the parameter α, we have

$$\lim_{\alpha\longrightarrow 1^-}\frac{\partial^2 \lambda^n}{\partial \tau^n \partial \tau^n} + \frac{\partial \lambda^n}{\partial \tau^n}\frac{\partial \lambda^n}{\partial \tau^m}\frac{\eta}{(1-\alpha)\left(\lambda^n \sigma_H + (1-\lambda^n)\rho_H(1-\delta\tau^n)\xi\right)} = -\infty.$$

Since $\frac{w_G^{*n}\eta}{1-\alpha} > 0$ for $\alpha \in (0,1)$, then (C.8) holds for α sufficiently close to one. ■

The following corollary provides the proof of Proposition 4:

Corollary 1. *Under the conditions in Lemma C.8, the best response τ^{*n} in Proposition 3 is increasing in other firms' maturity choices, that is,*

$$\frac{\partial \tau^{*n}}{\partial \tau^m} > 0 \quad \textit{for all } m \in \mathcal{N}\setminus\{n\}.$$

Proof. Increasing best responses is a standard property for supermodular games (e.g., Topkis, 1998). ■

Appendix D

Proof of Theorem 1. We prove the theorem in three steps. As a first step, we take the number of listed firms N as given and we prove the listed firms' choice of project duration, managerial compensation, and shareholder value in Eqs. (26)–(30). Step (ii) provides technical lemmas. Step (iii) combines those lemmas to derive the threshold γ^* and its dependency on the parameter K.

Step (i). In this step, we focus on the listed firms' equilibrium choices taking the number N of listed firms as given. First, we assume $N > 1/\bar{z}$. This must be true in equilibrium, as shown below in Step (ii) of this proof. Second, we note that payoff functions are symmetric and best responses are increasing (Proposition 4). Therefore, listed firms' project maturity choices must be symmetric in any pure strategy equilibrium. We proceed to show that such a symmetric choice of project maturity exists and is unique.

In case of a symmetric project maturity choice, $\tau^m = \tau^*$ for all $m \in \mathcal{N}$, Eq. (A.10) implies that the sensitivity of price informativeness to τ^n, denoted by $\Theta(\tau^*)$, is given by

$$\Theta(\tau^*) \equiv \left.\frac{\partial \lambda^n(\tau^n)}{\partial \tau^n}\right|_{\tau^n=\tau^*,\tau^m=\tau^*,\forall m\in\mathcal{N}\setminus\{n\}} = -\frac{\gamma(N-1)(N\bar{z}-1)}{N^2\bar{z}(1-\gamma\tau^*)} < 0, \tag{D.1}$$

which is decreasing in τ^* because

$$\Theta'(\tau^*) = -\frac{\gamma^2(N-1)(N\bar{z}-1)}{N^2\bar{z}(1-\gamma\tau^*)^2} < 0. \tag{D.2}$$

For clarity, throughout this proof, we denote $w_G^*(\tau^*)$ and $w_S^*(\tau^*)$ as functions of τ^* explicitly. $w_G^*(\tau^*)$ and $w_S^*(\tau^*)$ are the optimal compensation for states $\omega = G$ and $\omega = S$ given maturity choice τ^* according to Proposition 2. We define an equilibrium mapping $\hat{Y} : [0,1] \to \mathbb{R}$ as follows:

$$\begin{aligned}\hat{Y}(\tau^*) \equiv\ & f'(\tau^*) - \Theta(\tau^*)\left[\sigma_H \Psi(w_G^*(\tau^*)) - \rho_H\left(1-\delta\tau^*\right)\Psi(w_S^*(\tau^*))\right] \\ & + \left(1-\frac{1}{N\bar{z}}\right)\delta\rho_H \Psi(w_S^*(\tau^*)).\end{aligned} \tag{D.3}$$

Then, it is clear that the solution τ^* for $\hat{Y}(\tau^*) = 0$ is the solution for the first-order condition in Eq. (22) under the assumption that $\tau^m = \tau^*$ for all $m \in \mathcal{N}\setminus\{n\}$, and vice versa. Therefore, it is sufficient to prove that a unique interior solution exists for the equation $\hat{Y}(\tau^*) = 0$ to finish the proof of this first step.

The first-order derivative of $\hat{Y}(\cdot)$ with respect to τ^* is given by

$$\begin{aligned}\frac{\partial \hat{Y}(\tau^*)}{\partial \tau^*} =\ & f''(\tau^*) - \Theta'(\tau^*)\left[\sigma_H \Psi(w_G^*(\tau^*)) - \rho_H\left(1-\delta\tau^*\right)\Psi(w_S^*(\tau^*))\right] \\ & - \Theta(\tau^*)\rho_H \delta \Psi(w_S^*(\tau^*)) \\ & - \Theta(\tau^*)\left[\sigma_H \Psi'(w_G^*(\tau^*))\left.\frac{\partial w_G^*(\tau^n)}{\partial \tau^n}\right|_{\tau^n=\tau^*}\right. \\ & \left.- \rho_H\left(1-\delta\tau^*\right)\Psi'(w_S^*(\tau^*))\left.\frac{\partial w_S^*(\tau^n)}{\partial \tau^n}\right|_{\tau^n=\tau^*}\right] \\ & + \left(1-\frac{1}{N\bar{z}}\right)\delta\rho_H \Psi'(w_S^*(\tau^*))\left.\frac{\partial w_S^*(\tau^n)}{\partial \tau^n}\right|_{\tau^n=\tau^*}.\end{aligned}$$

The first term is negative because f is concave. The second term is negative due to Eqs. (B.17) and (D.2). The third term is negative because $\Psi(\cdot)$ is negative (Eq. (B.13)) and $\Theta(\cdot)$ is negative (D.1). The fourth term is negative due to Eqs. (B.20) and (D.1). The fifth term is negative because $1 - 1/(N\bar{z})$ is positive, $\Psi'(\cdot)$ is negative (Eq. (B.13)), and $\partial w_S^{*n}/\partial\tau^n$ is positive (Lemma B.5).[49] Because all five terms in the RHS is negative, $\hat{Y}(\cdot)$ is decreasing in τ^*. Furthermore, we have

$$\hat{Y}(0) = f'(0) - \Theta(0)\left[\sigma_H\Psi(w_G^*(0)) - \rho_H(1-\delta)\Psi(w_S^*(0))\right] + \left(1-\frac{1}{N\bar{z}}\right)\delta\rho_H\Psi(w_S^*(0)) > 0,$$

because $f'(0) = \infty$ and the second and the third terms are finite similarly as in the proof of Proposition 3. Likewise, we have

$$\hat{Y}(1) = f'(1) - \Theta(1)\left[\sigma_H\Psi(w_G^*(1)) - \rho_H(1-\delta)\Psi(w_S^*(1))\right] + \left(1-\frac{1}{N\bar{z}}\right)\delta\rho_H\Psi(w_S^*(1)) < 0,$$

because $f'(1) = 0$ and the second and the third terms are negative. The second term is negative due to Eqs. (B.17) and (D.1). The third term is negative because $\Psi(\cdot)$ is negative.

Therefore the intermediate value theorem implies a unique equilibrium choice of project maturity for listed firms.

Step (ii). In this step, we provide five technical lemmas.

Lemma D.9. *In an equilibrium, the number of listed firms N must satisfy $N > \frac{1}{\bar{z}}$.*

Proof. By contradiction, assume $N \le \frac{1}{\bar{z}}$. Then, each listed firm's price is fully revealing regardless of project maturity choices because

$$\lambda^n = \frac{1}{\bar{z}} - \sum_{m\in\mathcal{N}\setminus\{n\}}\lambda^m \ge \frac{1}{\bar{z}} - (N-1) \ge 1, \tag{D.4}$$

where the equality in Eq. (D.4) is simply a restatement of the informational resource constraint in Eq. (12), the first inequality in Eq. (D.4) follows from the fact that each λ^m is a probability, and the second inequality follows from $N \le 1/\bar{z}$. Thus, we have $\frac{\partial\lambda^n}{\partial\tau^n} = 0$ and $\lambda^n = 1$, in which case Proposition 3 implies that $\tau^{*n} = 1$ and $w_G^* = u^{-1}\left(\frac{K}{\Delta\sigma}\right)$. Therefore, each listed firm's shareholder value with fully revealing prices, denoted S^{FR}, equals

$$S^{FR} = f(1) + \rho_H\Delta V - \sigma_H u^{-1}\left(\frac{K}{\Delta\sigma}\right). \tag{D.5}$$

Eq. (D.5) and the definition of S^U in Eq. (24) imply

$$S^{FR} > S^U \iff K < \Delta\sigma u\left(\frac{\Delta\rho\Delta V}{\sigma_H}\right) \equiv \bar{K}. \tag{D.6}$$

Therefore, if $N \le \frac{1}{\bar{z}}$ no firm would optimally remain unlisted. But since $M > \frac{1}{\bar{z}}$ by assumption, then $N \le \frac{1}{\bar{z}}$ implies $N < M$, that is, some firms must find it optimal to remain unlisted, a contradiction. ■

Lemma D.10. *τ^* and S^* are continuous, strictly decreasing functions of K. Furthermore, $\tau^*|_{K=0} = 1$ and $S^*|_{K=0} = f(1) + \rho_H\Delta V$.*

Proof. We first show that τ^* is decreasing in K. In Step (i) we established that $\hat{Y}(\tau^*)$ is decreasing in τ^*. Next, we prove that $\hat{Y}(\tau^*)$ is decreasing in K. We have

$$\frac{\partial\hat{Y}(\tau^*)}{\partial K} = -\Theta(\tau^*)\frac{\partial\left[\sigma_H\Psi(w_G^*(\tau^*)) - \rho_H(1-\delta\tau^*)\Psi(w_S^*(\tau^*))\right]}{\partial K} + \left(1-\frac{1}{N\bar{z}}\right)\delta\rho_H\Psi'(w_S^*(\tau^*))\frac{\partial w_S^*(\tau^*)}{\partial K}. \tag{D.7}$$

We prove that the first term in Eq. (D.7) is negative. Omitting explicit dependence on τ^* to ease notation, we have

$$\begin{aligned}
&\frac{\partial\left[\sigma_H\Psi(w_G^*) - \rho_H(1-\delta\tau^*)\Psi(w_S^*)\right]}{\partial K}\\
&= \sigma_H\Psi'(w_G^{*n})\frac{\partial w_G^{*n}}{\partial K} - (1-\delta\tau^n)\rho_H\Psi'(w_S^{*n})\frac{\partial w_S^{*n}}{\partial K}\\
&= \frac{\partial w_G^{*n}}{\partial K}\left[\sigma_H\Psi'(w_G^{*n}) - (1-\delta\tau^n)\rho_H\Psi'(w_S^{*n})\left(\frac{\rho_H}{\sigma_H}\frac{\Delta\sigma}{\Delta\rho}\right)\frac{u''(w_G^{*n})}{u''\left(w_S^{*n}\right)}\right]\\
&= \sigma_H\frac{u''(w_G^{*n})}{\left(u'(w_G^{*n})\right)^2}\frac{\partial w_G^{*n}}{\partial K}\left[u(w_G^{*n}) - (1-\delta\tau^n)\left(\frac{\rho_H^2}{\sigma_H^2}\frac{\Delta\sigma}{\Delta\rho}\right)u(w_S^{*n})\left(\frac{u'(w_G^{*n})}{u'(w_S^{*n})}\right)^2\right]\\
&= \sigma_H\frac{u''(w_G^{*n})}{\left(u'(w_G^{*n})\right)^2}\frac{\partial w_G^{*n}}{\partial K}\left[u(w_G^{*n}) - (1-\delta\tau^n)\left(\frac{\Delta\rho}{\Delta\sigma}\right)u(w_S^{*n})\right] < 0,
\end{aligned} \tag{D.8}$$

where the second equality is due to Eq. (B.8), the third equality is due to Eq. (B.12), and the fourth equality is due to Eq. (B.6). Because $u'' < 0$, $\frac{\partial w_G^{*n}}{\partial K} > 0$ (Lemma B.5), and $u(w_G^{*n}) - (1-\delta\tau^n)\left(\frac{\Delta\rho}{\Delta\sigma}\right)u(w_S^{*n}) > 0$ (Eq. (B.21)), then Eq. (D.8) is negative. Since $\Theta(\tau^*) < 0$ (Eq. (D.1), the first term in Eq. (D.7) is indeed negative.

Finally, because $\Psi' < 0$ and $\frac{\partial w_S^*(\tau^*)}{\partial K} > 0$ (Lemma B.5), the second term in Eq. (D.7) is also negative.

Since for all K there is a unique τ^* solving $\hat{Y}(\tau^*) = 0$, and $\hat{Y}(\tau^*)$ is continuous and decreasing in τ^* and K (Lemma B.5), Lemma B.3 implies τ^* is continuous and decreasing in K. Furthermore, for $K = 0$, $w_G^* = w_S^* = 0$. Since $\Psi(0) = 0$, Eq. (D.3) implies, for $K = 0$, $\hat{Y}(\tau^*) = 0$ is solved by $\tau^* = 1$, that is, $\tau^*|_{K=0} = 1$. Therefore, $S^*|_{K=0} = f(1) + \rho_H\Delta V$.

Next, we prove S^* is decreasing in K. By Eq. (38) we have

$$\frac{\partial S^*}{\partial K} = \left(f'\left(\tau^*\right) - \frac{\partial\mathcal{W}^n}{\partial\tau^*}\right)\frac{\partial\tau^*}{\partial K} - \frac{\partial\mathcal{W}^n}{\partial K}. \tag{D.9}$$

By the Envelope Theorem (see the proof of Lemma B.6) we have

$$\frac{\partial\mathcal{W}^n}{\partial\tau^*} = -\left(1-\frac{1}{Nz}\right)\delta\rho_H\psi\left(w_S^*\right), \tag{D.10}$$

$$\frac{\partial\mathcal{W}^n}{\partial K} = \frac{\sigma_H}{\Delta\sigma u'\left(w_S^*\right)}. \tag{D.11}$$

Substituting $\frac{\partial\mathcal{W}^n}{\partial\tau^*}$ and $\frac{\partial\mathcal{W}^n}{\partial K}$ in Eqs. (D.10)–(D.11) into $\frac{\partial S^*}{\partial K}$ in Eq. (D.9), using $\hat{Y}(\tau^*) = 0$ and the definition of $\hat{Y}(\tau^*)$ in Eq. (D.3), we obtain,

$$\frac{\partial S^*}{\partial K} = \Theta(\tau^*)\left[\sigma_G\Psi(w_G^*(\tau^*)) - \rho_H\left(1-\delta\tau^*\right)\Psi(w_S^*(\tau^*))\right]\frac{\partial\tau^*}{\partial K} - \frac{\sigma_H}{\Delta\sigma u'\left(w_S^*\right)}. \tag{D.12}$$

Eqs. (B.17) and (D.1) imply the first term in Eq. (D.12) is negative. Since $u' > 0$, then also the second term in Eq. (D.12) is negative. Therefore, $\frac{\partial S^*}{\partial K} < 0$. ■

Lemma D.11. *τ^* and S^* are continuous, strictly decreasing functions of N. Furthermore, $\tau^*|_{N=1/\bar{z}} = 1$ and $S^*|_{N=1/\bar{z}} = S^{FR}$, where S^{FR} is defined in Eq. (D.5).*

Proof. We first show that τ^* is decreasing in N. In Step (i) we established that $\hat{Y}(\tau^*)$ is decreasing in τ^*. Next, we prove that $\hat{Y}(\tau^*)$ is decreasing in N. Using Eq. (D.3) we obtain

$$\begin{aligned}
\frac{\partial\hat{Y}(\tau^*)}{\partial N} = &-\frac{\partial\Theta(\tau^*)}{\partial N}\left[\sigma_H\Psi(w_G^*(\tau^*)) - \rho_H\left(1-\delta\tau^*\right)\Psi(w_S^*(\tau^*))\right]\\
&-\Theta(\tau^*)\frac{\partial\left[\sigma_H\Psi(w_G^*(\tau^*)) - \rho_H(1-\delta\tau^*)\Psi(w_S^*(\tau^*))\right]}{\partial N}\\
&+\left(1-\frac{1}{N\bar{z}}\right)\delta\rho_H\Psi'(w_S^*(\tau^*))\frac{\partial w_S^*(\tau^*)}{\partial N} + \frac{1}{N^2\bar{z}}\delta\rho_H\Psi(w_S^*(\tau^*)).
\end{aligned} \tag{D.13}$$

[49] We note that λ^n for $n\in\mathcal{N}$ is fixed with symmetric maturity choices, so the effect of τ^* on w_G^{*n}, w_S^{*n} is only the direct effect identified in the proof of Lemma B.5.

