Stock-Based Compensation and CEO (Dis)Incentives *

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Abstract

The use of stock-based compensation as the solution to agency problems between shareholders and managers has increased dramatically since the early 1990's. In a dynamic rational expectations model with asymmetric information, we show that while stock-based compensation induces managers to exert costly effort, it also induces them to conceal bad news about future growth options, and choose sub-optimal investment policies to support the pretense. This leads to a severe overvaluation and a subsequent crash in the stock price. Still, shareholders often prefer to induce high effort with stock-based compensation rather than low-effort with an earnings-based compensation, even if the latter induces optimal investments. A firm-specific compensation package based on both stock and earnings performance induces the first-best combination of high effort, information disclosure and optimal investments. Our model produces many predictions that are consistent with the empirical evidence, and are relevant to understanding the current crisis.

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1. Introduction

While a large theoretical literature views stock-based compensation as a solution to an agency problem between shareholders and managers, there is a growing body of empirical evidence that shows it may lead to earnings management, misreporting, and outright fraudulent behavior. Does stock-based compensation amplify the tension between the incentives of managers and shareholders instead of aligning them?

The ongoing global financial crisis has brought forth renewed concerns about the adverse incentives that stock-based compensation may encourage. Many managers of the recently troubled financial institutions were amongst the highest-paid executives in the U.S., with huge equity-based personal profits realized at the time when their firms' stock prices were high.[1] While the subsequent sharp decline of their firms' stock prices may be due to exogenous systemic shocks to the economy, it is an important open question whether the size of the stock-based compensation may have induced CEOs to willingly drive prices up in full awareness of the impending crash. Indeed, similar concerns about these possible perverse effects of stock-based compensations on CEOs' behavior were raised after the burst of the Dot.Com bubble. As governments across the globe are preparing a new wave of sweeping regulation, it is important to study the incentives induced by stock-based compensation, as well as the trade-offs involved in any decision that may affect the stock component in executives' compensation packages.[2]

In this paper, we show formally that while stock-based compensation induces managers to exert costly effort to increase the firms' investment opportunities, it also induces incentives for sub-optimal investment policies designed to hide bad news about the firm long term growth. We analyze a dynamic rational expectations equilibrium model, and identify conditions under which stock-based executive compensation leads to misreporting, suboptimal investment, run-up and a subsequent sharp decline in equity prices.

More specifically, we study a hidden action model of a firm that is run by a CEO, whose

[1]For instance, Richard Fuld, the former CEO of bankrupt Lehman Brothers was the 14th highest-paid CEO in 2007, with $71.92 million in compensation including more than $40 million from realized stock options. Angelo Mozilo, the CEO of Countrywide Financial Corp was the 3rd highest-paid CEO in 2007, making $125 million. Mozilo's total compensation from July 1, 2003 to June 30, 2008 mounted to $470 million, out of which $378 million were proceeds from stock sales. Similarly, during the same period, James E. Cayne, the former CEO and Chairman of the Board of Bear Stearns took home $163 million with $111 million as proceeds from exercising options and selling stocks.

[2]For instance, in January 2009 the U.S. Government has imposed further restrictions on the non-performance-related component of the compensation packages. In light of our results, it seems that the administration is moving in the wrong direction.

compensation is linked to either the stock price or the dividends. The firm initially experiences high growth in investment opportunities and the CEO must invest intensively to exploit the growth options. The key feature of our model is that at a random point in time the rate of growth of the firm's investment opportunities slows down. The CEO is able to increase the expected time of this decline by exercising costly effort. But when the investment opportunities growth does inevitably slow down, the investment policy of the firm should change appropriately. We assume asymmetric information: while the CEO privately observes the decrease in the growth rate, shareholders are oblivious to it. Moreover, they do not observe investments, but base their valuation only on dividend payouts. When investment opportunities decline, the CEO has two options: revealing the decline in investment opportunities to shareholders, or behaving as if nothing had happened. Revealing the decline to shareholders leads to an immediate decline in the stock price. If the CEO chooses not to report the change in the business environment of the firm, the stock price does not fall, as the outside investors have no way of deducing this event, and equity becomes overvalued. In order to behave as if nothing has changed the CEO must design a sub-optimal investment strategy to maintain the pretense. We assume that as long as the reported dividends over time are consistent with the high growth rate, the CEO keeps her job. Any deviation that is not at the time of a declared drop of the growth rate leads to the CEO's dismissal.

We show that when the CEO compensation is based on the firm's dividends, the only pure strategy Nash equilibrium is separating, in which the CEO reveals the decline in investment opportunities growth and follows the optimal investment policy. In sharp contrast, we find that whenever the CEO has a large stock-based component in her compensation, and the range of possible growth rates is large, there is a pooling Nash equilibrium for most parameter values. In this equilibrium, the CEO of a firm that experienced a decline in the growth rate of investment opportunities must follow a suboptimal investment policy designed to maintain the pretense that investment opportunities are still strong. We are able to solve for the dynamic pooling equilibrium in closed form and fully characterize the CEO's investment strategy. In particular, since the CEO is interested in keeping a high growth profile for as long as possible, initially she invests in negative NPV projects as storage of cash, and later on foregoes positive NPV projects in order to meet rapidly-growing demand for dividends. In both cases, she destroys value. Since this strategy cannot be kept forever, at some point the firm experiences a cash shortfall, the true state is revealed and the stock price sharply declines as the firm needs to recapitalize.

Our model highlights the tension that stock-based compensation creates. While the common wisdom of hidden action models is to align the manager's incentive with those of investors by tying her compensation to the stock price, stock-price-based compensation may lead the manager to invest suboptimally and destroy value. The trade off is made apparent by the fact that for most reasonable parameter values, and especially for medium to high growth companies, we find that dividend-based compensation induces a dynamic equilibrium characterized by full revelation but low effort, while stock-based compensation induces an equilibrium with high effort but the suboptimal "conceal" investment strategy. That is, the cost of inducing high managerial effort ex-ante comes from the suboptimal investment policy after the slowdown in investment opportunities.

We show that this double incentive problem (i.e. induce high effort and revelation) can often be overcome by a firm-specific combined compensation package: by appropriately choosing a combination of dividends and stock-based compensation, it is possible to shift the equilibrium to a (High Effort / Reveal) equilibrium and obtain the first best for shareholders. Most important, we show that different types of firms need to put in place a different composition of dividends and stocks in the compensation package. Specifically, we find that the CEO's compensation package of growth firms, that is, those with high investment opportunities growth and high return on capital, should have only little stock-price sensitivity, but large dividend sensitivity to induce the first best. Indeed, a calibration of the model shows that for most firms the stock-based compensation component should never be above 50% of the total CEO compensation in order to induce truth revelation and optimal investments. Similarly, for most firms with medium-high return on investment the stock-based compensation component should be strictly positive to induce high effort. These results suggest that policymakers and firms' boards of directors should be careful with both an outright ban of stock-based compensation as well as with too much reliance on it.

Our model's predictions are consistent with the empirical evidence documenting that stock-based executive compensation is associated with earnings management, misreporting and restatements of financial reports, and outright fraudulent accounting (e.g. Healy (1985), Beneish (1999), Bergstresser and Philippon (2006), Ke (2005), Burns and Kedia (2006) and Kedia and Philippon (2006).) In fact, our model's predictions go beyond the issue of earnings manipulation and restatements, as we focus on the entire investment behavior of the firm over the long haul. Similarly, our model's predictions are consistent with the survey results of Graham et al. (2004), according to which most managers state that they would forego a positive NPV project if it causes them to miss the earnings target, with high tech firms much more likely to do so. High tech firms are also much more likely to cut R&D and other discretionary spending to meet the target. On the same note, our model's prediction are also consistent with Skinner and Sloan (2002), who show that the decline in firm value following a failure to meet the analysts' forecasts is more pronounced in high growth firms.

While our paper is related to the literature on managerial "short-termism" and myopic corporate behavior (e.g. Stein (1989), Bebchuk and Stole (1993), Jensen (2005), Aghion and Stein (2007)) our results do not rely on behavioral biases, and apply to a wider range of firms. In terms of assumptions, our paper bears some similarities to Miller and Rock (1985) who study the effects of dividends announcements on the value of the firm. Similarly to Eisfeldt and Rampini (2007) and Inderst and Mueller (2006), we also assume that the CEO has a significant informational advantage over investors, but differently from them we focus on investors' beliefs about future growth rates and their effect on the incentives of the managers. Our paper is also related to Bolton, Scheinkman and Xiong (2006), Goldman and Slezak (2006), and Kumar and Langberg (2007), but it differs from them as we emphasize the importance of firms' long term growth options, which have a "multiplier" impact on the stock price and thus on CEO incentives to hide any worsening of investment opportunity growth. Overall, these papers complement each other, and conclude that contrary to the traditional prescriptions, providing managers with large high-powered short-run incentives based on the stock price may be dangerous, because the stock price accumulates the beliefs about the uncertain future. The manager can use deceptive or even fraudulent practices that destroy value to maintain the pretense of a bright tomorrow.

Finally, our paper is also related to the recent literature on dynamic contracting under asymmetric information (e.g. Quadrini (2004), Clementi and Hopenhayn (2006), DeMarzo and Fishman (2007)). These papers focus on the properties of the optimal contract that induces full revelation, such that there is no information asymmetry in equilibrium. While we also find the contract that induces full revelation and the first best, the main focus of our paper is to study the properties of the dynamic *pooling* equilibrium in which the manager does *not* reveal the true state, which we believe to be widespread. This analysis is complicated by the feedback effect that the equilibrium price dynamics exerts on the CEO compensation and thus on her optimal intertemporal investment strategy, which in turn affects the equilibrium price dynamics itself through shareholders beliefs. The solution of this fixed point problem is absent in other dynamic contracting models, but is at the heart of our paper.

The rest of the paper is organized as follows. Section 2. presents the model setup. Section 3. analyzes the benchmark case of full information. Section 4. presents the case with asymmetric information. In Section 5. we calibrate the model and Section 6. concludes.

2. The Model

We consider a firm run by a manager who *a*) chooses effort that affects the growth opportunities of the firm; *b*) privately observes the realization of the growth opportunities, and decides whether to report them to the public; and *c*) chooses the investment strategy of the firm that is consistent with her public announcement. Our analysis focuses on the manager's tradeoff between incentives to exert costly effort to maintain a high growth of investment opportunities, and her incentives to reveal to shareholders when investment opportunities growth slows down.

We start by defining firm's investment opportunities that are described by the following production technology: given the stock of capital K_t, firm's operating profit (output) Y_t is:

$$Y_t = \begin{cases} zK_t & \text{if} \quad K_t \leq J_t \\ zJ_t & \text{if} \quad K_t > J_t \end{cases}, \tag{1}$$

where z is the rate of return on capital, and J_t defines an upper bound on the amount of deployable productive capital that depends on the technology, operating costs, demand and so on. The Leontief technology specification (1) implies constant return to scale up to the upper bound J_t, and then zero return for $K_t > J_t$. This simple specification of a decreasing return to scale technology allows us to conveniently model the evolution of the growth rate in profitable investment opportunities, which serves as the driving force of our model. The existing stock of capital depreciates at the rate of δ.

We assume that the upper bound J_t in (1) grows according to

$$\frac{dJ_t}{dt} = \tilde{g} J_t \tag{2}$$

where $\tilde{g}$ is a stochastic variable described below. The combination of (1) and (2) yields growing investment opportunities of the firm. Since the technology displays constant returns to scale up to J_t, it is optimal to keep the capital at the level J_t if these investments are profitable, which we assume throughout. Figure 1 illustrates investment opportunities growth.

We set time $t = 0$ to be the point when shareholders know firm's capital K_0, as well as the current growth rate of investment opportunities $\tilde{g} = G$. One can think of $t = 0$ as the time of the firm's IPO, SEO or of a major corporate event, such as a reorganization, that has elicited much information about the state of the firm. This is mostly a technical simplifying assumption, as we believe that all the insights would remain if the market has a system of beliefs over the initial capital and the growth rate.

Firms tend to experience infrequent changes in their growth rates. We are interested in the declines of the growth rate, as this is the time when the manager faces a hard decision of whether to reveal the bad news to the public. Any firm may experience such a decline, thus our analysis apply to a wide variety of scenarios. We model the stochastic decline in investment opportunities growth as a discrete shift from the high growth regime, $\tilde{g} = G$, to a low growth regime, $\tilde{g} = g(< G)$, that occurs at a random time τ^*. Formally,

$$\tilde{g} = \begin{cases} G & \text{for} \quad t < \tau^* \\ g & \text{for} \quad t \geq \tau^* \end{cases}, \tag{3}$$

We assume that τ^* is exponentially distributed with parameter λ:

$$f(\tau^*) = \lambda e^{-\lambda \tau^*}.$$

At every instant dt, there is a constant probability λdt that a shift from G to g occurs.

We assume that manager's actions affect the time at which the decline occurs. After all, CEOs must actively search for investment opportunities, monitor markets and internal developments, all of which require time and effort. In our model, higher effort translates into a smaller probability to shift to a lower growth. More specifically, the manager can choose to exert high or low effort, $e^H > e^L$. Choosing higher effort increases the expected time τ^* at which the investment opportunities growth decline. Formally:

$$\lambda^H \equiv \lambda(e^H) < \lambda(e^L) \equiv \lambda^L \Longleftrightarrow E[\tau^*|e^H] > E[\tau^*|e^L]$$

The cost of high effort is positive, whereas the cost of low effort is normalized to zero:

$$c(e) \in \{c^H, c^L\}, \ s.t. \ c^H > c^L = 0.$$

To keep the analysis simple, we assume linear preferences of the manager:

$$U_t = E_t \left[\int_t^T e^{-\beta(u-t)} w_u \left[1 - c(e)\right] du \right], \tag{4}$$

where w_u is the periodic wage of the CEO, and β is her discount rate.[3] We specify a cost of effort in a multiplicative fashion, which allows us to preserve scale invariance. Economically, this assumption implies a complementarity between the wage and "leisure" $[1 - c(e)]$, a relatively standard assumption in macroeconomics. That is, effort is costly exactly because it does not allow the CEO to enjoy her pay w_t as much as possible.

[3]Linear preferences simplify the analysis. However, our results also hold with risk averse managers, although the analytical tractability is lost.

In (4), T is the time at which the manager leaves the firm, possibly $T = \infty$.[4] However, the departing date T may occur earlier, as the manager may be fired if the shareholders learn that she has followed a suboptimal investment strategy.

We assume that CEO receives a performance-based compensation w_t as long as she stays with the firm. We consider two simple pure compensation schemes: stock-based and dividend-based. While these cases are extreme, concentrating on them first enables us to better clarify the intuition behind the incentives provided by dividends or stocks. The optimal compensation scheme, which we explore later, is a combination of the two. Specifically,

$$w_t = \begin{cases} \eta_p P_t & \text{for stock-based compensation} \\ \eta_d D_t & \text{for dividend-based compensation} \end{cases},$$

where η_p and η_d are two positive constants. Their levels are not important for now, but it is important to note that we can choose their values so to make the equilibrium present value of payments to the manager the same under the two compensation schemes. For analytical tractability, we assume that manager's compensation is external to the firm and thus does not affect its value directly - we assume that the compensation contract is settled elsewhere.[5]

We must make several technical assumptions to keep the model from diverging, degenerating or becoming intractable. First, we assume for tractability that manager's decisions are firm-specific, and thus do not affect the systematic risk of the stock and its cost of capital, which we denote r. Then we must assume that

$$z > r + \delta, \tag{5}$$

that is, the return on capital z is sufficiently high to compensate for the cost of capital r and depreciation δ. This assumption implies that it is economically optimal for investors to provide capital to the company and invest up to its fullest potential, as determined by the Leontief technology described in (1).

To ensure a finite value of the firm's stock price, we must assume that

$$r > G - \lambda^H \quad \text{and} \quad r > g.$$

We further assume that $\beta > G$, which is required to keep the total utility of the manager

[4] $T = \infty$ also corresponds to the case in which there is a constant probability that the manager leaves the firm or dies, whose intensity is then included in the discount rate β, as in Blanchard (1985).

[5] For example, the manager may be selling her shares to outside investors, which has no direct impact on firm valuation. Including compensation into the firm valuation would not change our results qualitatively, but would significantly complicate the analysis. In Section 5.5. we approximate the compensation costs to the firm across compensation schemes, and show that their inclusion would in fact re-inforce our results.

finite. We also assume that $\beta \geq r$, i.e. the manager has a higher discount rate than fully diversified investors.[6]

While we assume that the market does not observe the investments and the capital stock, there is a limit to what the firm can conceal. We model this by assuming that to remain productive, the firm must maintain a minimum level of capital $K_t \geq \underline{K}_t$, where $\underline{K}_t$ is exogenously specified, and for simplicity it depends on the optimal size of the firm:

$$K_t \geq \underline{K}_t = \xi J_t \quad \text{for} \quad 0 \leq \xi < 1 \tag{6}$$

where J_t is defined in (2). This is a purely technical assumption and ξ is a free parameter.

Finally, we assume for simplicity that the firm does not retain earnings, thus the dividend rate equals its operating profit Y_t derived from its stock of capital, K_t, less the investment it chooses to make, I_t. Given the technology in (1), the dividend rate is

$$D_t = z \min(K_t, J_t) - I_t. \tag{7}$$

3. Benchmark: Symmetric Information

It is useful to go through the benchmark case in which the manager and shareholders share the same information. To maximize the firm value the manager must invest to its fullest potential, that is, to keep $K_t = J_t$ for all t. We solve for the investment rate I_t that ensures this constraint is satisfied, and we obtain the following:

Proposition 1: *The first-best optimal investment policy given λ is*

$$I_t = \begin{cases} (G+\delta)e^{Gt} & \textit{for} \quad t < \tau^* \\ (g+\delta)e^{G\tau^* + g(t-\tau^*)} & \textit{for} \quad t \geq \tau^* \end{cases} . \tag{8}$$

The dividend stream of a firm that fully invests is given by:

$$D_t = zK_t - I_t = \begin{cases} D_t^G = (z-G-\delta)e^{Gt} & \textit{for} \quad t < \tau^* \\ D_t^g = (z-g-\delta)e^{G\tau^* + g(t-\tau^*)} & \textit{for} \quad t \geq \tau^* \end{cases} . \tag{9}$$

The top panel of Figure 2 plots the dynamics of the optimal dividend path for a firm with a high growth in investment opportunities until τ^*, and a low growth afterwards. As

[6]It is intuitive that the discount rate of an individual, β, is larger than the discount rate of shareholders: for instance, a manager may be less diversified than the market, or β may reflects some probability of leaving the firm early or death, or simply a shorter horizon than the market itself.

the figure shows, the slowdown in the investment opportunities requires a decline in the investment rate, which initially increases the dividend payout rate: $D^g_{\tau^*} - D^G_{\tau^*} = (G-g)e^{G\tau^*}$.