From Eq. (D.1) we can write $\Theta(\tau^*) = -\frac{\gamma\left(1-\frac{1}{N}\right)\left(\bar{z}-\frac{1}{N}\right)}{\bar{z}(1-\gamma\tau^*)}$, which, since $\bar{z} > \frac{1}{N}$, is decreasing in N. Since $\sigma_H \Psi(w^*_G(\tau^*)) - \rho_H (1-\delta\tau^*)\Psi(w^*_S(\tau^*)) < 0$ (Eq. (B.17)), the first term in Eq. (D.13) is negative. The same steps as in Eq. (D.8) yield

$$\frac{\partial\left[\sigma_H \Psi(w^*_G) - \rho_H (1-\delta\tau^*)\Psi(w^*_S)\right]}{\partial N} = \sigma_H \frac{u''(w^{*n}_G)}{\left(u'(w^{*n}_G)\right)^2}\frac{\partial w^{*n}_G}{\partial N}\left[u(w^{*n}_G) - (1-\delta\tau^n)\left(\frac{\Delta\rho}{\Delta\sigma}\right)u(w^{*n}_S)\right]. \tag{D.14}$$

Since $u'' < 0$ and $\frac{\partial w^*_G(\tau^*)}{\partial N} > 0$ (Lemma B.5) and the term in square brackets in Eq. (D.14) is positive (Eq. (B.21)), Eq. (D.14) is negative. Therefore, since $\Theta(\tau^*) < 0$ (Eq. (D.1)), the second term in Eq. (D.13) is negative. Since $\frac{\partial w^*_G(\tau^*)}{\partial N} > 0$ and $\Psi' < 0$ and $\Psi < 0$, the third term is also negative. Since for all N there is a unique τ^* solving $\hat{\Upsilon}(\tau^*) = 0$, and $\hat{\Upsilon}(\tau^*)$ is continuous and decreasing in τ^* and N (due to Lemma B.5 and by the fact that $\lambda^n = 1/(N\bar{z})$), Lemma B.3 implies τ^* is continuous and decreasing in N. Furthermore, the proof of Lemma D.9 shows that for $N \geq \frac{1}{\bar{z}}$, we have $\tau^* = 1$ and $S^* = S^{FR}$, where S^{FR} is defined in Eq. (D.5).

Next, we prove S^* is decreasing in N. By Eq. (38) we have

$$\frac{\partial S^*}{\partial N} = \left(f'(\tau^*) - \frac{\partial \mathcal{W}^n}{\partial \tau^*}\right)\frac{\partial \tau^*}{\partial N} - \frac{\partial \mathcal{W}^n}{\partial N}. \tag{D.15}$$

By the Envelope Theorem (see the proof of Lemma B.6), we have

$$\frac{\partial \mathcal{W}^n}{\partial N} = -\frac{1}{\bar{z}N^2}\left[\sigma_G \Psi(w^*_G(\tau^*)) - \rho_H\left(1-\delta\tau^*\right)\Psi(w^*_S(\tau^*))\right]. \tag{D.16}$$

Substituting $\frac{\partial \mathcal{W}^n}{\partial \tau^*}$ in Eq. (D.10) and $\frac{\partial \mathcal{W}^n}{\partial N}$ in Eq. (D.16) into $\frac{\partial S^*}{\partial K}$, using $\hat{\Upsilon}(\tau^*) = 0$ and the definition of $\hat{\Upsilon}(\tau^*)$ in Eq. (D.3), we obtain,

$$\frac{\partial S^*}{\partial N} = \left[\sigma_G \Psi(w^*_G(\tau^*)) - \rho_H\left(1-\delta\tau^*\right)\Psi(w^*_S(\tau^*))\right]\left(\Theta(\tau^*)\frac{\partial \tau^*}{\partial N} + \frac{1}{\bar{z}N^2}\right). \tag{D.17}$$

Since $\left[\sigma_G \Psi(w^*_G(\tau^*)) - \rho_H (1-\delta\tau^*)\Psi(w^*_S(\tau^*))\right] < 0$ (Eq. (B.17)), $\frac{\partial \tau^*}{\partial N} < 0$, and $\Theta(\tau^*) < 0$ (Eq. (D.1)), we conclude that $\frac{\partial S^*}{\partial N} < 0$. ■

Lemma D.12. *τ^* and S^* are continuous, strictly decreasing functions of γ.*

Proof. We first show that τ^* is decreasing in γ. In Step (i) we established that $\hat{\Upsilon}(\tau^*)$ is decreasing in τ^*. Next, we prove that $\hat{\Upsilon}(\tau^*)$ is decreasing in γ. Since price informativeness is independent of γ, Eqs. (28)–(29) imply that the wage is unchanged by an increase in γ fixing τ^*, i.e.,

$$\frac{\partial w^*_G(\tau^*)}{\partial \gamma} = \frac{\partial w^*_S(\tau^*)}{\partial \gamma} = 0. \tag{D.18}$$

Using Eqs. (D.3) and (D.18), we can obtain

$$\frac{\partial \hat{\Upsilon}(\tau^*)}{\partial \gamma} = -\frac{\partial \Theta(\tau^*)}{\partial \gamma}\left[\sigma_H \Psi(w^*_G(\tau^*)) - \rho_H\left(1-\delta\tau^*\right)\Psi(w^*_S(\tau^*))\right]. \tag{D.19}$$

Eq. (B.17) implies that the term $\sigma_H \Psi(w^*_G(\tau^*)) - \rho_H (1-\delta\tau^*)\Psi(w^*_S(\tau^*))$ is negative. Furthermore, Eq. (27) implies

$$\frac{\partial \Theta(\tau^*)}{\partial \gamma} = -\frac{(N-1)(N\bar{z}-1)}{N^2\bar{z}(1-\gamma\tau^*)^2} < 0. \tag{D.20}$$

From Eqs. (D.19) and (D.20), we conclude that $\hat{\Upsilon}(\tau^*)$ is decreasing in γ at any given level of τ^*. Thus, by Lemma B.5, τ^* is continuous and decreasing in γ.

Next, we prove S^* is decreasing in N. By Eq. (38) we have

$$\frac{\partial S^*}{\partial \gamma} = \left(f'(\tau^*) - \frac{\partial \mathcal{W}^n}{\partial \tau^*}\right)\frac{\partial \tau^*}{\partial \gamma}.$$

By the Envelope Theorem (see the proof of Lemma B.6), we have

$$\frac{\partial \mathcal{W}^n}{\partial \tau^*} = -\left(1-\frac{1}{Nz}\right)\delta\rho_H \psi\left(w^*_S\right).$$

Substituting $\frac{\partial \mathcal{W}^n}{\partial \tau^*}$ into $\frac{\partial S^*}{\partial \gamma}$, using $\hat{\Upsilon}(\tau^*) = 0$ and the definition of $\hat{\Upsilon}(\tau^*)$ in Eq. (D.3), we obtain,

$$\frac{\partial S^*}{\partial \gamma} = \Theta(\tau^*)\left[\sigma_G \Psi(w^*_G(\tau^*)) - \rho_H\left(1-\delta\tau^*\right)\Psi(w^*_S(\tau^*))\right]\frac{\partial \tau^*}{\partial \gamma}. \tag{D.21}$$

Since $\left[\sigma_G \Psi(w^*_G(\tau^*)) - \rho_H (1-\delta\tau^*)\Psi(w^*_S(\tau^*))\right] < 0$ (Eq. (B.17)), $\frac{\partial \tau^*}{\partial \gamma} < 0$, and $\Theta(\tau^*) < 0$ (Eq. (D.1)), we conclude that $\frac{\partial S^*}{\partial \gamma} < 0$. ■

In the following lemma, we denote $\underline{N} = \frac{1}{\bar{z}}$ and we denote $S^*_0 = S^*|_{\gamma=0}$ and $S^*_1 = S^*|_{\gamma=1}$.

Lemma D.13. *Let $N = M$. There exist strictly positive values K_1, K_2 such that $K_1 < K_2 < \bar{K}$ with the property that $S^*|_{\gamma=1,K=K_1} = S^*|_{\gamma=0,K=K_2} = S^{FR}|_{K=\bar{K}} = S^U$ and:*

(i) if $K \in [0, K_1]$, then $S^* \geq S^U$ for all $\gamma \in [0,1]$, with a strict inequality unless both $K = K_1$ and $\gamma = 1$;
(ii) if $K \in (K_1, K_2)$, then there exists a unique $\hat{\gamma} \in (0,1)$ such that $S^* \gtreqless S^U \Leftrightarrow \gamma \lesseqgtr \hat{\gamma}$;[50]
(iii) if $K \geq K_2$, then $S^* \leq S^U$ for all $\gamma \in [0,1]$, with a strict inequality unless both $K = K_2$ and $\gamma = 0$,

where S^{FR} and $\bar{K}$ are defined in Eqs. (D.5) and (D.6).

Proof. By Lemma D.10, S^* is decreasing in K for all $\gamma \in [0,1]$, and $S^*|_{K=0} = f(1) + \rho_H \Delta V > S^U$. Furthermore,

$$S^*|_{N=M,K=\bar{K}} < S^*|_{N=1/\bar{z},K=\bar{K}} = S^{FR}|_{K=\bar{K}} = S^U, \tag{D.22}$$

where the first inequality follows because S^* is decreasing in N (Lemma D.11), and the two equalities follow from the definitions of S^{FR} and $\bar{K}$ in Eqs. (D.5)–(D.6) in the proof of Lemma D.9. Thus, $S^*|_{K=0} > S^U > S^*|_{N\in(1/\bar{z},M],K=\bar{K}}$. Since S^* is a continuous function of K by Lemma D.10, the intermediate value theorem implies that for each $N \in (\frac{1}{\bar{z}}, M]$ and $\gamma \in [0,1]$ there exists a unique K^* such that $S^*|_{K=K^*} = S^U$. Define $K_1 = K^*|_{N=M,\gamma=1}$ and $K_2 = K^*|_{N=M,\gamma=0}$. Since S^* is decreasing in N and γ (Lemmas D.11 and D.12), it is immediate that $0 < K_1 < K_2 < \bar{K}$.

Parts (i) and (iii) in the lemma follow immediately from the fact that S^* is continuous and decreasing in K and γ (Lemmas D.10 and D.12) together with the definitions of K_1 and K_2. Part (ii) in the lemma follows from the intermediate value theorem and the facts that (i) $S^*|_{\gamma=0} > S^U > S^*|_{\gamma=1}$ for $K \in (K_1, K_2)$, and (ii) that S^* is decreasing in γ (Eq. D.12). ■

Step (iii). In this step, we combine the technical results from Step (ii) and derive the critical value γ^*.

Lemma D.13-(i) and Lemma D.11 imply that for all $K \leq K_1$ firms are strictly better off by listing compared to not listing for all N unless both $K = K_1$ and $\gamma = 1$, in which case firms are indifferent if $N = M$ and strictly better off listing for $N < M$. Thus, Theorem 1 holds with $\gamma^* = 0$.

Lemma D.13-(ii) and Lemma D.11 imply that for all $K \in (K_1, K_2)$ firms are strictly better off by listing compared to not listing for all $\gamma < \hat{\gamma}$ and N, and, therefore all firms list in equilibrium for $\gamma < \hat{\gamma}$. For $\gamma = \hat{\gamma}$ we have that firms are indifferent between listing and not listing for $N = M$ and strictly prefer listing for $N < M$. Thus, in equilibrium, all firms list when $\gamma = \hat{\gamma}$. Finally, for $\gamma > \hat{\gamma}$, firms prefer not listing over listing for $N = M$, but prefer listing over not listing for N sufficiently close to $1/\bar{z}$. By Lemma D.11 and the Intermediate Value Theorem, there exists a unique value $N^* \in (1/\bar{z}, M)$ such that N^* firms list in equilibrium and firms are indifferent ex-ante (i.e., $S^* = S^U$). Thus, Theorem 1 holds with $\gamma^* = \hat{\gamma}$.

[50] The notation $z \gtreqless y \Leftrightarrow z \lesseqgtr h$ means "x is greater than y, equal to y, or less than y if and only if z is less than h, equal to h, or greater than h ".

For the case $K \geq K_2$, Lemma D.13-(iii) and Lemma D.11 imply that all firms are strictly better off by not listing compared to listing for $N = M$ unless both $K = K_2$ and $\gamma = 0$, in which case firms are indifferent if $N = M$ and strictly better off listing for $N < M$. Thus, in this case all firms list in equilibrium. For all other cases (that is, either $K > K_2$ and $\gamma \geq 0$ or $K \geq K_2$ and $\gamma > 0$), firms prefer not listing over listing for $N = M$, but prefer listing over not listing for N sufficiently close to $1/\bar{z}$. By Lemma D.11 and the intermediate value theorem, there exists a unique value $N^* \in (1/\bar{z}, M)$ such that N^* firms list in equilibrium and firms are indifferent ex-ante (i.e., $S^* = S^U$). Thus, Theorem 1 holds with $\gamma^* = 0$. This completes the proof of the theorem. ■

Appendix E

Proof of Theorem 2. We prove the theorem in several steps.

Lemma E.14. *The project maturity is longer in the coordinated benchmark than in the effort without price benchmark, i.e., $\tau^{CB} > \tau^{EP}$.*

Proof. We prove by contradiction. Suppose that $\tau^{CB} \leq \tau^{EP}$. Because $f'(\cdot) > 0, f''(\cdot) < 0$, the first-order conditions in Eqs. (31) and (35) imply that

$$-\left(1 - \frac{1}{N\bar{z}}\right)\delta\rho_H\Psi(w_S^{CB}) \geq -\delta\rho_H\Psi(w_S^{EP}) > 0,$$

which implies

$$\Psi(w_S^{CB}) \leq \Psi(w_S^{EP}) < 0. \tag{E.1}$$

Because $\Psi(\cdot) < 0, \Psi'(\cdot) < 0$, Eq. (E.1) implies $w_S^{CB} \geq w_S^{EP}$. Then, because $w_G^{CB} > w_S^{CB} > 0$ (Proposition 2), it should be the case that $w_G^{CB} > w_S^{CB} \geq w_S^{EP}$.