Given the above assumptions, the dividend rate is always positive. Moreover, from (9) the dividend growth rate equals the growth rate of investment opportunities, $\tilde{g}$. Given the dividend profile, the price of the stock follows:

Proposition 2: *Given λ, under symmetric information the value of the firm is:*

$$P^{after}_{fi,t} = \int_t^\infty e^{-r(s-t)} D^g_s ds = \left(\frac{z-g-\delta}{r-g}\right) e^{G\tau^*+g(t-\tau^*)} \qquad for \quad t \geq \tau^*, \tag{10}$$

$$P^{before}_{fi,t} = E_t\left[\int_t^{\tau^*} e^{-r(s-t)} D^G_s ds + e^{-r(\tau^*-t)} P^{after}_{fi,\tau^*}\right] = e^{Gt} A^{fi}_\lambda \qquad for \quad t < \tau^* \tag{11}$$

where

$$A^{fi}_\lambda = \frac{(z-G-\delta)}{r+\lambda-G} + \lambda\left(\frac{z-g-\delta}{(r-g)(r+\lambda-G)}\right). \tag{12}$$

In the pricing functions (10) and (11) the subscript "fi" stands for "full information" and superscripts "$after$" and "$before$" are for $t \geq \tau^*$ and $t < \tau^*$, respectively. Under full information, the share price drops at time τ^* by:

$$P^{after}_{fi,\tau^*} - P^{before}_{fi,\tau^*} = -e^{G\tau^*} \frac{(z-r-\delta)(G-g)}{(r-g)(r+\lambda-G)},$$

which increases in τ^*. The bottom panel of Figure 2 plots the price path in the benchmark case corresponding to the dividend path in the top panel.

3.1. Managers Incentives under Symmetric Information

Under full information, the time of decline in the investment opportunities growth, τ^*, and the investment strategy I_t are observable. As in the standard principal-agent model, the only variable that shareholders cannot observe is the effort level e_t. We now show that in this setting, dividend-based compensation may not provide a sufficient incentive for the agent to exert effort, even if effort is not costly at all. Stock-based compensation instead is better able to align the manager's incentives with shareholders objectives (see Bhattacharya and Cohn (2008) for a discussion).

First, we show that all else equal, shareholders prefer the manager to exert high effort, as the choice of e^H maximizes firm value.

Corollary 1. *The firm value under* e^H *is always higher than under* e^L*, that is*

$$P^{before}_{fi,t}\left(\lambda^H\right) > P^{before}_{fi,t}\left(\lambda^L\right). \tag{13}$$

By simple substitution in Proposition 2, it is easy to see that (13) holds if and only if

$$z - r - \delta > 0, \tag{14}$$

which is always satisfied (see condition (5)). Next proposition characterizes the equilibrium:

Proposition 3.

(a) Under dividend-based compensation*, the manager exerts high effort,* e^H*, iff*

$$\frac{\lambda^L + \beta - G}{\lambda^H + \beta - G} > \frac{1 + \lambda^L H^{Div}}{1 - c^H + \lambda^H H^{Div}}, \tag{15}$$

where

$$H^{Div} = \frac{(z - g - \delta)}{(z - G - \delta)(\beta - g)}. \tag{16}$$

A Nash equilibrium *with high (low) effort obtains iff (15) is (is not) satisfied.*

(b) Let shareholders believe that λ *is the current intensity of* τ^**, so that the stock price is* $P^{before}_{fi,t} = e^{Gt} A^{fi}_{\lambda}$ *where* A^{fi}_{λ} *is in (12). Then, under* stock-based compensation*, the manager exerts high effort,* e^H*, iff*

$$\frac{\lambda^L + \beta - G}{\lambda^H + \beta - G} > \frac{A^{fi}_{\lambda} + \lambda^L H^{Stock}}{A^{fi}_{\lambda}(1 - c^H) + \lambda^H H^{Stock}}, \tag{17}$$

where

$$H^{Stock} = \frac{z - g - \delta}{(r - g)(\beta - g)},$$

It follows that a high effort Nash equilibrium *occurs iff (17) is satisfied for* $A^{fi}_{\lambda^H}$*. A* low effort Nash equilibrium *occurs if and only if (17) is not satisfied for* $A^{fi}_{\lambda^L}$*.*

(c) Let the following condition hold:

$$\left(1 - c^H\right) > \frac{\lambda^H}{\lambda^L}. \tag{18}$$

Then there exist parameters for which low effort e^L *is a Nash equilibrium under dividend-based compensation, and high effort* e^H *is a Nash equilibrium under stock-based compensation.*

Condition (15) is intuitive. First, when effort does not produce much increase in the expected τ^*, i.e. when $\lambda^H \approx \lambda^L$, then the condition is never satisfied with $c^H > 0$, and therefore the manager does not exert high effort. Second, and perhaps less intuitively, even when effort is costless, the manager may not choose high effort with dividend-based compensation. Indeed, when $c^H = 0$, condition (15) is satisfied if and only if[7]

$$z - \beta - \delta > 0. \tag{19}$$

This is similar to (14), but with the manager discount β taking place of the shareholders' discount r. If the manager has the same discount rate as the diversified shareholders, then dividend-based compensation always induces the optimal effort by assumption. The problem manifests itself when the manager is impatient, and the return on capital is low, so that $\beta > z - \delta$. Then high effort is not optimal for the manager even if the cost of effort is zero. This is puzzling at first, but recall the dividend profiles under high growth and low growth (see Figure 2): a high growth rate implies low dividends today, but high in the future. It is worth to exert effort and have a longer-lasting high dividend growth only if the manager is patient – as her payoff today is lower compared to the future – or the return on capital is very high, so that dividends tend to be high as well. If $c^H > 0$, the bound becomes even tighter, and even lower levels of β are not able to induce the manager to exert high effort.

Condition (17) for stock-based compensation is similar to (15) in point (a), and thus has a similar intuition. Part (c) of Proposition 3 shows that if the cost of effort c^H is not too high, then the dividend-based compensation is not as effective as stock-based compensation in inducing high effort. That is, that the right hand side of (15) is larger than the right hand side of (17), creating a potential for two differing equilibria under two compensation schemes: low effort under the dividend-based compensation, and high effort under the stock-based. As we show below in Section 5., this scenario obtains for a wide range of parameters values.

4. Asymmetric Information

Clearly the manager has much more information than the investors regarding the future growth opportunities of the firm, as well as about its actual investments. We assume that the decline in investment opportunities is private information of the manager and cannot be observed by investors. Neither can they observe the investment activity of the firm, at least not on the margin. This assumption is plausible in many industries, such as those with high R&D expenditures, intellectual property, high degree of opacity in their operation,

[7] This condition is obtained by substituting $c^H = 0$ and the value of H_{Div} into (15) and rearranging terms.

and especially the rapidly growing new industries, as the market does not know how to distinguish between investments and costs. We assume, therefore, that investors have to base the valuation of the firm's prospects only on the dividend stream D_t.[8]

Shareholders know that at $t = 0$ the firm has a given K_0 of capital and high growth rate G of investment opportunities. Since it is prohibitively costly to monitor the investment strategy of the firm, shareholders must use dividends to assess whether the firm at any later time t is a G firm or a g firm. As long as the firm is of type G, they expect a dividend as described in (9).[9] We also assume that whenever the dividend deviates from the path of a G firm, shareholders perform an internal investigation in which the whole history of investments is made public.

At time τ^* the manager has to choose whether to reveal the decline in the growth rate of investment opportunities, or conceal it. If the manager reveals the shift in fundamentals, the price drops to P^{after}_{fi,τ^*} as shown above; shareholders find no wrongdoing and the manager continues under full information. The optimal investment under the full revelation is identical to the case of symmetric information in Section 3., and so is the equilibrium. Next section examines the case in which the manager conceals the truth.

4.1. Investment under Conceal Strategy

If the CEO decides to conceal the truth, she must design an investment strategy that enables the firm to continue paying the high growth dividend stream D_t^G in (9). Intuitively, such strategy cannot be held forever, as it will require more cash than the firm produces. We denote by T^{**} the time at which the firm experiences a cash shortfall and must disclose the truth to investors. Since the firm's stock price will decline at that time, and the manager will lose her job, it is intuitive that the best strategy for the CEO is to design an investment strategy that maximizes T^{**}, as established in the following Lemma:

Lemma 1: *Conditional on the decision to conceal the true state at τ^*, the manager's optimal*

[8]While this seems like a strong assumption, it counterbalances other two assumptions that we make, namely, deterministic production function and deterministic return on capital. Relaxing all of these assumptions to a more realistic situation in which the revenues are imperfectly observed sometime after the investment, and return on capital and the production function are subject to stochastic shocks makes the behavior of the manager even less predictive, yet prevents us from solving for the fixed point in the dynamic rational expectations equilibrium model. We have no reason to believe that our results would not hold under this modification.

[9]The assumption that dividends can be used to reduce agency costs and monitor managers has been suggested by Easterbrook (1984).

investment policy is to maximize the time of the cash shortfall T^{**}.