However, the IC constraints in Eqs. (32) and (36) together with $w_G^{CB} > w_S^{CB} \geq w_S^{EP}$ would imply that

$$\begin{aligned}\left(1 - \delta\tau^{EP}\right)\Delta\rho u\left(w_S^{EP}\right) &= \frac{1}{N\bar{z}}\Delta\sigma u\left(w_G^{CB}\right)\\ &\quad + \left(1 - \frac{1}{N\bar{z}}\right)\left(1 - \delta\tau^{CB}\right)\Delta\rho u\left(w_S^{CB}\right)\\ &> \left(1 - \delta\tau^{CB}\right)\Delta\rho u\left(w_S^{CB}\right),\end{aligned} \tag{E.2}$$

where the in where the inequality is true because $u(w_G^{CB}) > u(w_S^{CB})$ and $\Delta\sigma > \Delta\rho$ (Lemma B.4). Then, Eq. (E.2) implies $\tau^{CB} > \tau^{EP}$. This contradicts. ■

Lemma E.15. *Equilibrium project maturity is shorter than in the coordinated benchmark, i.e., $\tau^* < \tau^{CB}$.*

Proof. We prove this by contradiction. Assume that all firms list in equilibrium, $N = M$, and suppose that $\tau^* \geq \tau^{CB}$. Note that Eqs. (28)–(29) are identical to Eqs. (36)–(37) except that τ^* is different from τ^{CB} (because $\lambda^n = 1/(N\bar{z})$ for all $n \in \mathcal{N}$ in both cases). Because w_G^{*n} and w_S^{*n} are increasing in τ^{*n} fixing λ^n (Lemma B.5), we have $w_G^* \geq w_G^{CB}$ and $w_S^* \geq w_S^{CB}$. Then, because $\Psi(\cdot) < 0, \Psi'(\cdot) < 0$, we have

$$\Psi(w_S^*) \leq \Psi(w_S^{CB}) < 0 \quad \Leftrightarrow \quad \left(1 - \frac{1}{N\bar{z}}\right)\delta\rho_H\Psi(w_S^*) \leq \left(1 - \frac{1}{N\bar{z}}\right)\delta\rho_H\Psi(w_S^{CB}) < 0. \tag{E.3}$$

Using Eqs. (B.17) and (E.4), we have

$$\left\{\begin{array}{c}\Theta(\tau^*)\left[\sigma_H\Psi(w_G^*) - \rho_H(1 - \delta\tau^*)\Psi(w_S^*)\right]\\ -\left(1 - \frac{1}{N\bar{z}}\right)\delta\rho_H\Psi(w_S^*)\end{array}\right\} > -\left(1 - \frac{1}{N\bar{z}}\right)\delta\rho_H\Psi(w_S^{CB}) > 0. \tag{E.4}$$

Because $f'(\cdot) > 0, f''(\cdot) < 0$, however, the first-order conditions in Eqs. (26) and (35) together with Eq. (E.4) imply that $\tau^* < \tau^{CB}$, which is a contradiction. ■

Using Lemmas E.14 and E.15, we conclude that $\tau^{CB} > \max(\tau^*, \tau^{EP})$. The inequality in Eq. (39) is immediate from the comparison between the FOCs between equilibrium and the effort without price benchmark. Because $f'(\cdot) > 0, f''(\cdot) < 0$, τ^* is smaller than τ^{EP} whenever the RHS of Eq. (26) is greater than that of Eq. (31), and vice versa. ■

Proof of Theorem 3. First, we prove that $S^* < S^{CB}$. The planner's problem in Eq. (34) is strictly concave in τ^s. This follows from the fact that (i) the production function f is strictly concave, and (ii) the proof of Lemma B.7 implies that under the optimal contract with fixed λ^n, $\mathcal{W}^n$ is convex in τ^n. Since $\tau^* < \tau^{CB}$, it follows that $S^* < S^{CB}$. Second, we prove that $S^* > S^{EP}$. By concavity of each firm's problem in project maturity, we have

$$S^* \geq S^n(\tau^{EP}; \tau^*) \equiv f(\tau^{EP}) - \mathcal{W}^n(\tau^{EP}, \lambda^n(\tau^{EP}; \tau^*)),$$

where $\mathcal{W}^n(\tau^{EP}, y)$ denotes firm n's wage bill under the optimal contract when $\tau^n = \tau^{EP}$ and $\lambda^n = y$ and $\lambda^n(\tau^{EP}; \tau^*)$ denotes firm n's price efficiency when $\tau^n = \tau^{EP}$ and all other listed firms' project maturity equals τ^*. By the Envelope Theorem (see the proof of Lemma B.6) we have

$$\frac{\partial\mathcal{W}^n(\tau^{EP}, \lambda^n)}{\partial\lambda^n} = \sigma_H\Psi(w_G^*) - \rho_H\left(1 - \delta\tau^*\right)\Psi(w_S^*) < 0.$$

Therefore,

$$S^* \geq S^n(\tau^{EP}; \tau^*) > f(\tau^{EP}) - \mathcal{W}^n(\tau^{EP}, 0) = S^{EP}.$$

This completes the proof.

Appendix F

Proof of Proposition 5. Consider the case where all firms list so that $N = M$. Let ζ be a positive constant such that $M\bar{z} = \zeta$ for any level of M (that is, an increase in M is compensated by a decrease in $\bar{z}$ to keep the product of the two at the constant level ζ). Then, the equilibrium informativeness is unchanged at the level given by Eq. (25). Therefore, Eqs. (28)–(29) imply that the wage is unchanged by an increase in M fixing τ^*, i.e.,

$$\left.\frac{\partial w_G^*(\tau^*)}{\partial M}\right|_{M\bar{z}=\zeta} = \left.\frac{\partial w_S^*(\tau^*)}{\partial M}\right|_{M\bar{z}=\zeta} = 0. \tag{F.1}$$

Thus, Proposition 5 follows from the proof of Lemma D.11 setting $N = M$ and $\left.\frac{\partial w_G^*(\tau^*)}{\partial N}\right|_{N\bar{z}=\zeta} = 0$. We also note that in the coordinated benchmark, τ^{CB} and S^{CB} are determined in Eqs. (35)–(38) and are unaffected by the parameter N when $N\bar{z}$ is constant.

For the case where M varies with $\bar{z}$ fixed, we have two cases. Either in equilibrium $N = M$, in which case Lemma D.11 implies that S^* and τ^* are a decreasing function of M. If, instead, $N < M$, then N remains constant as M varies, so that the number of unlisted firms $M - N$ increases with M, but listed firms' project choice and shareholder value do not change. Thus, overall, S^* and τ^* are a weakly decreasing in M. ■

Proof of Proposition 6. Consider first the case where all firms list so that $N = M$. In this case, Lemma D.12 implies that τ^* and S^* decreasing functions of γ. We also note that in the coordinated benchmark, τ^{CB} and S^{CB} are determined in Eqs. (35)–(38) and are unaffected by the parameter γ.

Next, consider the case where some firms remain unlisted, $N < M$. In this case, τ^* and N are determined by the following system of equations:

$$\hat{Y}(\tau^*) = 0; \tag{F.2}$$

$$S^* = S^U, \tag{F.3}$$

where $\hat{Y}(\tau^*)$ is defined in Eq. (D.3), S^* is defined in Eq. (30), and S^U is defined in Eq. (24) and is a fixed value independent of τ^*, N, and γ.

Since S^U is independent of τ^*, N, and γ, Eq. (F.3) implies that S^* is unaffected by an increase in γ.

Next, we prove that τ^* decreases in γ. Step-(i) in the proof of Theorem 1 establishes that $\hat{Y}(\tau^*)$ is decreasing in τ^*, the proof of Lemma D.11 establishes that $\hat{Y}(\tau^*)$ is decreasing in N, and the proof of Lemma D.12 establishes that $\hat{Y}(\tau^*)$ is decreasing γ. Therefore, by Lemma B.5, Eq. (F.2) defines N as a decreasing function of both τ^* and γ. Thus, using Eq. (30) we can write Eq. (F.3) as

$$f(\tau^*) - \mathcal{W} - S^U = 0, \tag{F.4}$$

where $\mathcal{W}$ is the wage bill under the optimal contract. We note that $\mathcal{W}$, depends on τ^* directly but also indirectly through N, whereas $\mathcal{W}$ depends on γ only indirectly through N (see Lemma B.6). Implicit differentiation of Eq. (F.4) gives

$$\frac{\partial \tau^*}{\partial \gamma} = \frac{\frac{\partial \mathcal{W}^n}{\partial N}\frac{\partial N}{\partial \gamma}}{f'(\tau^*) - \frac{\partial \mathcal{W}^n}{\partial \tau}^* - \frac{\partial \mathcal{W}^n}{\partial N}\frac{\partial N}{\partial \tau}^*}. \tag{F.5}$$

Since $\frac{\partial \mathcal{W}^n}{\partial N} > 0$ (Eq. (D.16) and N is decreasing in γ, the numerator of Eq (F.5) is negative. For the denominator, using the expression for $\frac{\partial \mathcal{W}^n}{\partial \tau^*}$ in Eq. (D.10) and $\hat{Y}(\tau^*) = 0$ and the definition of $\hat{Y}(\tau^*)$ in Eq. (D.3), we obtain

$$f'(\tau^*) - \frac{\partial \mathcal{W}^n}{\partial \tau}^* = \Theta(\tau^*)\left[\sigma_G \Psi(w_G^*(\tau^*)) - \rho_H \left(1 - \delta\tau^*\right)\Psi(w_S^*(\tau^*))\right] > 0 \tag{F.6}$$

where the inequality follows by Eqs. (B.17) and (D.1). Furthermore, since $\frac{\partial \mathcal{W}^n}{\partial N} > 0$ (Eq. (D.16) and N is decreasing in τ^*, we conclude that the denominator of Eq (F.10) is positive. Therefore, we concludes that $\frac{\partial \tau^*}{\partial \gamma} < 0$. ■

Proof of Proposition 7. Consider first the case where all firms list so that $N = M$. In this case, Lemma D.10 implies that τ^* and S^* decreasing functions of K. We also note that the first term in the RHS of Eq. (D.7) depends on the sensitivity of price informativeness $\Theta(\tau^*)$ and represents the amplification effect due to the strategic complementarity in project maturity. This term equals zero in the coordinated benchmark, where price informativeness is independent of project maturity.

Next, consider the case where some firms remain unlisted, $N < M$. In this case, τ^* and N are determined by the system of equations in Eqs. (F.2)–(F.3), where $\hat{Y}(\tau^*)$ is defined in Eq. (D.3), S^* is defined in Eq. (30), and S^U is defined in Eq. (24) and is a fixed value independent of τ^*, N, and K.

Since S^U is independent of τ^*, N, and K, Eq. (F.3) implies that S^* is unaffected by an increase in K.

Next, we prove that N decreases in K. Step-(i) in the proof of Theorem 1 establishes that $\hat{Y}(\tau^*)$ is decreasing in τ^*, the proof of Lemma D.11 establishes that $\hat{Y}(\tau^*)$ is decreasing in N, and the proof of Lemma D.10 establishes that $\hat{Y}(\tau^*)$ is decreasing K. Therefore, by Lemma B.5, Eq. (F.2) defines τ^* as a decreasing function of both N and K. Using Eq. (30) we can write Eq. (F.3) as

$$f(\tau^*) - \mathcal{W}^n - S^U = 0. \tag{F.7}$$

Implicit differentiation of Eq. (F.7) gives

$$\frac{\partial N}{\partial K} = -\frac{\left(f'(\tau^*) - \frac{\partial \mathcal{W}^n}{\partial \tau^*}\right)\frac{\partial \tau^*}{\partial K} - \frac{\partial \mathcal{W}^n}{\partial K}}{\left(f'(\tau^*) - \frac{\partial \mathcal{W}^n}{\partial \tau^*}\right)\frac{\partial \tau^*}{\partial N} - \frac{\partial \mathcal{W}^n}{\partial N}}. \tag{F.8}$$

Using $\frac{\partial \mathcal{W}^n}{\partial \tau^*}$ in Eqs. (D.10) and using $\hat{Y}(\tau^*) = 0$ and the definition of $\hat{Y}(\tau^*)$ in Eq. (D.3), we obtain,

$$\left(f'(\tau^*) - \frac{\partial \mathcal{W}^n}{\partial \tau^*}\right)\frac{\partial \tau^*}{\partial K} = \Theta(\tau^*)\left[\sigma_G \Psi(w_G^*(\tau^*)) - \rho_H \left(1 - \delta\tau^*\right)\Psi(w_S^*(\tau^*))\right] \times \frac{\partial \tau^*}{\partial K}.$$

Eqs. (B.17) and (D.1) and the fact that τ^* is decreasing in K imply that the previous expression, and, therefore, the first term in both the numerator and denominator of Eq. (F.8), is negative. Since $\frac{\partial \mathcal{W}^n}{\partial K}$ and $\frac{\partial \mathcal{W}^n}{\partial N}$ are both positive by Eqs. (D.11) and (D.16), conclude that $\frac{\partial N}{\partial K}$ in Eq. (F.8) is negative.

Finally, we argue that the effect of K on τ^* is ambiguous. The argument used in this proof to show that τ^* is decreasing function of both N and K also implies that N is a decreasing function of both τ^* and K. Using Eq. (30) we can write Eq. (F.3) as

$$f(\tau^*) - \mathcal{W}^n - S^U = 0. \tag{F.9}$$

Implicit differentiation of Eq. (F.9) gives

$$\frac{\partial \tau^*}{\partial K} = \frac{\frac{\partial \mathcal{W}^n}{\partial K} + \frac{\partial \mathcal{W}^n}{\partial N}\frac{\partial N}{\partial K}}{f'(\tau^*) - \frac{\partial \mathcal{W}^n}{\partial \tau}^* - \frac{\partial \mathcal{W}^n}{\partial N}\frac{\partial N}{\partial \tau}^*}. \tag{F.10}$$

The proof of Proposition 6 shows that the denominator of Eq. (F.10) is positive. Since $\frac{\partial \mathcal{W}^n}{\partial K} > 0$ (Eq. (D.11) and $\frac{\partial \mathcal{W}^n}{\partial N} > 0$ (Eq. (D.16) and N is decreasing in K, the sign of the numerator of Eq (F.10) is ambiguous. Hence, the sign of $\frac{\partial \tau^*}{\partial K}$ is ambiguous.

The proof for δ is similar and is omitted. ■

Appendix G

Proof of Proposition 8. As a preliminary step, we prove the following results about the financial equilibrium induced by firms' project maturity choices with long- and short-term investors.

Lemma G.16.

(i) Let $\tau^m = \tau$ for all $m \in \mathcal{N} \setminus \{n\}$ and $\tau^n < \tau$. Then, for $\mu \geq 1 - 1/N$ we have $\lambda^n = 1/(N\bar{z})$, whereas for $\mu < 1 - 1/N$ we have $\lambda^n = \min\{(1-\mu)/\bar{z}, \lambda^*\} > 1/(N\bar{z})$ where λ^* solves short-term investors' indifference condition

$$\left(1 - \lambda_n\right)(1 - \tau^n\gamma) = (1 - \lambda^m)(1 - \tau\gamma) \text{ for all } m \in \mathcal{N} \setminus \{n\}.$$

(ii) Let $\tau^m = \tau$ for all $m \in \mathcal{N}\setminus\{n\}$ and $\tau^n > \tau$. Then, for $\mu \geq 1/N$ we have $\lambda^n = 1/(N\bar{z})$, whereas for $\mu < 1/N$, we have $\lambda^n = \max\{\mu/\bar{z}, \lambda^*\} < 1/(N\bar{z})$ where λ^* solves short-term investors' indifference condition

$$\left(1 - \lambda_n\right)(1 - \tau^n\gamma) = (1 - \lambda^m)(1 - \tau\gamma) \text{ for all } m \in \mathcal{N} \setminus \{n\}.$$

■

Proof of Lemma G.16. -(i): Let $\tau^m = \tau$ for all $m \in \mathcal{N} \setminus \{n\}$ and $\tau^n < \tau$. We show that for $\mu \geq 1 - 1/N$ long-term investors are marginal investors for all firms in that $\lambda^n = \lambda^m$ for all $m \in \mathcal{N} \setminus \{n\}$. In other words, a firm that deviates from a symmetric maturity choice by lowering its project maturity has no impact on its price informativeness. In this case, all short-term investors choose firm n because it has informativeness identical to other firms but lower maturity. By contrast, long-term investors are indifferent across all firms; ε_L unit mass of long-term investors choose firm n, and $\mu - \varepsilon_L$ unit mass of them are equally distributed over the remaining $N - 1$ firms. The condition $\lambda^n = \lambda^m$ for all $m \in \mathcal{N} \setminus \{n\}$ requires

$$\lambda^n = \frac{1 - \mu + \varepsilon_L}{\bar{z}} = \frac{\mu - \varepsilon_L}{(N-1)\,\bar{z}} = \lambda^m, \tag{G.1}$$

which is equivalent to $\varepsilon_L = \mu - (N-1)/N$. Therefore, there exists $\varepsilon_L \in [0, \mu]$ such that (G.1) holds if and only if $\mu \geq 1 - 1/N$.