Next proposition characterize the investment strategy that maximizes T^{**}:

Proposition 4: *Let K_{τ^*-} denote the capital accumulated in the firm by time τ^*. If the CEO chooses to conceal the decline in growth opportunities at τ^*, then:*

1. *She employs all the existing capital stock: $K_{\tau^*} = K_{\tau^*-}$.*
2. *Her investment strategy for $t > \tau^*$ is:*

$$I_t = z\ \min(K_t, J_t) - (z - G - \delta)e^{Gt}. \tag{20}$$

3. *The firm's capital dynamics is characterized as follows: Let h^* and h^{**} be the two constants defined in (36) and (37) in the Appendix, with $T^{**} = \tau^* + h^{**}$. Then :*
   - *(a) For $t \in [\tau^*, \tau^* + h^*]$ firm's capital K_t exceeds its optimal level J_t.*
   - *(b) For $t \in [\tau^* + h^*, T^{**}]$, firm's capital K_t is below its optimal level J_t*

Point 1 of Proposition 4 shows that in order to maximize the time of cash shortfall T^{**}, the manager must invest all of its existing capital in the suboptimal investment strategy. This suboptimal investment strategy, in (20), ensures that dividends are equal to the higher growth profile $D_t^G = (z - G - \delta)e^{Gt}$ (see (9)) for as long as possible. The extent of the suboptimality of this investment strategy is laid out in point 3 of Proposition 4. In particular, the CEO initially amasses an amount of capital that is above its optimal level J_t (for $t < \tau^* + h^*$), while eventually the capital stock must fall short of J_t (for $t \in [\tau^* + h^*, T^{**}]$).

These dynamics are illustrated in Figure 3 for a parametric example. Panel A shows that the optimal capital stock initially exceeds the upper bound on the employable capital, $K_t > J_t$. This implies that the pretending firm must initially invest in *negative* NPV projects, as shown in Panel B. Indeed, while the excess capital stock $K_t - J_t$ has a zero return by assumption, it does depreciate at the rate δ. Intuitively, when investment opportunities slow down, the CEO is supposed to return capital to the shareholders (see Figure 2). Instead, if the CEO pretends that nothing has happened, she will invest this extra cash in negative NPV projects as a storage of value to delay T^{**} as much as possible. Panel B of Figure 3 shows that as the time goes by the pretending firm engages in disinvestment to raise cash for the larger dividends of the growing firm. The firm can do this as long as its capital K_t is above the minimal capital $\underline{K}_t$. Indeed, T^{**} is determined by the condition $K_{T^{**}} = \underline{K}_{T^{**}}$.[10]

[10] Therefore the technical assumption of a minimal capital stock in equation (6) affects the time at which the firm can no longer conceal the decline in its stock of capital.

In a conceal Nash equilibrium, rational investors anticipate the behavior of the managers, and price the stock accordingly. We derive the pricing function next.

4.2. Pricing Functions under Asymmetric Information

At time T^{**} the pretending firm experiences a cash shortfall and is not able to pay its dividends D_t^G. At this time, there is full information revelation and thus the valuation of the firm becomes straightforward. The only difference from the symmetric information case is that the firm now does not have sufficient capital to employ to its full potential, thus it needs to re-capitalize. Since at T^{**} the firm's capital equals the minimum employable capital level, $K_{T^{**}} = \underline{K}_{T^{**}}$, while the optimal capital should be $J_{T^{**}}$, the firm must raise $J_{T^{**}} - \underline{K}_{T^{**}}$. From assumption (6), $\underline{K}_{T^{**}} = \xi J_{T^{**}}$, which yields the pricing function:

$$P^L_{ai,T^{**}} = \int_{T^{**}}^{\infty} D_t^g e^{-r(t-T^{**})} dt - J_{T^{**}}(1-\xi) = e^{(G-g)\tau^* + gT^{**}} \left(\frac{z-r-\delta}{r-g} + \xi \right) \tag{21}$$

The pricing formula for $t < T^{**}$ is then

$$P_{ai,t} = E_t \left[\int_t^{T^{**}} e^{-r(s-t)} D_s^G ds + e^{-r(T^{**}-t)} P^L_{ai,T^{**}} \right] \tag{22}$$

The subscript "*ai*" in (22) stands for "Asymmetric Information". Expression (22) can be compared with the analogous pricing formula under full information (11): the only difference is that the switch time τ^* is replaced by the (later) T^{**}, and the price P^{after}_{fi,τ^*} is replaced with the much lower price $P^L_{ai,T^{**}}$. We are able to obtain an analytical solutions:

Proposition 5: *Let shareholders believe that λ is the current intensity of τ^*. Under asymmetric information and conceal strategy equilibrium, the value of the stock for $t \geq h^{**}$ is:*[11]

$$P_{ai,t} = e^{Gt} A_\lambda^{ai} \tag{23}$$

where

$$A_\lambda^{ai} = \frac{(z-G-\delta)}{(r+\lambda-G)} + \lambda e^{-(G-g)h^{**}} \left(\frac{z-r-\delta+(r-g)\xi}{(r-g)(r+\lambda-G)} \right) \tag{24}$$

Comparing the pricing formulas under asymmetric and symmetric information, (23) and (11), we observe that the first term in the constants A_λ^{fi} and A_λ^{ai} is identical. However, the second term is smaller in the case of asymmetric information: the reason is that under

[11] The case of $t < h^{**}$ does not yield additional intuition relative to the case of $t \geq h^{**}$, yet it is much more complex to analyze. For this reason, we leave it to the appendix.

asymmetric information, rational investors take into account two additional effects. First, even if the switch time τ^* has not been declared yet, it may be possible that it has already taken place and the true investment opportunities are growing at a lower rate g for a while (up to h^{**}). The adjustment $e^{-(G-g)h^{**}} < 1$ takes into account this possibility. Second, at time T^{**} the firm must re-capitalize to resume operations, which is manifested by the smaller numerator of the second term, compared to the equivalent expression in (11).

The top panel of Figure 4 illustrates the value loss associated with the conceal strategy. Since the manager's compensation is not coming out of the firm's funds, the value loss is equal to the loss of the shareholders relative to what they would have got under the reveal strategy (full information). These costs can be measured by the present value (as of τ^*) of the difference in the dividends paid out to the shareholders under the two equilibria. Relative to reveal strategy, the conceal strategy pays lower dividends for a while, as the manager pretends to actively invest, and then must pay higher dividends, that arise from allegedly high cash flow. These higher dividend payouts come at the expense of investment, thus are essentially borrowed from the future dividends. The lower the minimum employable capital $\underline{K}_t$ (i.e. lower ξ in (6)), the longer the CEO can keep the pretense, and thus the higher the required recapitalization that is necessary when the firm experience a cash shortfall This also implies lower dividends forever after the default.

How does the information asymmetry affect the price level? The bottom panel of Figure 4 plots price dynamics under the conceal equilibrium and compares them to prices under the reveal equilibrium. Rational investors initially reduce prices in the conceal equilibrium, as they correctly anticipate the suboptimal manager's behavior after τ^*. The stock price however at some point exceeds the full information price, as the firm's cash payouts increase (see top panel). The price finally drops at T^{**} when the firm experiences a severe cash shortfall, and needs to recapitalize. The exact size of underpricing and price drop depends on parameter values, as further discussed in Section 5..

The conceal equilibrium discussed in this section also provides CEOs a motive to "meet analysts' dividend (or earnings) expectations," a widespread managerial behavior, as recently documented by Graham et al. (2005). Indeed, the stock behavior at T^{**} is consistent with the large empirical evidence documenting sharp price reductions following failures to meet earnings (dividend) expectations, even by a small amount (see e.g. Skinner and Sloan (2002)).

4.3. Equilibrium Strategy at $t = \tau^*$

Now that we computed the equilibrium pricing function under conceal equilibrium, we can consider the manager's incentives at time τ^* to conceal or reveal the true growth rate. Since after τ^* there is nothing the manager can do to restore high growth G the choice is driven solely by the comparison between the present value of the infinite compensation stream under the reveal strategy, and the finite stream under the conceal strategy. Recall also that after τ^* the manager no longer faces any uncertainty (even T^{**} is known to her), and thus the two utility levels can be computed exactly under dividend and stock-based compensation (see formulas (39) and (40) in the Appendix).

We begin with the dividend-based compensation case:

Proposition 6: *Under dividend-based compensation, a necessary and sufficient condition for a "reveal" equilibrium at* $t = \tau^*$ *is:*

$$\left(\frac{z - G - \delta}{\beta - G}\right)\left(1 - e^{-(\beta - G)h^{**}}\right) < \left(\frac{z - g - \delta}{\beta - g}\right). \tag{25}$$

Intuitively, the left-hand-side is the discounted value of future dividends under the high growth profile up to T^{**}, while the right-hand-side is the discounted value of future dividends under the low growth profile, up to infinity. Condition (25) already uncovers the tension between providing incentives to exert high effort and to reveal the truth. Indeed, condition (25) is always satisfied if $z - \beta - \delta > 0$. From (19) we recall that this same condition implies that the dividend-compensated manager would *not* choose to exert high effort even if its cost is zero. It follows that under dividend-based compensation, $z - \beta - \delta > 0$ then a rational expectation equilibrium has the manager choose low effort at time 0 and reveal at $t = \tau^*$.

We now turn to stock-based compensation. In this case, the rational expectations pure strategies Nash equilibrium must take into account investors' beliefs about the manager strategy at time τ^*, since they determine the price function. There are three intertemporal utility levels to be computed at τ^* depending on the equilibrium. In a *Reveal Equilibrium*, the manager's utility is determined by $P_{fi,t}^{after}$ in equation (10) if at τ^* the manager decides to reveal. In contrast, if the manager decides to conceal, her utility is determined by the price function $P_{fi,t}^{before}$ in equation (11). In a *Conceal Equilibrium*, if the manager follows the Nash equilibrium strategy (conceal at τ^*), then the price function must be the asymmetric information price function $P_{ai,t}$ in equation (23). If instead, the manager reveals at τ^* the true state of the firm, the price function reverts back to the full information price $P_{fi,t}^{after}$

in equation (10). Next proposition obtain the resulting conditions for a reveal and conceal equilibrium under stock-based compensation:

Proposition 7: *Let $\tau^* \geq h^{**}$.*[12] *A necessary and sufficient condition for a* **conceal equilibrium** *under stock-based compensation is*

$$\frac{A_\lambda^{ai}}{(\beta - G)}\left(1 - e^{-(\beta - G)h^{**}}\right) > \frac{(z - g - \delta)}{(r - g)(\beta - g)} \tag{26}$$

where the constant A_λ^{ai} is given in equation (24). Similarly, a necessary and sufficient condition for a **reveal equilibrium** *under stock-based compensation is*

$$\frac{A_\lambda^{fi}}{(\beta - G)}\left(1 - e^{-(\beta - G)h^{**}}\right) < \frac{(z - g - \delta)}{(r - g)(\beta - g)} \tag{27}$$

where the constant A_λ^{fi} is given in equation (12).

Intuitively, the right-hand-side of both conditions (26) and (27) is the discounted utility under reveal strategy. Since the compensation is stock-based, the stock multiplier "$1/(r-g)$" enters the formula. The left-hand-side of both conditions is the discounted utility value under the conceal strategy. In particular, now the stock multiplier A_λ^{ai} appears under the conceal equilibrium, while the stock multiplier A_λ^{fi} appears under the reveal equilibrium. Since $A_\lambda^{fi} > A_\lambda^{ai}$, conditions (26) and (27) imply that the two equilibria in pure strategies are mutually exclusive, and thus it is not possible to find parameters for which both equilibria can exist at the same time. However, it may happen that for some parameter combination, no pure strategy Nash equilibrium exists.

Comparing condition (26) and (25), we see that stock-based compensation is more likely to imply a conceal equilibrium than dividend-based compensation if

$$A_\lambda^{ai}(r - g) > z - G - \delta \tag{28}$$

Using equation (24) we find condition (28) is certainly satisfied whenever $G > g + \lambda$, that is, whenever the initial growth rate G is sufficiently high compared to the rate of growth after the switch, g. Intuitively, when G is high, the stock price is high as well, reflecting higher future dividend growth. Higher stock price implies higher compensation for the firm's manager, and thus generates a greater incentive for her to conceal the decrease in g. Indeed, below we find that condition (26) is satisfied for most parameter values, unless G is close to g. In the latter case the reduction in growth is not worth concealing, as the impact of pretending on compensation is small.

[12]The solution for the case $\tau^* < h^{**}$ is cumbersome, thus delegated to the Appendix.

4.4. Rational Expectations Equilibrium with the Choice of Effort

We now move back to $t < \tau^*$and obtain conditions for Nash equilibrium that includes the manager's effort choice. The equilibrium depends on the type of compensation and on the equilibrium at time τ^*. The expected utility for $t < \tau^*$ is given by

$$U_t = E_t \left[\int_t^{\tau^*} e^{-\beta(u-t)} w_u \left[1 - c(e)\right] du + e^{-\beta(\tau^*-t)} U_{\tau^*} \right], \tag{29}$$

where U_{τ^*} is the manager utility at τ^*, computed in the previous section, whose exact specification depends on the equilibrium itself.

We briefly discuss the dividend-based compensation first. As discussed earlier, and shown below in Section 5., a reveal equilibrium at $t = \tau^*$ is pervasive in this case. It follows that the Nash equilibrium is the same as in the benchmark case with full information discussed Section 3.. In particular, Proposition 3 (a) applies also to this case in which τ^* is private information, as the manager has an incentive to reveal it.

We now derive the conditions under which the stock-based compensation induces high effort. Since "conceal" is the most frequent equilibrium at $t = \tau^*$ (see Section 5.), we focus our attention only to this case.

Proposition 8: *Let $t \geq h^{**}$ and let λ^H be such that a conceal equilibrium obtains at τ^*. Then, high effort e^H is the equilibrium strategy if and only if*

$$\frac{\lambda^L + \beta - G}{\lambda^H + \beta - G} > \frac{1 + \lambda^L H_{ai}^{Stock}}{1 - c^H + \lambda^H H_{ai}^{Stock}} \tag{30}$$

where

$$H_{ai}^{Stock} \equiv \frac{1 - e^{-(\beta - G)h^{**}}}{\beta - G}$$

To see the intuition behind this proposition, note that condition (30) is similar to condition (17) in the benchmark case. Two properties are important. First, if effort is costly and has a low impact on λ, i.e. $\lambda^H \approx \lambda^L$, then the condition is violated, and the manager never chooses high effort. Second, if effort costs little, $c^H \approx 0$, then the manager always chooses high effort. Intuitively, the benefit for the manager to exert high effort stems from the longer tenure period (T^{**} is pushed forward) while enjoying the long term rewards of her efforts earlier, as they are capitalized in the stock price.

The key question is whether the stock-based compensation is more likely to produce a high-effort equilibrium than dividend-based compensation. Comparing conditions (15) in Propositions 3 for dividend-based compensation and condition (30) in Proposition 8 for stock-based compensation shows that this is the case.

Corollary 2. *Let* $\left(1 - c^H\right) > \lambda^H / \lambda^L$ *(condition (18)). Then, there are parameters such that* (Low Effort, Reveal) *is an equilibrium for dividend-based compensation, and* (High Effort, Conceal) *is an equilibrium for stock-based compensation.*

Intuitively, condition (18) requires that higher effort increases the expected shift time τ^* sufficiently compared to the cost c^H. In this case, as shown in Proposition 8, a high effort / conceal equilibrium prevails under the stock-based compensation. In contrast, dividend-based compensation implies that for high enough β the manager always prefers low effort, as already discussed after Proposition 3. Section 5. further discusses the set of parameters in which both equilibria exist.

4.5. *Ex ante* Optimality for Shareholders

Under the conditions of Corollary 2, the shareholders are in a conundrum: if the choice is between a dividend-based versus a stock-based compensation, is it better to induce a (Low Effort / Reveal) equilibrium through dividend-based compensation, or (High Effort / Conceal) equilibrium through a stock-based compensation? The decision on which equilibrium is *ex ante* optimal for shareholders crucially depends on the impact that effort has on the expected time $E[\tau^*]$, even if the latter is unobservable.[13]

Corollary 3. *There are* $\underline{\lambda}^H$ *and* $\overline{\lambda}^L$ *such that for* $\lambda^H < \underline{\lambda}^H$ *and* $\lambda^L > \overline{\lambda}^L$ *the value of the firm under (High Effort / Conceal) equilibrium is higher than under (Low Effort / Reveal) equilibrium. That is,* $P_{ai,0} > P_{fi,0}^{before}$.

Intuitively, as $\lambda^H \to 0$, the price under asymmetric information converges to the Gordon growth formula with high growth: $P_{ai,0} \to (z - G - \delta)/(r - G)$. Similarly, as $\lambda^L \to \infty$, the price under full information converges to the same model, but with low growth rate g, $P_{fi,0}^{before} \to (z - g - \delta)/(r - g)$. Since in our model $z > r + \delta$, in the limit $P_{ai,0} > P_{fi,0}^{before}$.

This corollary implies that if the manager's effort strongly affects the investment opportunities growth, then shareholders prefer an incentive scheme that induces a conceal strategy as a side effect. They are willing to tolerate the stock price crash at T^{**} and re-capitalization as a delayed cost to provide incentives for longer term growth.

[13] Since each type of equilibrium is independent of the parameters η_p and η_d, we can choose these parameters to make both equilibrium compensations equally costly ex ante. See discussion in Section 5.5.

This fact implies that it is not necessarily true that finding *ex-post* managers that have not been investing optimally during their tenure is in contrast with shareholders' *ex-ante* choice. Given the choice between these two equilibria, *ex ante* shareholders would be happy to induce high growth at the expense of the later cost of a market crash. We believe that this is a new insight in the literature. Section 5. below shows that stock-based compensation is ex-ante optimal for a wide range of reasonable parameters.

4.6. Implementing (High Effort / Reveal) Equilibrium

We conclude this section with a solution to the incentive problem. The earlier sections showed that dividend-based compensation tends to induces a reveal equilibrium but also low effort, while stock-based compensation induces a conceal equilibrium, but also high effort. A solution is a combination of the two. Consider a performance-based contract which is a convex combination of dividends and stock-based contract:

$$w_t = \omega\eta_p P_t + (1-\omega)\eta_d D_t. \tag{31}$$

The linearity of the utility function implies that for any t the utility under the combined package equals the weighted average of utilities under stock-based and dividend-based compensation:

$$U_{Comb,t} = \omega U_{Stock,t} + (1-\omega)U_{Div,t}$$

In order to obtain a (High Effort/Reveal) equilibrium we proceed as follows. Assume that indeed the manager follows a (High Effort/Reveal) strategy, so that the equilibrium price function is (11) with $\lambda = \lambda^H$. Conditional on this price function, we can search for the ω's such that reveal is optimal at τ^* and high effort is optimal before τ^*. The resulting conditions are contained in Proposition 9. For expositional simplicity, we restrict the values of the free parameters, η_p and η_d, such that $\eta_d = \eta_p/(r-g)$. This choice ensures that the utility from the revealing strategy is identical under dividend and stock-based compensation (see formulas (39) and (41) in the Appendix). We obtain the following:

Proposition 9: *Let $\omega^* \in [0,1]$ be such that*

$$\mathcal{L}_2 > \mathcal{L}_1(\omega^*)\left(\frac{1-e^{-(\beta-G)h^{**}}}{\beta-G}\right) \tag{32}$$

$$\frac{\lambda^L+\beta-G}{\lambda^H+\beta-G} > \frac{\mathcal{L}_1(\omega^*)+\lambda^L\mathcal{L}_2}{(1-c^H)\mathcal{L}_1(\omega^*)+\lambda^H\mathcal{L}_2} \tag{33}$$

where $\mathcal{L}_1(\omega)$ and $\mathcal{L}_2$ are in the Appendix. Then, the combined compensation $w = \omega^*\eta_p P_t + (1-\omega^*)\eta_d D_t$ achieves the first best (High Effort / Reveal) equilibrium.