Next, consider the case where short-term investors are marginal investors for all firms. Since $\tau^n < \tau$, it must be $\lambda^n > \lambda^m$ for all $m \in \mathcal{N} \setminus \{n\}$, which implies that long-term investors do not invest in firm n. Then, $1 - \mu - \varepsilon_S$ unit mass of short-term investors invest in firm n, and ε_S unit mass of short-term investors are equally distributed over the remaining $N-1$ firms. The condition $\lambda^n > \lambda^m$ for all $m \in \mathcal{N} \setminus \{n\}$ requires

$$\lambda^n = \frac{1-\mu-\varepsilon_S}{\bar{z}} > \frac{\mu+\varepsilon_S}{(N-1)\,\bar{z}} = \lambda^m, \tag{G.2}$$

which is equivalent to $\varepsilon_S < 1-\mu-1/N$. Therefore, Eq. (G.2) holds for some $\varepsilon_S \in [0, 1-\mu]$ if and only if $\mu < 1-1/N$. Short-term investors are marginal investors for all firms if the following indifference condition holds:

$$(1-\lambda^n)(1-\tau^n\gamma) = (1-\lambda^m)(1-\tau\gamma) \text{ for all } m \neq n,$$

or equivalently,

$$\left(1-\frac{1-\mu-\varepsilon_S}{\bar{z}}\right)(1-\tau^n\gamma) = \left(1-\frac{\mu+\varepsilon_S}{(N-1)\,\bar{z}}\right)(1-\tau\gamma). \tag{G.3}$$

When $\tau^n = \tau$, the above equation is solved for $\varepsilon_S = 1-\mu-1/N$. As τ^n decreases, ε_S must decrease for the equality to hold. By inspecting Eq. (G.3) it is easy to verify that there exists $\varepsilon_S \geq 0$ that solves Eq. (G.3) for all $\tau^n \in [0, \tau)$ if $(1-\mu)/\bar{z} \geq 1$. If, instead, $(1-\mu)/\bar{z} < 1$, then there exists $t \in [0, \tau)$ such that Eq. (G.3) holds for all $\tau^n \in [t, \tau)$, but for all $\tau^n \in [0, t)$ short-term investors are strictly better off investing in firm n and $\lambda^n = (1-\mu)/\bar{z}$; long-term investors are strictly better off investing in all other firms. ■

Proof of Lemma G.16. -(ii): Let $\tau^m = \tau$ for all $m \neq n$ and $\tau^n > \tau$. We show that for $\mu \geq 1/N$ long-term investors are marginal investors for all firms such that $\lambda^n = \lambda^m$ for all $m \in \mathcal{N} \setminus \{n\}$. In other words, a firm that deviates from a symmetric maturity choice by increasing its project maturity has no impact on its price informativeness. Since firm n has same price informativeness as other firms but longer maturity, short-term investors do not invest in firm n. On the other hand, long-term investors are indifferent across all firms; $\mu-\varepsilon_L$ unit mass of long-term investors choose firm n, and ε_L unit mass of them are equally distributed over the remaining $N-1$ firms. The condition $\lambda^n = \lambda^m$ requires

$$\lambda_n = \frac{\mu-\varepsilon_L}{\bar{z}} = \frac{1-\mu+\varepsilon_L}{(N-1)\,\bar{z}} = \lambda_m, \tag{G.4}$$

or equivalently, $\varepsilon_L = \mu - 1/N$. Then, there exists $\varepsilon_L \in [0, \mu]$ solving Eq. (G.4) if and only if $\mu \geq 1/N$.

Next, consider the case where short-term investors are marginal across all firms. Since $\tau^n > \tau$, it must be $\lambda^n < \lambda^m$ for all $m \in \mathcal{N} \setminus \{n\}$, which implies that all long-term investors invest in firm n because it has lower price informativeness than other firms. On the other hand, ε_S unit mass of short-term investors invest in firm n, and $1-\mu-\varepsilon_S$ unit mass of them are equally distributed over the remaining $N-1$ firms. The condition $\lambda^n < \lambda^m$ requires

$$\lambda_n = \frac{\mu+\varepsilon_S}{\bar{z}} < \frac{1-\mu-\varepsilon_S}{(N-1)\,\bar{z}} = \lambda_m, \tag{G.5}$$

or $\varepsilon_S < 1/N - \mu$. Then, there exists $\varepsilon_S \in [0, 1-\mu]$ such that Eq. (G.5) holds if and only if $\mu < 1/N$. Furthermore, λ^n must satisfy short-term investors' indifference condition

$$(1-\lambda^n)(1-\tau^n\gamma) = (1-\lambda^m)(1-\tau\gamma) \text{ for all } m \neq n,$$

or equivalently,

$$\left(1-\frac{\mu+\varepsilon_S}{\bar{z}}\right)(1-\tau^n\gamma) = \left(1-\frac{1-\mu-\varepsilon_S}{(N-1)\,\bar{z}}\right)(1-\tau\gamma) \text{ for all } m \neq n. \tag{G.6}$$

When $\tau^n = \tau$, the above equation is solved for $\varepsilon_S = 1/N - \mu$. As τ^n increases, ε_S must decrease for the equality to hold. There exists $\varepsilon_S \geq 0$ that solves Eq. (G.6) for all $\tau^n \in (\tau, 1]$ if $\mu \leq \mu_L(\tau)$, where $\mu_L(\tau)$ solves

$$\left(1-\frac{\mu_L(\tau)}{\bar{z}}\right)(1-\gamma) = \left(1-\frac{1-\mu_L(\tau)}{(N-1)\,\bar{z}}\right)(1-\tau\gamma), \tag{G.7}$$

and it is immediate to verify that $\mu_L(\tau) \in (0, 1/N)$. If, instead, $\mu \in (\mu_L(\tau), 1/N)$, then there exists $t' \in (\tau, 1)$ such that Eq. (G.6) holds for all $\tau^n \in (\tau, t']$, but for all $\tau^n \in (t', 1]$ long-term investors are strictly better off investing in firm n and $\lambda^n = \mu/\bar{z}$; short-term investors are strictly better off investing in all other firms. ■

Proof of Proposition 8. -(i): Assume all firms choose maturity τ. For $\mu < 1/N$, Lemma G.16 implies that when a firm deviates locally to some $\tau^n \neq \tau$, its price efficiency is determined by the same indifference condition as in the original model without long-term investors. Therefore, by the strict concavity of the firm's problem established in Appendix B (Lemma B.7), if a symmetric equilibrium exists, it must be equal to the original model, $\tau^\mu = \tau^*$.

Consider a firm's deviation to $\tau^n < \tau^*$. Then, λ^n is at most the value that short-term investors' indifference condition is satisfied (Lemma G.16-i). Therefore, the firm has no incentive to deviate because its payoff of deviation is less than or equal to the payoff of deviation in the original model.

Consider a firm's deviation to $\tau^n > \tau^*$. Then, there are two cases. Define $\mu^* = \mu_L(\tau^*)$ (see Eq. (G.7)). If $\mu \leq \mu^*$, the payoff of deviation is identical to the payoff of deviation in the original model (Lemma G.16-ii). Therefore, the firm has no incentive to deviate, which implies choosing τ^* is the unique equilibrium. If $\mu \in (\mu^*, 1/N)$, if a symmetric equilibrium exists, it must be equal to τ^* (Lemma G.16-ii). ■

Proof of Proposition 8. -(ii): Assume all firms choose maturity τ. For $\mu \geq 1-1/N$, Lemma G.16 implies that when a firm deviates to some $\tau^n \neq \tau$, its price efficiency is unchanged and equal to $1/(\bar{z}N)$. Therefore, this is the same as the case where informed trading is exogenous and the equilibrium is τ^{CB}. ■

Proof of Proposition 8. -(iii): Suppose that there exists a symmetric equilibrium, and all firms choose maturity τ. For $\mu \in [1/N, 1-1/N)$, Lemma G.16 implies that when a firm deviates to some $\tau^n > \tau$, its price efficiency is unchanged and equal to $1/(\bar{z}N)$. Therefore, $\tau^\mu \geq \tau^{CB}$ is necessary for otherwise deviating to $\tau^n > \tau^\mu$ is profitable. However, when a firm deviates to some $\tau^n < \tau$, its price efficiency is determined by short-term investors' indifference condition. Therefore, $\tau^\mu \leq \tau^*$ is necessary for otherwise deviating to $\tau^n < \tau^\mu$ is profitable. Since $\tau^{CB} > \tau^*$, the two necessary conditions cannot be met simultaneously.

This concludes the proof of Proposition 8. ■

Proof of Proposition 9. In a clientele equilibrium, N_S firms choose maturity τ_S and $N-N_S$ firms choose maturity τ_L, where $\tau_S < \tau_L$. Initially we take N_S, τ_S, τ_L as given and derive conditions such that it is optimal for short-term investors to invest in short-term firms and for long-term investors to invest in long-term firms. Let $\mathcal{N}_S$ be the set of short-term firms and $\mathcal{N}_L$ the set of long-term firms. With this allocation of investors across firms, price efficiency for short-term firms, λ_S say, equals

$$\lambda_S = \frac{1-\mu}{\bar{z}N_S}.$$

Similarly, price efficiency for long-term firms equals

$$\lambda_L = \frac{\mu}{\bar{z}\left(N-N_S\right)}.$$

We denote α_S the fraction of short-term firms, $\alpha_S = \frac{N_S}{N}$, and we denote the level of price efficiency in a symmetric equilibrium as $\bar{\lambda} = \frac{1}{\bar{z}N}$. With these definitions, we can write

$$\lambda_S = \frac{(1-\mu)\,\bar{\lambda}}{\alpha_S}; \qquad \lambda_L = \frac{\mu\bar{\lambda}}{1-\alpha_S}. \tag{G.8}$$

Since $\tau_S < \tau_L$, short-term investors will invest in short-term firms only if $\lambda_L < \lambda_S < 1$, and therefore, by Eq. (G.8), we must have

$$\bar{\alpha} \equiv 1-\mu > \alpha_S > (1-\mu)\,\bar{\lambda} \equiv \underline{\alpha}. \tag{G.9}$$

Since $1 \leq N_S \leq N-1$, Eq. (G.9) also implies

$$1-(N-1)\bar{z} < \mu < 1-\frac{1}{N}. \tag{G.10}$$

Furthermore, for short-term investors to invest in short-term firms, $\lambda_S, \lambda_L, \tau_S, \tau_L$ must satisfy

$$\left(1-\lambda_S\right)\left(1-\tau_S\gamma\right) \geq \left(1-\lambda_L\right)\left(1-\tau_L\gamma\right).$$

Since $\lambda_S > \lambda_L$, it is optimal for long-term investors to invest in long-term firms.

Next, we define

$$v_S\left(\tau^n, \tau_S, \alpha_S\right) \equiv f(\tau^n) - \mathcal{W}\left(\tau^n, \lambda^n\right),$$

where λ^n solves short-term investors' indifference condition

$$\left(1-\lambda^n\right)\left(1-\tau^n\gamma\right) = \left(1-\lambda^m\right)\left(1-\tau_S\gamma\right), \text{ for all } m \in \mathcal{N}_S \backslash \{n\}. \tag{G.11}$$

Because λ^m in Eq. (G.11) is a function of α_S, λ^n is a function of τ^n, τ_S, α_S. Let $\tau_s\left(\tau_S; \alpha_S\right)$ be the best response

$$\tau_s\left(\tau_S; \alpha_S\right) \in \arg\max_{\tau^n} v_S\left(\tau^n, \tau_S, \alpha_S\right).$$

By Theorem 1 (with N replaced by $N\alpha_S$) the fixed point $\tau_S^* = \tau_s\left(\tau_S^*; \alpha_S\right)$ exists and is unique. Hence, we denote

$$\hat{v}_S = v_S\left(\tau_S^*, \tau_S^*, \alpha_S\right).$$

Also, define

$$v_L\left(\tau^n, \tau_L, \alpha_S\right) \equiv f(\tau^n) - \mathcal{W}\left(\tau^n, \lambda_L\right)$$

where $\lambda_L = \frac{\mu\bar{\lambda}}{1-\alpha_S}$ (Eq. (G.8)). Let $\tau_l\left(\tau_L; \alpha_S\right)$ be the best response

$$\tau_l\left(\tau_L; \alpha_S\right) \in \arg\max_{\tau^n} v_L\left(\tau^n, \tau_L, \alpha_L\right).$$

By Section 5.2.2 (with N replaced by $N\left(1-\alpha_S\right)$), the fixed point $\tau_L^* = \tau_l\left(\tau_L^*; \alpha_S\right)$ exists and is unique. Hence, we denote

$$\hat{v}_L \equiv v_L\left(\tau_L^*, \tau_L^*, \alpha_S\right).$$

For clarity, in the rest of the proof, we make explicit the dependence of $\tau_L^*, \tau_S^*, \hat{v}_L, \hat{v}_S$ on α_S by writing $\tau_L^*\left(\alpha_S\right), \tau_S^*\left(\alpha_S\right), \hat{v}_L\left(\alpha_S\right), \hat{v}_S\left(\alpha_S\right)$.

Lemma G.17.

(i) $\lambda_S\left(\alpha_S\right)$ *is continuous and decreasing in* α_S *with* $\lambda_S\left(\underline{\alpha}\right) = 1$ *and* $\lambda_S\left(\bar{\alpha}\right) = \bar{\lambda}$; $\lambda_L\left(\alpha_S\right)$ *is continuous and increasing in* α_S *with* $\lambda_L\left(\underline{\alpha}\right) = (\bar{\lambda}\mu)/(1-(1-\mu)\bar{\lambda})$ *and* $\lambda_L\left(\bar{\alpha}\right) = \bar{\lambda}$.

(ii) $\tau_S\left(\alpha_S\right)$ *is continuous and decreasing in* α_S *with* $\tau_S\left(\underline{\alpha}\right) = 1$ *and* $\tau_S\left(\bar{\alpha}\right) = \tau^*$; $\tau_L\left(\alpha_S\right)$ *is continuous and increasing in* α_S *with* $\tau_L\left(\underline{\alpha}\right) < \tau_L\left(\bar{\alpha}\right) = \tau^{CB}$.

(iii) $\hat{v}_S\left(\alpha_S\right)$ *is continuous and decreasing in* α_S *with* $\hat{v}_S\left(\underline{\alpha}\right) = f(1) - \mathcal{W}(1,1)$ *and* $\hat{v}_S\left(\bar{\alpha}\right) = f(\tau^*) - \mathcal{W}\left(\tau^*, \bar{\lambda}\right)$; $\hat{v}_L\left(\alpha_S\right)$ *is continuous and increasing in* α_S *with* $\hat{v}_L\left(\underline{\alpha}\right) = f\left(\tau_L\left(\underline{\alpha}\right)\right) - \mathcal{W}\left(\tau_L\left(\underline{\alpha}\right), \frac{\bar{\lambda}\mu}{1-(1-\mu)\bar{\lambda}}\right)$ *and* $\hat{v}_L\left(\bar{\alpha}\right) = f(\tau^{CB}) - \mathcal{W}\left(\tau^{CB}, \bar{\lambda}\right)$.

Proof of Lemma G.17. -(i): This is immediate from Eq. (G.8). ■

Proof of Lemma G.17. -(ii): Following the same steps as in Proposition 5, we can show that τ_S^* is decreasing in α_S and that τ_L^* is decreasing in α_S. By the implicit function theorem, τ_S^*, τ_L^* are continuous in α_S. Furthermore, since $\lambda_S\left(\underline{\alpha}\right) = 1$, it is immediate that $\tau_S\left(\underline{\alpha}\right) = 1$. This is because firms have no incentive to deviate to a shorter maturity to increase price informativeness, and the manager's compensation only depends on the price realization in $t = 1$. Also, since $\lambda_S\left(\bar{\alpha}\right) = \bar{\lambda}$, it is immediate that $\tau_S\left(\bar{\alpha}\right) = \tau^*$ by Theorem 1. Similarly, the analysis in Section 5.2.2 implies that for $\lambda_L\left(\bar{\alpha}\right) = \bar{\lambda}$ we have $\tau_L\left(\bar{\alpha}\right) = \tau^{CB}$. ■

Proof of Lemma G.17. -(iii): We first show that $\hat{v}_L\left(\alpha_S\right)$ is increasing and continuous in α_S. This is because $\lambda_L(\alpha)$ is continuous and increasing in α, and, by the Envelope Theorem, each firm's wage bill is continuous and decreasing in price informativeness (see the proof of Lemma B.6). Therefore, by the Envelope Theorem and the planner's problem in Eq. ((34)) (with N replaced by $N\left(1-\alpha_S\right)$), $\hat{v}_L\left(\alpha_S\right)$ is increasing and continuous in α_S.