Condition (32) guarantees that "Reveal" is optimal at time τ^*, conditional the full information pricing function (11) with $\lambda = \lambda^H$. The second condition (33) guarantees that "High Effort" is optimal at $t < \tau^*$, conditional on reveal being optimal at time τ^*. While these conditions are not satisfied for all parameter values, we show below that they apply widely.

5. Quantitative Implications

Although our model is stylized, its dynamic properties still allow us for a reasonable calibration of its parameters, and therefore to gauge its quantitative implications. In particular, we show that for most plausible parameter values, pure stock-based compensation leads to a conceal equilibrium. In spite of this, however, we also find that a pure stock-based compensation is preferable to a dividend-based compensation as it still maximizes firm value, in average, because it provides an incentive to exert effort. In this exercise, we also consider the potential costs to the firm to provide incentives through stocks or dividends. Finally, we characterize the optimal weight on stock in the combined compensation package.

5.1. Conceal Equilibrium at $t = \tau^*$

Given the effort choice e and thus λ, when is it optimal to conceal the change in the growth rate of investment opportunities? Figure 5 plots the areas in which pure strategy Nash conceal or reveal equilibria obtain under *stock-based compensation*. The base numerical values of the parameters are in Table 1. In all panels, the x-axis reports the initial high growth rate, G, ranging between 0 and 16%, while the y-axis represents a different variable in each panel: in the top panel it is low growth rate g; in the middle panel, it is the return on investment z, which ranges between 14% and 25%, and in the bottom panel, it is the expected time of maturity of the firm $E[\tau^*] = 1/\lambda$, that ranges between 3 and 25 years. Starting with the top panel, under stock-based compensation even a small difference between G and g is sufficient to induce a conceal Nash equilibrium, in which the manager chooses the conceal strategy and investors rationally anticipate this behavior. In striking contrast, for *no* combination of G and g the dividend-based compensation leads the manager to conceal the change in growth rate (this finding cannot be seen in the figure). That is, dividend-based compensation induces truth telling for a very wide range of parameter values. Moreover, stock-based compensation does not generate a reveal Nash equilibrium for any combination of G and g. The intuition is as follows: if investors think that the manager will follow a reveal strategy, the pricing function would reflect this belief and it is then given by the perfect information pricing formula (11). However, given these high prices, it is optimal for the manager to deviate and conceal the shift in investment opportunities.

The middle panel of Figure 5 plots the areas of conceal and reveal equilibrium under stock-based compensation in the (z, G) space, where z is the return on capital. We see that the conceal strategy choice is, once again, a pervasive equilibrium outcome. As before, even in this case we could not find any combination of (G, z) that would yield an optimal conceal strategy under dividend-based compensation. However, in contrast with the top panel, there is a small region in which a reveal Nash equilibrium obtains under stock-based compensation. This is the area in the top-left corner, in which G is small and the return on capital z is high. The intuition is that if growth is low, and return on capital high, there is little gain from concealing the change in investment opportunities (G is low anyway) and the cost of future repercussion is high, as the higher profitability of investments implies higher future prices, and thus a higher utility of the manager.

Finally, the bottom panel reports the conceal and reveal strategy areas under stock-based compensation in the space $(E[\tau^*], G)$. The outcome is once again the same: the conceal equilibrium prevails for most parameters, and especially for high growth G and high expected maturity time τ^* (or low λ). As before, for all combinations of parameters reveal is optimal under dividend-based compensation.

These examples point to a broad dichotomy: the stock-based compensation induces concealing strategy, while the dividend-based compensation yields truth revelation.

5.2. Choice of Effort before τ^*

The previous subsection considers the regions in which at τ^* a conceal or reveal equilibrium, which depend on the type of compensation. We now consider the partition of the regions in the parameter space in which, in addition, high effort or low effort is induced.

Figure 6 shows the partition of the parameter space of (z, G) into regions corresponding to various equilibria.[14] In the top-right area the manager chooses high effort regardless of the compensation mode. Consequently, in this region compensating the manager based only on dividends achieves the first best, as in this case she also reveals the bad news to investors, and maximizes firm value.[15] This region consists of firms characterized by high returns on

[14] In fact the space is $(z, G - g)$ as we assume $g = 0$ in these numerical calculations.

[15] In a model in which the growth in investment opportunities can go up as well, it is also possible that under dividends-based compensation, the manager will be reluctant to reveal good news and hence will not

investment, z, and high growth G of investment opportunities. Such firms do not have to use stock-based compensation to induce high effort.

The region below and to the left of the top-right area is where the dividend-based compensation no longer induces high effort, while the stock-based compensation does, although in a conceal equilibrium. This is indeed the most interesting region, where we observe a trade-off between the effort inducement and truth telling inducement - one cannot obtain both. Firms with reasonably high growth rates and return on investment are in that region. Finally, the region below and to the left from there is where we no longer have a pure strategy equilibrium under stock-based compensation, while dividend-based compensation still induces a low effort equilibrium. This is a region where a stock-compensated manager prefers to conceal if she chooses high effort, but would no longer choose high effort, if conceals. Part of that region corresponds to the conceal-low effort equilibrium (the worst possible scenario), whenever it exists. The existence depends on λ^L: it does not exist for high levels of λ^L. The remainder of the region corresponds to equilibria in mixed strategies. Solving for those is complicated, as the dynamic updating of investors' beliefs becomes very tedious. They are not likely to provide new intuitions, thus we ignore them. In fact we find the region above that, where the real trade-off takes place, of most interest.

5.3. Dividend-based or Stock-based Compensation?

The previous section shows a large area in the parameter space in which both a (High Effort / Conceal) equilibrium and (Low Effort / Reveal) equilibrium may co-exist. Are shareholders better off with low effort and an optimal investment strategy, or high effort and a suboptimal investment strategy? Corollary 3 shows that the choice depends on the difference between λ^L and λ^H. This section provides a quantitative illustration of the trade off.

To illustrate the trade off, Figure 7 plots the hypothetical price and dividend paths under the stock-based compensation (High Effort / Conceal) equilibrium and the dividend-based compensation (Low Effort / Reveal) equilibrium. For comparison, it also reports the first best, featuring high effort and the optimal investment after τ^*. As shown in Corollary 3, this figure suggests that the dividend-based compensation may induce too low an effort, and this loss outweighs the benefits of the optimal investment behavior at τ^*. Stock-based compensation, in contrast, gets closer to the first best, yet also leads to suboptimal investment behavior, which generates the bubble-like pattern in dividend growth and prices.

exert effort ex-ante or reveal the truth ex-post. Stock-based compensation instead would lead the CEO to reveal good news.

In order to gauge the size of the trade-off between the two equilibria under various parameter choices, Table 2 reports the firm value at time $t = 0$, $P_{ai,0}$ and $P_{fi,0}^{before}$, under the two equilibria (columns 2 and 4), and the average decline in price when the true growth rate of investment is revealed, at T^{**} in the stock-based compensation (column 3) and at τ^{*} in the dividend-based compensation (column 5). The appendix contains closed form formulas to compute the average decline (see Corollary A1). The first column reports the parameter that we vary compared to the benchmark case in Table 1. The last two columns report the value and the expected decline in the first best case.

Panel A of Table 2 shows that even for a low growth of investment opportunities $G = 5\%$, stock-based compensation achieves a higher firm value ($P_{ai,0} = 2.24$) than dividend-based compensation ($P_{fi,0}^{before}(\lambda^L) = 1.98$), even though the former equilibrium induces a substantial expected market crash $E\left[P_{T^{**}}/P_{T^{**}_{-}} - 1\right] = -49.28\%$ at T^{**}, against a milder decline of only $E\left[P_{\tau^{*}}/P_{\tau^{*}_{-}} - 1\right] = -4.12\%$ in the case of dividend-based compensation. The last two columns show that the first best achieves an even higher firm value, $P_{fi,0}^{before}(\lambda^H) = 2.28$, although this value is not so much higher than the one under asymmetric information. Note that at revelation, even in the first best case there is a market decline (-16%), although far smaller than in the asymmetric information case.

The remainder of Table 2 (Panels B to F) shows that a similar pattern realizes for a large range of parameter choices. For instance, in the base case low effort induces an expected time of investment growth $E[\tau^{*}|e^L] = 2$ years. However, Panel B shows that even if low effort induces a longer expected time $E[\tau^{*}|e^L]$, in fact up to 8 years, a similar result applies. In this case, the distance between the asymmetric information price $P_{ai,0}$ and $P_{fi,0}^{before}(\lambda^L)$ declines, but the latter price is still lower. Panel C shows that higher return on investments z leads to an increase in prices (across equilibria) and a mild decline in size of the crash at T^{**} for the asymmetric information case. Panel D shows that higher cost of capital r reduces both the prices across the equilibria and the decline at revelation, although the impact on the asymmetric information case is smaller than in the symmetric information case. The last two panels show the results for various depreciation rates δ and minimum employable capital ξ. In particular, the smaller is the minimum capital requirement ξ and the higher is the size of the crash at T^{**}, as the firm can pretend for longer and will need an even larger recapitalization at T^{**}. We note that there are parameter values that do not affect the comparative statics: for instance, the manager discount rate β or the cost of effort c^H only affect whether a conceal equilibrium or reveal equilibrium obtains. But since the CEO strategy conditional on concealing is just to push the time of cash shortfall T^{**} as far in the future as possible, the latter only depends on the technological parameters, and not on preferences. Thus, both the value of the firm and the size of the crash at T^{**} are independent of these preference parameters.