Next, we show that $\hat{v}_S\left(\alpha_S\right)$ is decreasing in α_S. By contradiction, assume $\alpha_S' > \alpha_S$ and $\hat{v}_S\left(\alpha_S'\right) \geq \hat{v}_S\left(\alpha_S\right)$, or, equivalently

$$f(\tau_S^*\left(\alpha_S'\right)) - \mathcal{W}\left(\tau_S^*\left(\alpha_S'\right), \lambda_S\left(\alpha_S'\right)\right) \geq f(\tau_S^*\left(\alpha_S\right)) - \mathcal{W}\left(\tau_S^*\left(\alpha_S\right), \lambda_S\left(\alpha_S\right)\right). \tag{G.12}$$

By Lemma G.17-(i) and -(ii), we have $\lambda_S\left(\alpha_S'\right) < \lambda_S\left(\alpha_S\right)$ and $\tau_S\left(\alpha_S'\right) < \tau_S\left(\alpha_S\right)$. Eq. (G.11) implies that when the fraction of short-term firms is α_S, if firm n deviates to $\tau^n = \tau_S^*\left(\alpha_S'\right) < \tau_S\left(\alpha_S\right)$, its price informativeness λ^n is such that $\lambda^n > \lambda_S\left(\alpha_S\right)$. Since $\mathcal{W}$ is decreasing in λ, we have

$$f(\tau_S^*\left(\alpha_S'\right)) - \mathcal{W}\left(\tau_S^*\left(\alpha_S'\right), \lambda^n\right) > f(\tau_S^*\left(\alpha_S'\right)) - \mathcal{W}\left(\tau_S^*\left(\alpha_S'\right), \lambda_S\left(\alpha_S'\right)\right).$$

By Eq- (G.12), this is a profitable deviation, which contradicts the optimality of $\tau_S^*\left(\alpha_S\right)$. Finally, $\mathcal{W}$ is continuous in τ_S, λ_S, and τ_S, λ_S are continuous in α_S. Therefore, $\hat{v}_S$ is continuous in α_S.

The values for $\hat{v}_S\left(\underline{\alpha}\right), \hat{v}_L\left(\underline{\alpha}\right), \hat{v}_S\left(\bar{\alpha}\right), \hat{v}_L\left(\bar{\alpha}\right)$ follow directly from the definitions of $\hat{v}_S, \hat{v}_L$ together with Lemma G.17-(i) and -(ii). ■

To conclude the proof of Proposition 9 we observe that, by Lemma G.17-(iii), we have $\hat{v}_S\left(\underline{\alpha}\right) > \hat{v}_L\left(\underline{\alpha}\right)$ and $\hat{v}_S\left(\bar{\alpha}\right) < \hat{v}_L\left(\bar{\alpha}\right)$. By continuity of $\hat{v}_S, \hat{v}_L$, there exists an intermediate value $\alpha^* \in \left(\underline{\alpha}, \bar{\alpha}\right)$ such that $\hat{v}_S\left(\alpha^*\right) = \hat{v}_L\left(\alpha^*\right)$. Since, by Lemma G.17-(i), we have $\lambda_S\left(\alpha^*\right) > \lambda_L\left(\alpha^*\right)$, then we can show that $\hat{v}_S\left(\alpha^*\right) = \hat{v}_L\left(\alpha^*\right)$ requires $\tau_S^*\left(\alpha^*\right) < \tau_L^*\left(\alpha^*\right)$. Suppose not, i.e., $\tau_S^*\left(\alpha^*\right) \geq \tau_L^*\left(\alpha^*\right)$. Then, $\hat{v}_S\left(\alpha^*\right) = \hat{v}_L\left(\alpha_S\right)$ is equivalent to

$$f(\tau_S^*\left(\alpha^*\right)) - f(\tau_L^*\left(\alpha^*\right)) = \mathcal{W}\left(\tau_S^*\left(\alpha^*\right), \lambda_S\left(\alpha^*\right)\right) - \mathcal{W}\left(\tau_L^*\left(\alpha^*\right), \lambda_L\left(\alpha^*\right)\right)$$

Since $\tau_S^*\left(\alpha^*\right) \geq \tau_L^*\left(\alpha^*\right)$ and f is increasing, it must be $\mathcal{W}\left(\tau_S^*\left(\alpha^*\right), \lambda_S\left(\alpha^*\right)\right) \geq \mathcal{W}\left(\tau_L^*\left(\alpha^*\right), \lambda_L\left(\alpha^*\right)\right)$. But this is impossible because $\mathcal{W}$ is decreasing in λ and increasing in τ (see the proof of Lemma B.6).

Furthermore, by Lemma G.17-(ii), we have $\tau^* < \tau_S^*\left(\alpha^*\right) < \tau_L^*\left(\alpha^*\right) < \tau^{CB}$.

Consider a candidate equilibrium number of short-term firms N_S where $\alpha_S = N_S/N$ is such that $\tau_S^*\left(\alpha^*\right) < \tau_L^*\left(\alpha^*\right)$. Short-term firms do not have an incentive to deviate to a lower τ nor to a marginally larger τ because a deviating firm's λ is determined by Eq. ((G.11)) and the deviation cannot dominate $\tau_S^*\left(\alpha_S\right)$ by construction. Hence, short-term firms do not have an incentive to deviate if

$$\hat{v}_S\left(\alpha_S\right) \geq \max_{\tau^n \geq \tau_S^*\left(\alpha_S\right)} f(\tau^n) - \mathcal{W}\left(\tau^n, \frac{\mu\bar{\lambda}}{\bar{z}\left(1-\alpha_S+\eta\right)}\right), \tag{G.13}$$

Where we define $\eta = 1/N$. Notice that Eq. (G.13) can be equivalently written as

$$\hat{v}_S\left(\alpha_S\right) \geq \hat{v}_L\left(\alpha_S - \eta\right), \tag{G.14}$$

Similarly, a long-term firm does not have an incentive to deviate to a greater τ nor to a marginally lower τ. This is because a deviating firm's λ is just $\lambda_L\left(\alpha_S\right)$, and the deviation cannot dominate $\tau_L^*\left(\alpha_S\right)$ by construction. Hence, long-term firms do not have an incentive to deviate if

$$\hat{v}_L\left(\alpha_S\right) \geq \max_{\tau^n \leq \tau_L^*\left(\alpha_S\right)} f(\tau^n) - \mathcal{W}\left(\tau^n, \lambda^n\right). \tag{G.15}$$

where λ^n solves short-term investors' indifference condition

$$\left(1-\lambda^n\right)\left(1-\tau^n\gamma\right) = \left(1-\lambda^m\right)\left(1-\tau_S\gamma\right), \text{ for all } m \in \mathcal{N}_S.$$

Notice that Eq. (G.15) can be equivalently written as

$$\hat{v}_L\left(\alpha_S\right) \geq v_S\left(\tau_s\left(\tau_S^*\left(\alpha_S\right);\alpha_S+\eta\right),\tau_S^*\left(\alpha_S\right),\alpha_S+\eta\right). \tag{G.16}$$

Therefore, $N_S, \tau_S^*\left(\alpha_S\right), \tau_L^*\left(\alpha_S\right)$ is an equilibrium if both Eq. ((G.14)) and Eq. (G.16) hold.

Next, we prove that, for $\alpha_S = \alpha^*$, both Eq. ((G.14)) and Eq. (G.16) hold. Eq. (G.14) holds because $\hat{v}_S(\alpha^*) = \hat{v}_L(\alpha^*)$ and $\hat{v}_S$ is decreasing. Eq. (G.16) holds because

$$\hat{v}_L\left(\alpha^*\right) = \hat{v}_S\left(\alpha^*\right) = v_S\left(\tau_s\left(\tau_S^*\left(\alpha^*\right);\alpha^*+\eta\right),\tau_S^*\left(\alpha^*\right),\alpha^*+\eta\right)|_{\eta=0}, \tag{G.17}$$

and, by the Envelope Theorem and the fact that the wage bill is decreasing in price efficiency, and price efficiency is decreasing in the number of firms, the RHS of Eq. (G.16) is decreasing in η.

Finally, consider the case where the integer constraint on N_S is taken into account. Let N_S^* be such that $N_S^*/N < \alpha^* < \left(N_S^*+1\right)/N$ and define $\alpha^- = N_S^*/N$ and $\alpha^+ = \left(N_S^*+1\right)/N$. For N finite but sufficiently large, the distance between α^- and α^+ can be made arbitrarily small. We can verify numerically that either N_S^* or N_S^*+1 are an equilibrium.

This concludes the proof. ∎

Appendix H

Proof of Proposition 10. The proof is parallel to that of Proposition 2 except that there are extra constraints due to the salary cap in Eq. (43). Using the same argument as in the proof of Proposition 2, we can find that $w_B^{**n} = w_F^{**n} = w_\emptyset^{**n} = 0$, and also drop the non-negativity constraints. Furthermore, because $w_G^{*n} > w_S^{*n}$ (Lemma B.5) under the optimal contract without salary cap, it is always the case that the constraint on w_G^n binds first between the two constraints on w_G^n and w_S^n. Therefore, to ensure that the incentive compatibility is implementable, it has to be the case that $w_S^n \leq \bar{w}$ never binds. Then, under such parametric values of $\bar{w}$, the optimal contracting problem becomes as follows:

$$\widehat{\mathcal{W}}^n(\tau^n) \equiv \min_{\{w_G^n,w_S^n\}\in\mathbb{R}_+^2} \lambda^n\sigma_H w_G^n + (1-\lambda^n)(1-\delta\tau^n)\rho_H w_S^n, \tag{H.1}$$

subject to the binding IC constraint (16):

$$\lambda^n\Delta\sigma u\left(w_G^n\right) + (1-\lambda^n)(1-\delta\tau^n)\Delta\rho u\left(w_S^n\right) = K, \tag{H.2}$$

and the salary cap from Eq. (43):

$$w_G^n \leq \bar{w}. \tag{H.3}$$

Then, the Lagrangian is given by

$$\begin{aligned}\mathcal{L} =& \lambda^n\sigma_H w_G^n + (1-\lambda^n)(1-\delta\tau^n)\rho_H w_S^n \\ &+ \psi_k\left[\begin{array}{c} K - \lambda^n\Delta\sigma u\left(w_G^n\right) \\ -(1-\lambda^n)(1-\delta\tau^n)\Delta\rho u\left(w_S^n\right)\end{array}\right] + \psi_w\left(\bar{w} - w_G^n\right),\end{aligned} \tag{H.4}$$

where ψ_k, ψ_w are the Lagrangian multipliers, which are non-negative. When the constraint in Eq. (H.3) does not bind ($\psi_w = 0$ and $w_G^{*n} < \bar{w}$), the optimization problem degenerates to the same problem in Proposition 2, i.e., $w_G^{**n} = w_G^{n*}$ and $w_S^{**n} = w_S^{n*}$. When it binds ($\psi_w > 0$ and $w_G^{*n} = \bar{w}$), the solution is given by

$$w_G^{**n} = \bar{w}, \quad \text{and} \quad w_S^{**n} = u^{-1}\left(\frac{K - \lambda^n\Delta\sigma u(\bar{w})}{(1-\lambda^n)(1-\delta\tau^n)\Delta\rho}\right).$$

The first-order conditions derived from Eq. (H.4) become

$$\begin{aligned}&\lambda^n\sigma_H - \psi_k\lambda^n\Delta\sigma u'(w_G^{**n}) - \psi_w = 0, \\ &\rho_H - \psi_k\Delta\rho u'(w_S^{**n}) = 0.\end{aligned} \tag{H.5}$$

As in Proposition 2, the Envelope theorem implies

$$\begin{aligned}\frac{\partial\widehat{\mathcal{W}}^n}{\partial\tau^n} =& \frac{\partial\lambda^n}{\partial\tau^n}\sigma_H w_G^{**n} - \left(\frac{\partial\lambda^n}{\partial\tau^n}(1-\delta\tau^n) - (1-\lambda^n)\delta\right)\rho_H w_S^{**n} \\ &- \psi_k\frac{\partial\lambda^n}{\partial\tau^n}\Delta\sigma u\left(w_G^{**n}\right) + \psi_k\left(\frac{\partial\lambda^n}{\partial\tau^n}(1-\delta\tau^n) - (1-\lambda^n)\delta\right)\Delta\rho u\left(w_S^{**n}\right) \\ =& \frac{\partial\lambda^n}{\partial\tau^n}\left[\sigma_H\left(w_G^{**n} - \psi_k\frac{\Delta\sigma}{\sigma_H}u(w_G^{**n})\right) - \rho_H(1-\delta\tau^n)\Psi(w_S^{**n})\right] \\ &+ (1-\lambda^n)\delta\rho_H\Psi(w_S^{**n}),\end{aligned} \tag{H.6}$$

where the second equality is due to the first-order conditions in Eq. (H.5). Using Eq. (H.5), we can alternatively represent Eq. (H.6) as

$$\begin{aligned}\frac{\partial\widehat{\mathcal{W}}^n}{\partial\tau^n} =& \frac{\partial\lambda^n}{\partial\tau^n}\left[\sigma_H\left(w_G^{**n} - \frac{\Delta\sigma\rho_H}{\sigma_H\Delta\sigma}\frac{u(w_G^{**n})}{u'(w_S^{**n})}\right) - \rho_H(1-\delta\tau^n)\Psi(w_S^{**n})\right] \\ &+ (1-\lambda^n)\delta\rho_H\Psi(w_S^{**n}),\end{aligned} \tag{H.7}$$

which is equal to Eq. (B.11) if salary cap does not bind, i.e., Eq. (H.7) becomes

$$\begin{aligned}\frac{\partial\widehat{\mathcal{W}}^n}{\partial\tau^n} =& \frac{\partial\lambda^n}{\partial\tau^n}\left[\sigma_H\Psi(w_G^{**n}) - \rho_H(1-\delta\tau^n)\Psi(w_S^{**n})\right] \\ &+ (1-\lambda^n)\delta\rho_H\Psi(w_S^{**n}),\end{aligned} \tag{H.8}$$

Then, similarly as in Eq. (B.18), we can derive

$$\begin{aligned}\frac{\partial^2\widehat{\mathcal{W}}^n}{(\partial\tau^n)^2} =& \frac{\partial^2\lambda^n}{(\partial\tau^n)^2}\left[\sigma_H\left(\bar{w} - \frac{\Delta\sigma\rho_H}{\sigma_H\Delta\sigma}\frac{u(\bar{w})}{u'(w_S^{**n})}\right) - (1-\delta\tau^n)\rho_H\Psi(w_S^{*n})\right] \\ &- \frac{\partial\lambda^n}{\partial\tau^n}\delta\rho_H\Psi(w_S^{*n}) + (1-\lambda^n)\delta\rho_H\Psi'(w_S^{*n})\frac{\partial w_S^{*n}}{\partial\tau^n} \\ &+ \frac{\partial\lambda^n}{\partial\tau^n}\left[\frac{\Delta\sigma\rho_H}{\Delta\sigma}\frac{u(\bar{w})}{u''(w_S^{**n})}\frac{\partial w_S^{*n}}{\partial\tau^n} - (1-\delta\tau^n)\rho_H\Psi'(w_S^{*n})\frac{\partial w_S^{*n}}{\partial\tau^n}\right].\end{aligned} \tag{H.9}$$

Because $\partial^2\lambda^n/(\partial\tau^n)^2$ is negative (Proposition 1), Eq. (B.17) implies that the first term in Eq. (H.9) is positive. Because $\partial\lambda^n/\partial\tau^n$ is positive (Proposition 1), and $\Psi(\cdot)$ is negative (Eq. (B.12)), the second term in Eq. (B.18) is also positive. Because $\Psi'(\cdot)$ is negative (Eq. (B.13)) and $\partial w_S^{*n}/\partial\tau^n$ is negative (Lemma B.5), the third term is also positive.

In case the constraint binds, $\psi_w > 0$, which in turn implies that ψ_k is greater than the case the constraint does not bind due to Eq. (H.5). Then, Eq. (H.6) further implies that the marginal increase in the wage bill $\widehat{\mathcal{W}}^n$ with respect to an increase in τ^n is greater under salary cap than without salary cap at any level of maturity τ^n, i.e.,

$$\begin{aligned}\frac{\partial\widehat{\mathcal{W}}^n}{\partial\tau^n} <& \frac{\partial\mathcal{W}^n}{\partial\tau^n} \\ =& \frac{\partial\lambda^n}{\partial\tau^n}\left[\sigma_H\Psi(w_G^{**n}) - \rho_H(1-\delta\tau^n)\Psi(w_S^{**n})\right] \\ &+ (1-\lambda^n)\delta\rho_H\Psi(w_S^{**n}) < 0,\end{aligned} \tag{H.10}$$

where the equality is due to Eq. (B.11), and the last inequality is due to Lemma B.6. When $w_G^{**n} < \bar{w}$, the first inequality holds with equality in Eq. (H.10). When $w_G^{**n} = \bar{w}$, and the first inequality holds strictly.