5.4. Combined Compensation and the First Best

We finally turn to the combined compensation package that induces the first best. Recall that this compensation package requires a weight ω on the stock component and $(1-\omega)$ on the dividend component. Figure 8 shows the range of the weight ω in the compensation package that can induce the first best outcome as a function of G. That is, those ω's that satisfy both conditions (32) and (33). The three panels assumes that the return on investment is $z = 17\%$ (top), $z = 20\%$ (middle) and $z = 23\%$ (bottom). In each panel, the upper line indicates the ω at which the manager is indifferent between conceal and reveal strategies under the high effort choice. For values of ω below that the manager prefers to reveal, which is what long term shareholders would like her to do. The lower line represents the level of at which the manager is indifferent between choosing high and low effort, when she is in a reveal equilibrium. For ω above that the manager prefers to exert high effort. Thus the area between the two lines represents all possible weights ω on stocks in the combined compensation package that support the first best.

Notice that when the lower line reaches zero, the dividend-based compensation alone is enough to induce high effort (recall the top-right area in Figure 6). This does not mean that a little stock-based component would necessarily ruin the incentives to reveal, but aggressive stock compensation (or high proportion of ownership) will. Indeed, across the three panels, we see that the maximal weight on stock-based compensation never reaches 50%. That is, it is never optimal to provide more than 50% of the total compensation to CEOs in stocks, however delivered. Still, across panels we see that the lower line is in general above zero, especially if the return on capital z is low, implying that a zero weight to stocks in the CEO compensation package is also suboptimal. Moreover, the first best equilibrium obtains for a larger set of parameters than the conceal equilibrium. Indeed, returning to Figure 6, while the stock-based compensation only induced high effort for a sufficiently high return on investment z and growth rate G, and no pure strategy equilibrium exists for lower values of both, the combined compensation package achieves a (High Effort / Reveal) equilibrium for all of the parameter combinations depicted in the figure.[16]

[16] This is not a generic statement though, as first best cannot always be achieved for all parameter combinations. For instance, a higher cost of effort reduces the area (z, G) in which first best holds, although the area is still larger than the conceal equilibrium.

In conclusion, this section shows that the choice of a compensation package should be firm-specific and depends on the firm's characteristics. As a consequence, the exact compensation package that induces the manager to act in the interest of the shareholders in all stages of the life cycle of the firm has to be chosen carefully. In particular, excessive stock compensation or too little stock compensation are clearly suboptimal choices for most cases. This implies, for instance, that executives' bonuses that depend exclusively on either earnings or stocks performance are not advisable. For the same reasons, situations in which the CEO owns a large packet of shares will also likely lead to suboptimal investment. Our model suggests that the manager should either reduce her holdings to what would be prescribed under the optimal compensation level, or commit to holding on to her shares for a very long term, in return the company should tie a large part of her compensation to dividends.[17]

5.5. Cost of CEO's Compensation

In our analysis so far we have abstracted from the costs that different incentive schemes impose on the firm itself. For instance, inducing high effort by using the combined compensation package may be too costly, and thus the firm could be better off with a low effort equilibrium. Endogenizing the compensation costs to the firm in our dynamic model, however, is quite hard, as dividend flows have to be adjusted depending on the equilibrium price, and the fixed point that sustains the Nash equilibrium is harder to obtain. However, we can approximate the size of these costs in the various equilibria by taking their present value at the cost of capital of the firm (r). We can then compare the value of the firm net of these costs across the various incentive schemes and gauge whether an incentive scheme is too onerous compared to another.

We approximate the total costs paid to the CEO under the various cases by computing:

$$V_0 = E\left[\int_0^\infty e^{-rt} w_t dt\right] \tag{34}$$

where w_t is the CEO compensation. We obtain closed form formulas in expressions (45), (46) and (47) in the Appendix, for the dividend-based, stock-based and combined compensation schemes, respectively. The key insight is that we can choose the parameters η_d and η_p in

[17] Indeed, our model provides a rationale to the vesting of stock shares in compensation packages, although the vesting period that is implied by our model is much longer than the relatively standard three or five years (see e.g. Figure 3). While theoretically it is advisable a long-term vesting, realistically the long term performance of a firm depends on stochastic variables that are independent of the manager's actions. Standard risk aversion arguments would imply that managers would demand a large compensation in exchange for a longer vesting of shares in their compensation contract.

order to make these costs very similar to each other. The reason is that under the two pure compensation schemes, the absolute levels of η_d and η_p have no impact on the equilibrium itself, as they drop out of all the relevant expressions. Given V_0 for each case, we can compute the quantity $P_0 - V_0$, that is, the firm value net of payments to the CEO.

More specifically, we start by setting $\eta_d = 5\%$ as our benchmark value under the dividend-based compensation in the (Low Effort/Reveal) equilibrium. In this case, the CEO's compensation equals 5% of firm value (see (45) in the appendix). Denote this compensation cost $V_{Div}^{reveal,L}$. Next, we compute the value of η_p to make the compensation cost under stock-based compensation (High Effort/ Conceal) equilibrium, $V_{Stock}^{Conceal,H}$, equal to the dividend-based (Low Effort/Reveal) equilibrium compensation cost $V_{Div}^{reveal,L}$. That is, such that $V_{Stock}^{Conceal,H} = V_{Div}^{Reveal,L}$. Finally, given these two values for η_d and η_p, we compute the cost for the combined compensation, denoted $V_{Comb}^{Reveal,H}$. In this latter case, we need to choose the weight ω from the range of possible values (see Figure 8). We choose the minimum ω that induces the CEO to exert costly effort, as in this case, when G and z are high, the combined compensation boils down to a dividend-based compensation with high effort (see bottom panel of Figure 8.)

Given the compensation costs, we then compute the net firm values in the three cases, namely, $\left[P_{fi,\lambda^L,0}^{before,fi}(\lambda^L) - V_{Div}^{reveal,H}\right]$ for dividend-based compensation, $\left[P_{ai,0} - V_{Stock}^{Conceal,H}\right]$ for stock-based compensation, and $\left[P_{fi,0}^{before} - V_{Comb}^{Reveal,H}\right]$ for the combined compensation. These quantities are plotted in Figure 9 as functions of the high growth rate G and for three values of return on investments z. In all panels, the solid line corresponds to the combined compensation case, the dotted line to the stock-based (High Effort/Conceal) equilibrium, and the dashed line to the dividend-based (Low Effort/Reveal) equilibrium. The figure makes apparent two facts: First, inducing high effort increases the net firm value, especially for high growth companies. This is true for both the stock-based compensation, which has the conceal strategy behavior as a side effect, and the combined compensation. Second, the combined compensation equilibrium leads to a higher net firm value compared to both the other equilibria.

This analysis, although approximate, shows that indeed, the combined optimal compensation plan discussed in the previous section achieve the first best without imposing too high a burden on the company.

6. Discussion and Conclusions

Our paper contributes to the debate on executive compensation.[18] On the one hand, advocates of stock-based compensation highlight the importance of aligning shareholder objectives with managers' and argue that compensating managers with stocks achieves the goal. Detractors argue that stock-based compensation instead gives managers the incentives to misreport the true state of the firm, and in fact even engage at times in outright fraudulent behavior. This paper sheds new light on the debate by analyzing both the ex ante incentive problem to induce managers to exert costly effort to maximize the firms' investment opportunities, and simultaneously to induce the manager to reveal the true state of the firm's outlook and thus follow an optimal investment rule.

We show that a combined compensation package that uses both dividend-based performance and stock-based performance reaches the first best, inducing the manager to exert costly effort and reveal any worsening of the investment opportunities, if it happens. Firm value is then maximized in this case. Each component (dividends and stocks) in the combined compensation package serves a different purpose and thus they are both necessary "ingredients": the stock-based component increases the manager's effort to expand the growth options of the firm, while compensating managers also proportionally to reported earnings significantly reduces her incentives to engage in value destroying activities to support the inflated expectations. It is crucial to realize, though, that the weight on stocks in the combined compensation package is not identical across firms: for instance, high growth firms should not make much use of stocks in their compensation package, while the opposite is true for low growth firms. That is, there is no fixed rule that work for every type of firm. As a consequence, generalized regulatory decisions that ban stock-based compensation, for instance, or board of directors' decisions on CEO compensation that are based on some "common wisdom" are particularly dangerous, as they do not consider that each firm necessitates a different incentive scheme.

Our model also sheds light on the incentives and disincentives of the CEO when her compensation is too heavily tilted towards stocks. Indeed, while we believe that the problem with too much stock-based compensation is widespread in general, the 1990's Hi-Tech boom and collapse as well as the 2007 - 2008 financial crisis offer interesting examples of the mechanism discussed in our model. The 1990's Hi-Tech boom was characterized by expectations of high growth rates and high uncertainty, coupled with high-powered stock-based

[18] See Murphy (1999), Hall and Murphy (2003), Bebchuk and Fried (2004), Edmans and Gabaix (2009), and Gabaix and Landier (2007) for recent discussions.

executive compensation. Firms with perceived high growth options were priced much higher than firms with similar operating performance, but with lower perceived growth options. We argue that because of their high-powered incentives, executives had an incentive to present theirs as high growth firms, even when the prospects of high future growth faded at the end of the 1990s. Our analysis suggests that the combination of high-powered incentives and the pretense of high growth firms will lead eventually to the firm's stock to crash.