In a symmetric equilibrium defined in Definition 1 but with salary cap, all firms choose the same contract, denoted by w_G^{**} and w_S^{**} (i.e., $w_G^{**} = w_G^{**n}$ and $w_S^{**} = w_S^{**n}$ for all $n \in \mathcal{N}$). They also choose the same maturity, denoted by τ^{**}, and thus, we have $\lambda^n = 1/(N\bar{z})$ for all $n \in \mathcal{N}$ in equilibrium. Therefore, given the equilibrium choice of τ^{**}, Eq. (H.7) should be equal to

$$\begin{aligned}\left.\frac{\partial\widehat{\mathcal{W}}^n}{\partial\tau^n}\right|_{\tau^n=\tau^{**}} =& \Theta(\tau^{**})\left[\sigma_H\left(w_G^{**} - \frac{\Delta\sigma\rho_H}{\sigma_H\Delta\rho}\frac{u(w_G^{**})}{u'(w_S^{**})}\right) - \rho_H(1-\delta\tau^n)\Psi(w_S^{**})\right] \\ &+ (1-\lambda^n)\delta\rho_H\Psi(w_S^{**}).\end{aligned} \tag{H.11}$$

Now, we prove that $\tau^{**} < \tau^{*}$ under a symmetric equilibrium when the salary cap binds. As in Theorem 1, the equilibrium maturity τ^{**} under salary cap is determined by trading off between production and managerial compensation:

$$f'(\tau^{**}) = \frac{\partial \widehat{\mathcal{W}}^n}{\partial \tau^n}\bigg|_{\tau^n=\tau^{**}}. \tag{H.12}$$

On the other hand, the equilibrium maturity τ^{*} without salary cap is determined by

$$f'(\tau^{*}) = \frac{\partial \mathcal{W}^n}{\partial \tau^n}\bigg|_{\tau^n=\tau^{*}}. \tag{H.13}$$

Because $f'(\cdot)$ is negative and increasing and $\partial\widehat{\mathcal{W}}^n/\partial\tau^n < \partial\mathcal{W}^n/\partial\tau^n < 0$ whenever $w_G^{**} = \bar{w}$, Eqs. (H.12)–(H.13) imply that $\tau^{**} > \tau^{*}$ whenever the salary cap binds in equilibrium. Note that $\tau^{**} = \tau^{*}$ when it does not bind.

Finally, it is straightforward to show that, fixing the choice of maturity $\tau^{**} = \tau^{*}$, the shareholder value is greater for the case without salary cap because the cost of compensation is smaller or equal to the case under salary cap (recall that the contracting problem under salary cap features one more constraint in the optimization problem.) Theorem 2 shows that the equilibrium maturity choice under endogenous choice without salary cap is already excessively short-term. Given the concavity of the shareholder value in the social planner's problem, the shareholder value becomes even lower as the maturity shortens (i.e., τ^{*} increases). But our result shows that the choice under salary cap is even more short-term than that without salary cap, which implies that the shareholder value should be lower under the salary cap.

Appendix I

Optimal Managerial Compensation with Hidden Choice of Project Maturity

In this appendix, we assume that the manager chooses the project duration and that this choice is private information of the manager. We further assume that the manager's compensation contract can depend on the timing of the project's payoff (i.e., whether the project pays off early or late).[51] In this scenario, shareholders offer an incentive compatible compensation contract that specifies the project duration τ^n that the manager will choose. The contract is observed by investors before they decide on which stock they will acquire information.

Compared to Section 4.2, the number of states that are relevant for contract expands. Using a similar argument as in the main model, however, we can show that: (i) the optimal contract does not depend on the timing of the payoff realization when the price reveals the signal to be good, and (ii) the optimal contract pays nothing to the manager when (a) the price reveals the signal to be bad, (b) the price is not revealing and the manager exits before the project pays off, or (c) the price is not revealing and the project fails (regardless of whether it realizes early or late). However, if the price is non-revealing and the project is successful, the optimal contract differentiates between an early realization of the payoff (with corresponding payment $w_{S_1}^n$) and a late realization of the payoff in case the manager does not exit early (with corresponding payment $w_{S_2}^n$).

The following proposition derives the optimal contract for a given choice of τ^n.

Proposition I.11 (*Optimal Managerial Contract with Hidden Choice of Project Maturity*). *Given τ^n, there exists a unique optimal contract. For the optimal contract, $w_B^{*n} = w_F^{*n} = w_\emptyset^{*n} = 0$ and $w_G^{*n} > w_{S_1}^{*n} > 0$ and $w_{S_2}^{*n} > w_{S_1}^{*n} > 0$, where $w_G^{*n}, w_{S_1}^{*n}$ and $w_{S_2}^{*n}$ simultaneously solve*

$$\lambda^n \Delta\sigma u\left(w_G^{*n}\right) + (1-\lambda^n)\Delta\rho u\left(w_{S_1}^{*n}\right) = K \tag{I.1}$$

$$\frac{\sigma_H}{\rho_H} = \frac{\Delta\sigma}{\Delta\rho}u'(w_G^{*n})\left[\frac{1-\tau^n}{u'(w_{S_1}^{*n})} + \frac{\tau^n}{u'(w_{S_2}^{*n})}\right] \tag{I.2}$$

$$w_{S_2}^n = u^{-1}\left(\frac{u(w_{S_1}^n)}{(1-\delta)}\right). \tag{I.3}$$

Furthermore, if $u(x) = \frac{x^{1-\alpha}}{1-\alpha}$, the wage bill $\mathcal{W}^n$ is increasing in τ^n.

For $\delta = 0$, Eq. (I.3) implies $w_{S_2}^n = w_{S_1}^n$. Intuitively, when the manager is long-lived any project maturity is incentive compatible because the manager is indifferent about the timing of the compensation. In this case, the optimal contract is identical to the case where shareholders choose τ (or, equivalently, to the case where the manager chooses τ and this choice is contractible). By contrast, for $\delta > 0$ Eq. (I.3) implies $w_{S_2}^n > w_{S_1}^n$. Intuitively, the late compensation must exceed the early compensation for an impatient manager to be indifferent among project maturities. Proposition I.11 shows that the main qualitative feature of the optimal contract in the main model (Proposition 2), that a decrease in the project duration reduces the wage bill, is robust to the case where the manager chooses τ and this choice is private information.

Proof of Proposition I.11. Using a similar argument as in the main model, we can show two preliminary results. First, the optimal contract does not differentiate between early and late realization of the payoff when the price reveals a good signal. This follows from the first-order conditions for the shareholder's problem. Second, the optimal contract does not differentiate between early and late realization of the payoff when the price reveals a bad signal or the project is unsuccessful. In these cases, all payments must be zero or shareholders could reduce the wage bill without affecting the manager's incentives. Incorporating these features of the optimal contract, the shareholders' wage bill is given by

$$\mathrm{E}\left[w^n\right] = \lambda^n\sigma_H w_G^n + (1-\lambda^n)\rho_H\left[(1-\tau^n)w_{S_1}^n + \tau^n(1-\delta)w_{S_2}^n\right]. \tag{I.4}$$

An optimal contract minimizes the shareholders' wage bill:

$$\mathcal{W}^n(\tau^n) \equiv \min_{\{w_G^n, w_{S_1}^n, w_{S_2}^n\}} \mathrm{E}\left[w^n\right], \tag{I.5}$$

subject to (i) the manager's participation constraint (PC):

$$\lambda^n\sigma_H u\left(w_G^n\right) + (1-\lambda^n)\rho_H\left[(1-\tau^n)u(w_{S_1}^n) + \tau^n(1-\delta)u(w_{S_2}^n)\right] \geq K, \tag{I.6}$$

(ii) the manager's incentive compatibility constraint (IC):

$$\lambda^n\sigma_H u\left(w_G^n\right) + (1-\lambda^n)\rho_H\left[(1-\tau^n)u(w_{S_1}^n) + \tau^n(1-\delta)u(w_{S_2}^n)\right] - K \geq \max\{\hat{u_H}, \hat{u_L}\}, \tag{I.7}$$

where we define

$$\hat{u_H} = \max_{\tau\in[0,1]} \lambda^n\sigma_H u\left(w_G^n\right) + (1-\lambda^n)\rho_H\left[(1-\tau)u(w_{S_1}^n) + \tau(1-\delta)u(w_{S_2}^n)\right] - K, \tag{I.8}$$

and

$$\hat{u_L} = \max_{\tau\in[0,1]} \lambda^n\sigma_L u\left(w_G^n\right) + (1-\lambda^n)\rho_L\left[(1-\tau)u(w_{S_1}^n) + \tau(1-\delta)u(w_{S_2}^n)\right], \tag{I.9}$$

and (iii) the limited liability constraint (LL):

$$w_G^n, w_{S_1}^n, w_{S_2}^n \geq 0. \tag{I.10}$$

Notice that in the RHS of Eqs. (I.8)–(I.9) price informativeness is not a function of the manager's choice of τ because investors do not

[51] More generally, the size of the cash flows at liquidation can also signal the manager's choice of τ. For simplicity, however, we assume that the size of the cash flows is not contractible.

observe this and they anticipate that the manager will implement the incentive compatible choice τ^n specified in the contract. Since the RHS of Eqs. (I.8)–(I.9) are linear in τ, it follows that $\tau^n \in (0,1)$ is incentive compatible if and only if

$$u(w^n_{S_1}) = (1-\delta)u(w^n_{S_2}),$$

which pins down $w^n_{S_2}$ as a function of $w^n_{S_1}$:

$$w^n_{S_2} = g(w^n_{S_1}) \equiv u^{-1}\left(\frac{u(w^n_{S_1})}{(1-\delta)}\right). \tag{I.11}$$

Therefore, we can rewrite the IC constraint in Eq. (I.7) as

$$\lambda^n \Delta\sigma u\left(w^n_G\right) + (1-\lambda^n)\Delta\rho\left(w^n_{S_1}\right) \geq K, \tag{I.12}$$

and standard augments imply that the IC constraint must bind.

To solve for $(w^n_G, w^n_{S_1})$ in case $\delta > 0$, we write the Lagrangian for the problem as

$$\mathcal{L} = \lambda^n \sigma_H w^n_G + (1-\lambda^n)\rho_H\left[(1-\tau^n)w^n_{S_1} + \tau^n(1-\delta)g(w^n_{S_1})\right] + \psi\begin{bmatrix} K - \lambda^n\Delta\sigma u\left(w^n_G\right) \\ -(1-\lambda^n)\Delta\rho u\left(w^n_{S_1}\right)\end{bmatrix},$$

where ψ is the Lagrangian multiplier. The first-order conditions with respect to w^n_G and $w^n_{S_1}$ are given by

$$\begin{aligned} &\sigma_H - \psi\Delta\sigma u'\left(w^{*n}_G\right) = 0, \\ &\rho_H\left[(1-\tau^n) + \tau^n(1-\delta)g'(w^{*n}_{S_1})\right] - \psi\Delta\rho u'\left(w^{*n}_{S_1}\right) = 0, \end{aligned} \tag{I.13}$$

which, together with the definition of g in Eq. (I.11), implies

$$\frac{\sigma_H}{\rho_H} = \frac{\Delta\sigma}{\Delta\rho}u'(w^{*n}_G)\left[\frac{1-\tau^n}{u'(w^{*n}_{S_1})} + \frac{\tau^n}{u'(g(w^{*n}_{S_1}))}\right]. \tag{I.14}$$

An optimal contract is therefore pinned down by $\{w^{*n}_G, w^{*n}_{S_1}, w^{*n}_{S_2}\}$ that solve Eq. (I.11), Eq. (I.14), and the IC constraint

$$\lambda^n\Delta\sigma u\left(w^{*n}_G\right) + (1-\lambda^n)\Delta\rho u\left(w^{*n}_{S_1}\right) = K. \tag{I.15}$$

Following similar steps as the proof of Proposition 2 we can further show that the optimal contract is unique given τ^n and that $w^{*n}_G > w^{*n}_{S_1}$.

Next, we consider the case $u(x) = x^{1-\alpha}/(1-\alpha)$. Given our assumption that $u(0) = 0$, we restrict our attention to $\alpha \in (0,1)$. In this case, Eqs. (I.11) and (I.14) imply

$$w^{*n}_{S_2} = \kappa_0 w^{*n}_{S_1} \tag{I.16}$$

$$w^{*n}_{S_1} = \kappa_1 w^{*n}_G \tag{I.17}$$

$$\kappa_2 w^{*n}_G = (1-\tau^n)w^{*n}_{S_1} + \tau^n(1-\delta)w^{*n}_{S_2}, \tag{I.18}$$

where

$$\kappa_0 = (1-\delta)^{-\frac{1}{1-\alpha}} \tag{I.19}$$

$$\kappa_1 = \left(\frac{\frac{\sigma_H\Delta\rho}{\rho_H\Delta\sigma}}{1-\tau^n+\tau^n(1-\delta)^{-\frac{\alpha}{1-\alpha}}}\right)^{\frac{1}{\alpha}} \tag{I.20}$$

$$\kappa_2 = \left(\frac{\sigma_H\Delta\rho}{\rho_H\Delta\sigma}\right)^{\frac{1}{\alpha}}\left(1-\tau^n+\tau^n(1-\delta)^{-\frac{\alpha}{1-\alpha}}\right)^{1-\frac{1}{\alpha}}, \tag{I.21}$$

Since $\sigma_G\Delta\rho < \rho_H\Delta\sigma$ from Lemma B.4 and $\alpha, \delta, \tau^n \in (0,1)$, then it is immediate to verify that Eqs. (I.19)–(I.21) imply $\kappa_0 > 1$ and $\kappa_1, \kappa_2 \in (0,1)$.

Next, we prove that $\mathcal{W}^n$ is increasing in τ^n. Following similar steps as in the proof of Lemma B.6, we obtain, after some manipulations, that

$$\frac{\partial\mathcal{W}^n}{\partial\tau^n} = \frac{\partial\lambda^n}{\partial\tau^n}\left[\sigma_H\Psi(w^{*n}_G) - \rho_H\left[(1-\tau^n)\Psi(w^{*n}_{S_1}) + \tau^n(1-\delta)\Psi(w^{*n}_{S_2})\right]\right] + (1-\lambda^n)\rho_H\left[(1-\delta)w^{*n}_{S_2} - w^{*n}_{S_1}\right], \tag{I.22}$$

where

$$\Psi(w) \equiv w - \frac{u(w)}{u'(w)} < 0.$$

Using Eqs. (I.16)–(I.18) and the definition of Ψ, Eq. (I.22) simplifies to

$$\frac{\partial\mathcal{W}^n}{\partial\tau^n} = -\frac{\partial\lambda^n}{\partial\tau^n}\frac{w^{*n}_G}{1-\alpha}\left(\sigma_H - \rho_H\kappa_2\right) + (1-\lambda^n)\rho_H w^{*n}_{S_1}\left(\kappa_0^\alpha - 1\right). \tag{I.23}$$

Because $\partial\lambda^n/\partial\tau^n$ is negative (Proposition 1), and $\sigma_H > \rho_H$, and $\kappa_0 > 1$ and $\kappa_2 < 1$, Eq. (I.23) implies that $\mathcal{W}^n$ is increasing in τ^n. ■

Appendix J

In this appendix we consider how the model solution is affected by the parameters α and β introduced in Sections 5.5.1 and 5.5.2. The assumptions introduced in Sections 5.5.1 and 5.5.2 imply that in case of success, the component of the payoff that is sensitive to managerial effort, R^n, equals ΔV if the project pays off early (with probability τ^n) and $\Delta V\frac{1+\alpha}{1-\beta}$ if the project pays off late (with probability $(1-\tau^n)(1-\beta)$; we remark that β captures the additional randomization that a successful project is subject to when it realizes late). In essence, these assumptions imply that $\alpha > 0$ affects the financial equilibrium and therefore $\{\lambda_n\}_{n=1}^M$ but leaves firms' problem unchanged (for given $\{\lambda_n\}_{n=1}^M$), whereas $\beta > 0$ has no effect on the financial equilibrium but affects firms' optimal compensation contracts.

Proofs for Section 5.5.1. First, we consider the impact on asset prices. The only modification to Lemma 1 is that asset prices must reflect expected liquidation values when $\alpha > 0$ in the project payoff formulation in Eq. (1). With this assumption, asset prices at $t = 0$ for the cases where the asset price reveals the bad signal, is not revealing, or reveals the good signal are, respectively,

$$P^n_B(0) = f(\tau^n) + v_B\Delta V(1+\tau\alpha), \quad P^n_\emptyset(0) = f(\tau^n) + \rho_H\Delta V(1+\tau\alpha),$$
$$P^n_G(0) = f(\tau^n) + v_G\Delta V(1+\tau\alpha).$$

Similarly, the corresponding prices in $t = 1$ if asset n's payoff does not realize early are

$$P^n_B(1) = f(\tau^n) + v_B\Delta V(1+\alpha), \quad P^n_\emptyset(1) = f(\tau^n) + \rho_H\Delta V(1+\alpha),$$
$$P^n_G(1) = f(\tau^n) + v_G\Delta V(1+\alpha).$$

Given these prices, the same steps in the proof of Lemma 2 show that the expected value of trading in stock n for an informed investor is equal to

$$J^n_0 = (1-\lambda^n(0))(1-\hat{\gamma}\tau^n)\Delta P, \tag{J.24}$$

where $\hat{\gamma} = \gamma - \alpha(1-\gamma)$ and $\Delta P \equiv \left[\sigma_H(v_G - \rho_H) + (1-\sigma_H)(\rho_H - v_B)\right]\Delta V$. To see how $\hat{\gamma}$ is derived, consider the expected profits of an informed investor with a good signal about firm n. These equal

$$\begin{aligned} &(1-\lambda^n(0))\{(1-\tau^n)\left(v_G\Delta V - P^n_\emptyset(0)\right) \\ &\quad + \tau^n\left[\gamma\left(P^n_\emptyset(1) - P^n_\emptyset(0)\right) + (1-\gamma)\left(v_G\Delta V(1+\alpha) - P^n_\emptyset(0)\right)\right]\} \\ &= (1-\lambda^n(0))(v_G - \rho_H)\Delta V\left[1-\tau^n(\gamma - \alpha(1-\gamma))\right], \end{aligned} \tag{J.25}$$

where the second line follows by substituting the expressions for $P^n_\emptyset(1)$ and $P^n_\emptyset(0)$ into the first line and simplifying. Similarly, consider the expected profits of an informed investor with a bad signal about firm n. These equal

$$\begin{aligned} &(1-\lambda^n(0))\{(1-\tau^n)\left(P^n_\emptyset(0) - v_B\Delta V\right) \\ &\quad + \tau^n\left[\gamma\left(P^n_\emptyset(0) - P^n_\emptyset(1)\right) + (1-\gamma)\left(P^n_\emptyset(0) - v_B\Delta V(1+\alpha)\right)\right]\} \\ &= (1-\lambda^n(0))(\rho_H - v_B)\Delta V\left[1-\tau^n(\gamma - \alpha(1-\gamma))\right]. \end{aligned} \tag{J.26}$$

Taking expectations of the investor's profits in Eqs. (J.25) and (J.26) over good and bad signal realizations yields Eq. (J.24). It is then immediate that investor indifference condition Eq. (11) becomes

$$(1-\lambda^n)(1-\tau^n\hat{\gamma}) = (1-\lambda^m)(1-\tau^m\hat{\gamma}), \tag{J.27}$$

for any pair of stocks $m, n \in \mathcal{N}$.

Proofs for Section 5.5.2. Here we consider the effect of the parameter β on the manager's compensation contract. We will show that the formulation of the problem is equivalent to that of the main model with the parameter δ replaced by $\hat{\delta} = \delta + \beta(1-\delta)$.

Consider firm $n \in \mathcal{N}$ offering a contract to its manager that induces high managerial effort. We solve the optimal contracting problem taking maturity choice τ^n and price efficiency λ^n as given. The same argument as in the proof of Proposition 2 implies that the PC constraint does not bind, the IC must bind, and the firm sets payments to zero in case the project fails or the price reveals the bad signal or the manager leaves early and the project has not paid off. Therefore, the shareholders' wage bill equals

$$\mathrm{E}\left[w^n\right] = \lambda^n \sigma_H w_G^n + (1-\lambda^n)\,\rho_H\left[(1-\tau^n)w_{S_1}^n + \tau^n(1-\delta)(1-\beta)w_{S_2}^n\right], \tag{J.28}$$

where the payments $w_{S_1}^n, w_{S_2}^n$ condition on the project being successful in period 1 and 2 respectively, and an optimal contract solves

$$\min_{\{w_G^n, w_{S_1}^n, w_{S_2}^n\}\in\mathbb{R}_+^3} \mathrm{E}\left[w^n\right], \tag{J.29}$$

such that the IC constraint binds:

$$\lambda^n \Delta\sigma u\left(w_G^n\right) + (1-\lambda^n)\,\Delta\rho\left[(1-\tau^n)u(w_{S_1}^n) + \tau^n(1-\delta)(1-\beta)u(w_{S_2}^n)\right] = K. \tag{J.30}$$

The Lagrangian formulation for this problems is given by

$$\begin{aligned}\mathcal{L} = {} & \lambda^n\sigma_H w_G^n + (1-\lambda^n)\,\rho_H\left[(1-\tau^n)w_{S_1}^n + \tau^n(1-\delta)(1-\beta)w_{S_2}^n\right] + \\ & \psi\left[K - \lambda^n\Delta\sigma u\left(w_G^n\right) - (1-\lambda^n)\,\Delta\rho\left[(1-\tau^n)u(w_{S_1}^n) + \tau^n(1-\delta)(1-\beta)u(w_{S_2}^n)\right]\right],\end{aligned}$$

where ψ is the Lagrangian multiplier. The first-order conditions with respect to $w_{S_1}^n$ and $w_{S_2}^n$ are given by

$$\rho_H - \psi\Delta\rho u'\left(w_{S_1}^{*n}\right) = 0; \quad \rho_H - \psi\Delta\rho u'\left(w_{S_2}^{*n}\right) = 0, \tag{J.31}$$

which implies

$$w_{S_1}^{*n} = w_{S_2}^{*n} = w_S^{*n}.$$

With this simplification, we can reformulate the optimization problem in Eqs. (J.29)–(J.30) as

$$\min_{\{w_G^n, w_S^n\}\in\mathbb{R}_+^2} \lambda^n\sigma_H w_G^n + (1-\lambda^n)\,\rho_H w_S^n\{1-\tau^n\left[\delta+\beta(1-\delta)\right]\}, \tag{J.32}$$

such that

$$\lambda^n\Delta\sigma u\left(w_G^n\right) + (1-\lambda^n)\,\Delta\rho_H u(w_S^n)\left\{1-\tau^n\left[\delta+\beta(1-\delta)\right]\right\} = K. \tag{J.33}$$

The optimization problem in Eqs. (J.32)–(J.33) is equivalent to that of the main model in Eqs. (B.1)–(B.2) with the parameter δ replaced by $\hat{\delta} = \delta + \beta(1-\delta)$. ∎

Appendix K

Maturity-Sensitive Cost Efficiency of Information Production

In this appendix, we demonstrate the impact of introducing information acquisition costs that depend on the maturity of a firm's project. Alternatively, this extension can be understood as exploring the impact of information precision that depends on the maturity (or the maturity-sensitive information efficiency of informed trading). A higher cost of information acquisition can be interpreted as lower precision of information in the context of collecting information using costly resources, as discussed in Han and Sangiorgi (2018). Therefore, in this analysis, we explore how our results may be affected when the cost of information acquisition is higher or lower for longer maturity projects (or equivalently, signal precision is lower or higher for longer maturity projects). Such situations, for example, may arise due to varying levels of uncertainty between short-term and long-term scenarios.

For simplicity, we assume that the cost of information acquisition is multiplicative with the trading profit. This is a technical assumption made solely for tractability, and a more standard assumption would involve an additive cost to the trading profit. Nevertheless, the primary economic force arising from the impact of information cost remains qualitatively unchanged, and this assumption facilitates our analysis by simplifying calculations.

More specifically, we assume that the trading profit of an informed trader is multiplied by a factor $0 < \chi(\tau^n) \le 1$, which is a differentiable function reflecting the cost of information acquisition that depends on the maturity of firm n's project. The benchmark is $\chi(\tau^n) = 1$, but it may be smaller than one if there exists information acquisition cost dependent on τ. For example, if gathering long-term information is more cost-efficient (or less cost-efficient), then $\chi'(\tau^n)$ is positive (or negative). Therefore, we will refer to $\chi(\tau^n)$ as the long-term information "scaling factor" for notational convenience.

Then, from Eq. (10), the expected value of trading stock n is given by

$$J_0^n = (1-\lambda^n)(1-\gamma\tau^n)\chi(\tau^n)\Delta P, \tag{K.34}$$

where ΔP is the constant given in Lemma 2. Note that we can denote $\lambda^n = \lambda^n(0)$ as in the main body of the paper (see Section 4.1) since the results in Lemma 2 are unaffected by the introduction of this new feature. This is because it only changes the scale of informed trading profits once the stock is selected.

We will now take similar steps as those of Proposition 1 from Section 4.1, but with the additional feature of costly information dependent on project maturities (refer to the proof of Proposition 1 in Appendix A for the original formulations). Let $\Lambda > 0$ be

$$\Lambda = (1-\lambda^n)(1-\gamma\tau^n)\chi(\tau^n) = (1-\lambda^m)(1-\gamma\tau^m)\chi(\tau^m),$$

for all $n, m \in \mathcal{N}$. Then, we can write each λ^n as

$$\lambda^n = 1 - \frac{\Lambda}{(1-\gamma\tau^n)\chi(\tau^n)}. \tag{K.35}$$

By adding Eq. (K.35) for all $n \in \mathcal{N}$ and using the informational resource constraint Eq. (12), we can obtain

$$\Lambda = \frac{\frac{N\bar{z}-1}{\bar{z}}}{\sum_{n=1}^{N}\frac{1}{(1-\gamma\tau^n)\chi(\tau^n)}}. \tag{K.36}$$

Therefore, there exists a unique solution for each λ^n for all $n \in \mathcal{N}$ given $\{\tau^n\}_{n\in\mathcal{N}}$ from Eqs. (K.35)–(K.36).

Now, we characterize under which conditions our results remain qualitatively identical to the benchmark case. Recall that, in the benchmark case, price informativeness λ^n is decreasing and concave in τ^n. λ^n is increasing in τ^m.

With the addition of maturity-sensitive efficiency, we find that λ^n is decreasing in τ^n and increasing in τ^m as long as the increment of efficiency in long-term information is not too high (i.e., $\chi'(\tau^n)$ is not too high). Furthermore, λ^n remains concave in τ^n regardless of parameter values. The following set of lemmas demonstrates these findings.

Lemma K.18. *λ^n is decreasing in τ^n if $\chi(\tau) - (1-\gamma\tau)\chi'(\tau) > 0$, and increases in τ^n otherwise.*

Proof. Now, we prove that, fixing $\{\tau^m\}_{m\in\mathcal{N}\setminus\{n\}}$, λ^n is decreasing and concave in τ^n, where the notation $B \setminus A$ is the set difference, defined as $B \setminus A = \{x \in B | x \notin A\}$. For notational convenience, we represent

Eqs. (K.35)–(K.36) as follows:

$$\lambda^n(\tau^n) = 1 - \frac{\frac{N\bar{z}-1}{\bar{z}} x(\tau^n)}{\sum_{m\in\mathcal{N}} x(\tau^m)},$$

where $x(\cdot)$ is a positive function such that

$$x(\tau) \equiv \frac{1}{(1-\gamma\tau)\chi(\tau)},$$

which is increasing in τ because

$$\frac{\partial x(\tau)}{\partial \tau} = \frac{\gamma(\tau)}{(1-\gamma\tau)^2\,[\chi(\tau)]^2}, \tag{K.37}$$

where $\gamma(\tau)$ is a function of τ such that

$$\gamma(\tau) \equiv \gamma\chi(\tau) - (1-\gamma\tau)\chi'(\tau).$$

The first-order derivative of λ^n with respect to τ^n is given by

$$\frac{\partial \lambda^n(\tau^n)}{\partial \tau^n} = -A \times \frac{\gamma(\tau)\,[x(\tau^n)]^2}{\left(x(\tau^n) + \sum_{m\in\mathcal{N}\setminus\{n\}} x(\tau^m)\right)^2}, \tag{K.38}$$

where A is a positive constant such that

$$A \equiv \left(\frac{N\bar{z}-1}{\bar{z}}\right) \sum_{m\in\mathcal{N}\setminus\{n\}} x(\tau^m).$$

which proves that λ^n is decreasing in τ^n whenever $\gamma(\tau)$ is positive, and increasing otherwise. ■

Lemma K.19. *λ^n is concave in τ^n regardless of parameter values.*

Proof. Similarly as in Eq. (K.38), the second-order derivative of λ^n with respect to τ^n is

$$\begin{aligned}\frac{\partial^2 \lambda^n(\tau^n)}{(\partial \tau^n)^2} &= -A\left[\frac{2\gamma(\tau)^2\,[x(\tau^n)]^3\left(x(\tau^n) + \sum_{m\in\mathcal{N}\setminus\{n\}} x(\tau^m)\right) - 2\gamma(\tau)^2\,[x(\tau^n)]^4}{\left(x(\tau^n) + \sum_{m\in\mathcal{N}\setminus\{n\}} x(\tau^m)\right)^3}\right] \\ &= -A\left[\frac{2\gamma(\tau)^2\,[x(\tau^n)]^3 \sum_{m\in\mathcal{N}\setminus\{n\}} x(\tau^m)}{\left(x(\tau^n) + \sum_{m\in\mathcal{N}\setminus\{n\}} x(\tau^m)\right)^3}\right] < 0,\end{aligned}$$

which proves that λ^n is concave in τ^n. ■

Lemma K.20. *λ^n is increasing in τ^m if $\chi(\tau) - (1-\gamma\tau)\chi'(\tau) > 0$, and increases in τ^m otherwise.*

Proof. Similarly as in Eq. (K.38), we can obtain

$$\frac{\partial \lambda^n(\tau^n)}{\partial \tau^m} = \left(\frac{N\bar{z}-1}{\bar{z}}\right) \frac{x(\tau^n)\gamma(\tau)\,[x(\tau^m)]^2}{\left[\sum_m x(\tau^m)\right]^2} > 0, \tag{K.39}$$

which yields the desired result. ■

The maturity-sensitive information efficiency $\chi(\tau)$ does not enter any other place in the model than the above-mentioned places. Therefore, the results remain qualitatively unchanged as long as $\chi(\tau) - (1-\gamma\tau)\chi'(\tau) > 0$ due to the above lemmas. Note that when $\chi(\tau) = 1$, this reverts to the benchmark case.

We will now offer interpretations about the condition $\chi(\tau) - (1-\gamma\tau)\chi'(\tau) > 0$. This condition is always true when (i) $\chi(\tau)$ is constant (the benchmark case), (ii) $\chi(\tau)$ decreases in τ (short-term information is more efficient), and (iii) $\chi(\tau)$ does not increase too fast (long-term information is more cost-efficient but not excessively relative to short-term information).

Another natural way to interpret the condition is to define the following elasticity for firm n:

$$\mathcal{E}^n = \frac{d\chi(\tau^n)}{d\tau}\frac{\tau^n}{\chi}.$$

When the elasticity is higher, the cost-efficiency gain for long-term information is greater as the maturity increases. When the elasticity is more negative, the cost-efficiency gain for short-term information is greater as the maturity decreases.

Using this definition of elasticity, the condition $\chi(\tau)-(1-\gamma\tau)\chi'(\tau) > 0$ that induces short-termism can be represented as

$$\mathcal{E}^n < \frac{\gamma\tau}{1-\gamma\tau}. \tag{K.40}$$

Therefore, all our results stay the same qualitatively if and only if $\mathcal{E}^n$ is less than $\gamma\tau/(1-\gamma\tau)$, which represents the likelihood ratio of successful liquidation of informed trading compared to unsuccessful liquidation due to short-horizon of informed traders (recall that $\gamma\tau = 1-\gamma+\gamma(1-\tau)$, which is the probability of either informed trader not suffering a liquidity shock or suffering a liquidity shock but the firm pays off earlier). The right-hand side represents the strength of preference for short-term trading due to liquidity concerns (or investor short-termism). That is, for informed investors to prefer long-term information, this elasticity should be substantially high, especially when there is stronger investor short-termism. Otherwise, investors will prefer short-term information.

To provide a more concrete illustration of the above discussions, we introduce a specific parametric example of the model mentioned above. We assume that

$$\chi(\tau) = e^{b\tau+c}, \tag{K.41}$$

where b and c are constants that satisfy $0 \le \chi(\tau) \le 1$ for all $\tau \in [0,1]$. In general, short-term information is more efficient than long-term information if b is negative, and less efficient otherwise. For example, if the shortest maturity ensures complete information efficiency, we assume

$$\chi(\tau) = e^{-a\tau},$$

where a is a positive constant. Conversely, in the case where the longest maturity guarantees complete information efficiency, the assumption is

$$\chi(\tau) = e^{a(\tau-1)},$$

where a is a positive constant.

By combining the results from Lemmas K.18–K.20 and the insights from the earlier discussions with the new parametric assumption, we can derive the following outcome.

Proposition I.12. *Under the parametric assumption in Eq. (K.41), our results remain qualitatively unchanged whenever $b < \gamma$. When investors are impatient ($\gamma = 1$), our findings are qualitatively consistent regardless of the sensitivity of information efficiency to maturity (b).*

Proof. Using the parametric example in Eq. (K.41), we can represent Eq. (K.40) as

$$b < \frac{\gamma}{1-\gamma\tau}. \tag{K.42}$$

As the right-hand side of Eq. (K.42) increases with τ, the inequality holds true if valid at $\tau = 0$. Therefore, the sufficient condition for the inequality to be true is $b < \gamma$. The second statement is an immediate consequence of the obtained result. ■

The theorem establishes that the short-termism trap inevitably emerges when short-term information is more efficient ($b < 0$). In scenarios where long-term information is more efficient ($b > 0$), the short-termism trap persists if the sensitivity of information efficiency to duration is sufficiently small (b low enough) and investors are sufficiently impatient (γ high enough). In situations where both informational sensitivity is high (b high enough) and investors are patient enough (γ low enough), the outcome may undergo a qualitative shift, potentially reversing the short-termism trap. However, even when long-term information is substantially efficient, a sufficiently strong investor short-termism can always result in a short-termism trap.

In summary, the short-termism trap will arise whenever long-term information is substantially more efficient. In particular, we can characterize it to be the On the other hand, when long-term information is substantially more efficient, an opposite situation may arise due to the extreme informativeness of long-term signals relative to costs.

References

Acharya, V., Xu, Z., 2017. Financial dependence and innovation: The case of public versus private firms. J. Financ. Econ. 124 (2), 223–243.

Agarwal, V., Vashishtha, R., Venkatachalam, M., 2018. Mutual fund transparency and corporate myopia. Rev. Financ. Stud. 31 (5), 1966–2003.

Aghion, P., Bloom, N., Blundell, R., Griffith, R., Howitt, P., 2005. Competition and innovation: an inverted-u relationship. Q. J. Econ. 120 (2), 701–728.

Aghion, P., Van Reenen, J., Zingales, L., 2013. Innovation and institutional ownership. Amer. Econ. Rev. 103 (1), 277–304.

Antia, M., Pantzalis, C., Park, J.C., 2010. CEO decision horizon and firm performance: An empirical investigation. J. Corp. Finance 16 (3), 288–301.

Asker, J., Farre-Mensa, J., Ljungqvist, A., 2015. Corporate investment and stock market listing: A puzzle? Rev. Financ. Stud. 28 (2), 342–390.

Baiman, S., Verrecchia, R.E., 1995. Earnings and price-based compensation contracts in the presence of discretionary trading and incomplete contracting. J. Account. Econ. 20 (1), 93–121.

Ball, R., Brown, P., 1968. An empirical evaluation of accounting income numbers. J. Account. Res. 6 (2), 159–178.

Bergstresser, D., Philippon, T., 2006. CEO incentives and earnings management. J. Financ. Econ. 80 (3), 511–529.

Berk, J.B., van Binsbergen, J.H., 2021. The impact of impact investing. Working paper, Stanford University Graduate School of Business Research Paper, Law & Economics Center at George Mason University Scalia Law School Research Paper Series No. 22-008.

Bernstein, S., 2015. Does going public affect innovation? J. Finance 70 (4), 1365–1403.

Bolton, P., Scheinkman, J.A., Xiong, W., 2006. Executive compensation and short-termist behaviour in speculative markets. Rev. Econ. Stud. 73 (3), 577–610.

Bond, P., Edmans, A., Goldstein, I., 2012. The real effects of financial markets. Annu. Rev. Finan. Econ. 4, 339–360.

Brochet, F., Loumioti, M., Serafeim, G., 2015. Speaking of the short-term: disclosure horizon and managerial myopia. Rev. Account. Stud. 20 (3), 1122–1163.

Brunnermeier, M.K., Pedersen, L.H., 2009. Market liquidity and funding liquidity. Rev. Financ. Stud. 22 (6), 2201–2238.

Bushee, B.J., 1998. The influence of institutional investors on myopic R&D investment behavior. Account. Rev. 73 (3), 305–333.

Callen, J.L., Fang, X., 2013. Institutional investor stability and crash risk: Monitoring versus short-termism? J. Bank. Financ. 37 (8), 3047–3063.

Cella, C., Ellul, A., Giannetti, M., 2013. Investors' horizons and the amplification of market shocks. Rev. Financ. Stud. 26 (7), 1607–1648.

Chemla, G., Rivera, A., Shi, L., 2022. Too much, too soon, for too long: The dynamics of competitive executive compensation. Working paper.

Chemmanur, T.J., Fulghieri, P., 2006. Competition and cooperation among exchanges: A theory of cross-listing and endogenous listing standards. J. Financ. Econ. 82 (2), 455–489.

Cremers, M., Pareek, A., Sautner, Z., 2020. Short-term investors, long-term investments, and firm value: Evidence from russell 2000 index inclusions. Manage. Sci. 66 (10), 4535–4551.

Davies, R., Haldane, A.G., Nielsen, M., Pezzini, S., 2014. Measuring the costs of short-termism. J. Financial Stab. 12 (1), 16–25.

Dechow, P.M., Sloan, R.G., 1991. Executive incentives and the horizon problem. An empirical investigation. J. Account. Econ. 14 (1), 51–89.

DeGroot, M., 1970. Optimal Statistical Decisions. McGraw-Hill, New York.

Dhaliwal, D.S., Lee, K.J., Fargher, N.L., 1991. The association between unexpected earnings and abnormal security returns in the presence of financial leverage. Contemp. Account. Res. 8 (1), 20–41.

Dow, J., Goldstein, I., Guembel, A., 2017. Incentives for information production in markets where prices affect real investment. J. Eur. Econom. Assoc. 15 (4), 877–909.

Dow, J., Gorton, G., 1994. Arbitrage chains. J. Finance 49 (3), 819–849.

Dow, J., Gorton, G., 1997. Stock market efficiency and economic efficiency: Is there a connection? J. Finance 52 (3), 1087.

Dow, J., Han, J., 2018. The paradox of financial fire sales: The role of arbitrage capital in determining liquidity. J. Finance 73 (1), 229–274.

Dow, J., Han, J., Sangiorgi, F., 2021. Hysteresis in price efficiency and the economics of slow-moving capital. Rev. Financ. Stud. 34, 2857–2909.

Dow, J., Rahi, R., 2003. Informed trading, investment and welfare. J. Bus. 76 (3), 439–454.

Dye, R.A., 1993. Auditing standards, legal liability, and auditor wealth. J. Polit. Econ. 101 (5), 887–914.

Echenique, F., Edlin, A., 2004. Mixed equilibria are unstable in games of strategic complements. J. Econom. Theory 118 (1), 61–79.

Edmans, A., 2009. Blockholder trading, market efficiency, and managerial myopia. J. Finance 64 (6), 2481–2513.

Edmans, A., Gabaix, X., Sadzik, T., Sannikov, Y., 2012. Dynamic CEO compensation. J. Finance 67 (5), 1603–1647.

Fishman, M.J., Hagerty, K.M., 1989. Disclosure decisions by firms and the competition for price efficiency. J. Finance 44 (3), 633–646.

Foucault, T., Frésard, L., 2019. Corporate strategy, conformism, and the stock market. Rev. Financ. Stud. 32 (3), 905–950.

Gaspar, J.-M., Massa, M., Matos, P., 2005. The influence of institutional investors on myopic R&D investment behavior. J. Financ. Econ. 76 (1), 135–165.

Giannetti, M., Yu, X., 2021. Adapting to radical change: The benefits of short-horizon investors. Manage. Sci. 67 (7), 4032–4055.

Goldstein, I., Ozdenoren, E., Yuan, K., 2013. Trading frenzies and their impact on real investment. J. Financ. Econ. 109 (2), 566–582.

Gopalan, R., Milbourn, T., Song, F., Thakor, A.V., 2014. Duration of executive compensation. J. Finance 69 (6), 2777–2817.

Graves, S.B., Waddock, S.A., 1990. Institutional ownership and control: implications for long-term corporate strategy. Acad. Manag. Perspect. 4 (1), 75–83.

Grossman, S.J., Hart, O.D., 1983. An analysis of the principal-agent problem. Econometrica 51 (1), 7–45.

Han, J., Sangiorgi, F., 2018. Searching for information. J. Econom. Theory 175, 342–373.

Hansen, G.S., Hill, C.W., 1991. Are institutional investors myopic? A time-series study of four technology-driven industries. Strateg. Manag. J. 12 (1), 1–16.

Hardin, G., 1968. The tragedy of the commons. Science 162 (3859), 1243–1248.

Harris, M., Raviv, A., 2008. A theory of board control and size. Rev. Financ. Stud. 21 (4), 1797–1832.

Hermalin, B.E., 1992. The effects of competition on executive behavior. Rand J. Econ. 23 (3), 350–365.

Holmstrom, B., 1979. Moral hazard and observability. Bell J. Econ. 10 (1), 74–91.

Holmstrom, B., Milgrom, P., 1991. Multitask principal–agent analyses: Incentive contracts, asset ownership, and job design. J. Law Econ. Organ. 7, 24–52.

Holmstrom, B., Tirole, J., 1993. Market liquidity and performance monitoring. J. Polit. Econ. 101 (4), 678–709.

Jacobs, M.T., 1991. Short-Term America: The Causes and Cures of Our Business Myopia. Havard Business School Press, Boston, MA.

Kang, Q., Liu, Q., 2010. Information-based stock trading, executive incentives, and the principal-agent problem. Manage. Sci. 56 (4), 682–698.

Keum, D.D., 2021. Innovation, short-termism, and the cost of strong corporate governance. Strateg. Manag. J. 42 (1), 3–29.

Kim, H.D., Kim, Y., Mantecon, T., Song, K.R., 2019. Short-term institutional investors and agency costs of debt. J. Bus. Res. 95, 195–210.

Kim, Y., Su, L.N., Zhu, X.K., 2017. Does the cessation of quarterly earnings guidance reduce investors' short-termism? Rev. Account. Stud. 22 (2), 715–752.

Kraft, A.G., Vashishtha, R., Venkatachalam, M., 2018. Frequent financial reporting and managerial myopia. Account. Rev. 93 (2), 249–275.

Kyle, A.S., 1985. Continuous auctions and insider trading. Econometrica 53 (6), 1315–1335.

Ladika, T., Sautner, Z., 2020. Managerial short-termism and investment: Evidence from accelerated option vesting. Rev. Finance 24 (2), 305–344.

Latham, S., Braun, M., 2010. Does short-termism influence firm innovation? An examination of S&P 500 firms, 1990–2003. J. Managerial Issues 22 (3), 368–382.

Lee, J.M., Park, J.C., Folta, T.B., 2018. CEO career horizon, corporate governance, and real options: The role of economic short-termism. Strateg. Manag. J. 39 (10), 2703–2725.

Levhari, D., Mirman, L.J., 1980. The great fish war: An example using a dynamic cournot-Nash solution. Bell J. Econ. 11 (1), 322.

Lin, T.C., Liu, Q., Sun, B., 2019. Contractual managerial incentives with stock price feedback. Amer. Econ. Rev. 109 (7), 2446–2468.

Lundstrum, L.L., 2002. Corporate investment myopia: A horserace of the theories. J. Corp. Finance 8 (4), 353–371.

Manconi, A., Massa, M., Yasuda, A., 2012. The role of institutional investors in propagating the crisis of 2007–2008. J. Financ. Econ. 104 (3), 491–518.

Mast, E., 2020. Race to the bottom? Local tax break competition and business location. Am. Econ. J.: Appl. Econ. 12 (1), 288–317.

Milbradt, K., Oehmke, M., 2015. Maturity rationing and collective short-termism. J. Financ. Econ. 118 (3), 553–570.

Murphy, K.J., 2013. Executive compensation: Where we are, and how we got there. In: Constantinides, G.M., Harris, M., Stulz, R.M. (Eds.), Handbook of the Economics of Finance. vol. 2, Elsevier, Amsterdam, pp. 211–356.

Nalebuff, B.J., Stiglitz, J.E., 1983. Information, competition and markets. Am. Econ. Rev. 73 (2), 278–283.

Nanda, R., Nicholas, T., 2014. Did bank distress stifle innovation during the Great Depression? J. Financ. Econ. 114 (2), 273–292.

Pathan, S., Haq, M., Faff, R., Seymour, T., 2021. Institutional investor horizon and bank risk-taking. J. Corp. Finance 66, 101794.

Peress, J., 2010. Product market competition, insider trading, and stock market efficiency. J. Finance 65 (1), 1–43.

Perry, M.K., 1984. Scale economies, imperfect competition, and public policy. J. Ind. Econ. 32 (3), 313.

Piccolo, A., 2022. The earnings game. Kelley School of Business Research Paper No. 2021-2022.
Porter, M.E., 1990. The Competitive Advantage of Nations. Free Press, New York.
Porter, M.E., 1992. Capital disadvantage: America's failing capital investment system. Harv. Bus. Rev. 70 (5), 65–82.
Raith, M., 2003. Competition, risk, and managerial incentives. Amer. Econ. Rev. 93 (4), 1425–1436.
Scharfstein, D., 1988. Product-market competition and managerial slack. Rand J. Econ. 19 (1), 147.
Schmidt, K.M., 1997. Managerial incentives and product market competition. Rev. Econ. Stud. 64 (2), 191–213.
Shavell, S., 1979. Risk sharing and incentives in the principal and agent relationship. Bell J. Econ. 10 (1), 55–73.
Shleifer, A., Vishny, R.W., 1990. Equilibrium short horizons of investors and firms. Am. Econ. Rev. 80 (2), 148–153.
Sockin, M., Xiong, W., 2015. Informational frictions and commodity markets. J. Finance 70 (5), 2063–2098.
Stein, J.C., 1989. Efficient capital markets, inefficient firms: A model of myopic corporate behavior. Q. J. Econ. 104 (4), 655–669.
Strobl, G., 2014. Stock-based managerial compensation, price informativeness, and the incentive to overinvest. J. Corp. Finance 29, 594–606.
Thakor, R.T., 2021. Short-termism, managerial talent, and firm value. Rev. Corp. Finance Stud. 10 (3), 473–512.
Thanassoulis, J., 2013. Industry structure, executive pay, and short-termism. Manage. Sci. 59 (2), 402–419.
Tirole, J., 2006. The Theory of Corporate Finance. Princeton University Press, Princeton, N.J..
Topkis, D., 1998. Supermodularity and Complementarity. Princeton University Press, Princeton, N.J.
Varas, F., 2018. Managerial short-termism, turnover policy, and the dynamics of incentives. Rev. Financ. Stud. 31 (9), 3409–3451.
Von Beschwitz, B., Lunghi, S., Schmidt, D., 2022. Fundamental arbitrage under the microscope: Evidence from detailed hedge fund transaction data. Rev. Asset Pricing Stud. 12 (1), 199–242.
Xiong, Y., Jiang, X., 2022. Economic consequences of managerial compensation contract disclosure. J. Account. Econ. 73 (2–3), 101489.
Yan, X.S., Zhang, Z., 2009. Institutional investors and equity returns: Are short-term institutions better informed? Rev. Financ. Stud. 22 (2), 893–924.