Similarly, the source of the banking crisis of 2007 - 2008 may also be partially understood through the mechanism discussed in the paper, as banks also share some of the key characteristics assumed in the model. In particular, there is lack of full transparency of banks investment behavior (e.g. complicated derivative structures) as well as of the available investment opportunities. In addition, high-powered, stock-based incentives have been traditionally applied in the banking sector. Consider for instance the growth in the mortgage market. It is reasonable to argue that banks' CEOs observed a slowdown in the growth rate of the prime mortgage market. When investment opportunities decline, the first best action is to disclose the news to investor, return some of the capital to shareholders, and suffer a capital loss on the stock market. However, if a CEO wants to conceal the decline in investment opportunities' growth, then our model implies that in order to maintain the pretense that nothing happened, the bank's manager has to first invest in negative NPV projects, such as possibly the subprime mortgages, if the mortgage rate charged does not correspond to the riskiness of the loan.[19]

Moreover, in order to keep the pretense for as long as possible the manager has also to disinvest and pass on positive NPV projects. According to the model, the outcome of the suboptimal investment program is a market crash of the stock price, and the need for a large recapitalization of the firm. As the debate about optimal CEO compensation is evolving, our model shows that too much stock sensitivity is "bad," as it induces this perverse effect on manager's investment ex-post. Nevertheless, too little stock sensitivity has also an adverse effect providing the CEO no incentives to search for good investment opportunities. Providing an incentive scheme that depends on both stocks and dividends (or earnings) can achieve the first best in many cases.

[19]Laeven and Levine (2008) provide empirical evidence that bank risk taking is postively correlated with ownership concentration.

Appendix

This appendix contains only sketches of the proofs of the propositions. Details can be found in a separate technical appendix available on the authors web pages.

Proof of Proposition 1. The capital evolution equation is given by

$$\frac{dK_t}{dt} = I_t - \delta K_t. \tag{35}$$

From (2), the target level of capital, J_t, is given by $J_t = e^{Gt}$ for $t < \tau^*$ and $J_t = e^{G\tau^* + g(t-\tau^*)}$ for $t \geq \tau^*$. Imposing $K_t = J_t$ for every t and using (35) the optimal investment policy is given by (8). From (7), the dividend stream is (9). **Q.E.D.**

Proof of Proposition 2. For $t \geq \tau^*$, the $P^{after}_{fi,t}$ stems from integration of future dividends. For $t < \tau^*$, the expectation in $P^{before}_{fi,t}$ can be computed by integration by parts.**Q.E.D**

Proof of Corollary 1: $P^{before}_{fi,t}\left(\lambda^H\right) > P^{before}_{fi,t}\left(\lambda^L\right)$ iff $A^{fi}_{\lambda^H} > A^{fi}_{\lambda^L}$. Substituting, this relation holds iff $z - r - \delta > 0$, which is always satisfied. **Q.E.D.**

Proof of Proposition 3: a) After τ^*, there is no benefit from exerting effort. Thus:

$$U_{Div,\tau^*} = \int_{\tau^*}^{\infty} e^{-\beta(t-\tau^*)} D^g_t dt = \frac{\eta_d(z-g-\delta)}{(\beta - g)} e^{G\tau^*}$$

Before τ^*, the utility of the manager for given effort e is

$$\begin{aligned} U_{Div,t}(e) &= E\left[\int_t^{\tau^*} e^{-\beta(u-t)} \eta_d D^G_u \left(1 - c(e)\right) du + e^{-\beta(\tau^*-t)} U_{Div,\tau^*}\right] \\ &= e^{Gt} \eta_d \frac{(z-G-\delta)}{\beta + \lambda(e) - G}\left[1 - c(e) + \lambda\left(e\right) \frac{(z-g-\delta)}{(z-G-\delta)\left(\beta - g\right)}\right] \end{aligned}$$

Given H^{Div} in (16), the condition $U_{Div,t}\left(e^H\right) > U_{Div,t}\left(e^L\right)$ translates into (15).

b) As before, from τ^* onward the manager will not exercise high effort, resulting in

$$U_{Stock,\tau^*} = \int_{\tau^*}^{\infty} e^{-\beta(s-t)} \left(\eta_p P^{after}_{fi,s}\right) ds = \frac{\eta_p\left(z-g-\delta\right)}{(r-g)\left(\beta - g\right)} e^{G\tau^*}.$$

Thus, for $t < \tau^*$ we have

$$\begin{aligned} U_{Stock,t}\left(e\right) = E&\left[\int_t^{\tau^*} e^{-\beta(s-t)} \left(\eta_p P^{before}_{fi,s}\right) \left(1 - c(e)\right) ds + e^{-\beta(\tau^*-t)} U_{Stock,\tau^*}\right] \\ = &\frac{\eta_p e^{Gt}}{\beta + \lambda(e) - G}\left[A^{fi}_{\lambda}\left(1 - c(e)\right) + \lambda(e)\left(\frac{z-g-\delta}{(r-g)\left(\beta - g\right)}\right)\right]. \end{aligned}$$

Let e^H be the optimal strategy in equilibrium. The price function is then $P_{fi,t}^{before}$ with $A_{\lambda^H}^{fi}$. We then obtain the condition $U_{Stock,t}\left(e^H\right) > U_{Stock,t}\left(e^L\right)$ iff (17) holds. The Nash equilibrium follows. Similarly, if e^L is the optimal strategy in equilibrium, then the price function is $P_{fi,t}^{before}$ with $A_{\lambda^L}^{fi}$. Thus, $U_{Stock,t}\left(e^H\right) < U_{Stock,t}\left(e^L\right)$ iff (17) does not hold.

c) The statement follows iff

$$\frac{1+\lambda^L H^{\text{Div}}}{1-c^H+\lambda^H H^{\text{Div}}} > \frac{A_{\lambda^H}^{fi}+\lambda^L H^{\text{Stock}}}{A_{\lambda^H}^{fi}\left(1-c^H\right)+\lambda^H H^{\text{Stock}}}$$

Algebra shows that this is true iff

$$\left(H^{\text{Div}}A_{\lambda^H}^{fi}-H^{\text{Stock}}\right)\left[\lambda^L\left(1-c^H\right)-\lambda^H\right] > 0.$$

The condition in Proposition 3 ensures the second term is positive. Substituting H^{Div}, $A_{\lambda^H}^{fi}$ and H^{Stock} and tedious algebra show that the first term is also always positive. **Q.E.D.**

Proof of Lemma 1. Conditional on the decision to conceal g, the manager must provide a dividend stream D_t^G, as any deviation make her lose her job. Since she cannot affect the stock price, after τ^* her utility only depends on the length of her tenure. Since we normalize the manager's outside options to zero, her optimal choice is to maximize T^{**}. **Q.E.D.**

Proof of Proposition 4: (a) The manager must mimic D_t^G for as long as possible. This target determines the investments I_t and thus the evolution of capital $\frac{dK_t}{dt}=I_t-\delta K_t$ for given initial condition $\widehat{K}_{\tau^*}$. From the monotonicity properties of differential equations in their initial value and the definition of T^{**} as the time at which $K_{T^{**}}=\underline{K}_{T^{**}}=\xi J_{T^{**}}$, T^{**} must be increasing with $\widehat{K}_{\tau^*}$. The claim follows from Lemma 1.

(b) At time τ^* we have $K_{\tau^*}=J_{\tau^*}=e^{G\tau^*}$, which implies

$$\frac{dK_t}{dt}|_{\tau^*}=ze^{G\tau^*}-\delta e^{G\tau^*}-\left(z-G-\delta\right)e^{G\tau^*}=Ge^{G\tau^*}$$

This implies that $dK_t/dt > dJ_t/dt$ after the switch, and thus $K_{t+dt} > J_{t+dt}$. The trajectory of capital at τ^* is then above J_t. By continuity, there is a period $[0,t_1]$ in which $K_t > J_t$. During this period, the ODE for capital accumulation becomes:

$$\frac{dK_t}{dt}=ze^{G\tau^*+g(t-\tau^*)}-\delta K_t-\left(z-G-\delta\right)e^{Gt}$$

Given the initial condition $K_{\tau^*}=J_{\tau^*}=e^{G\tau^*}$, the ODE solution implies the excess capital:

$$K_t-J_t=e^{G\tau^*}\left[\left(\frac{z-\delta-g}{\delta+g}\right)\left(e^{g(t-\tau^*)}-e^{-\delta(t-\tau^*)}\right)-\frac{z-G-\delta}{\delta+G}(e^{G(t-\tau^*)}+e^{-\delta(t-\tau^*)})\right]$$

As t increases, $K_t - J_t \to -\infty$. Since $K_{\tau^*} - J_{\tau^*} > 0$, there must be a t_1 at which $K_{t_1} - J_{t_1} = 0$. Since $t_1 > \tau^*$, we can define $h^* \equiv t_1 - \tau^*$. Substituting in $K_{t_1} - J_{t_1} = 0$, h^* must satisfy:

$$0 = \left(\frac{z-g-\delta}{\delta+g}\right) e^{-Gh^*}\left(e^{gh^*} - e^{-\delta h^*}\right) + \left(e^{-(\delta+G)h^*} - 1\right)\left[\frac{z-G-\delta}{\delta+G}\right] \tag{36}$$

For $t > t_1$, $K_t < J_t$, and thus the ODE switches to

$$\frac{dK_t}{dt} = (z-\delta)\,K_t - (z-G-\delta)\,e^{Gt}$$

Given the initial condition $K_{t_1} = J_{t_1}$, the ODE solution yields

$$K_t - J_t = e^{G\tau^*}e^{G(t-t_1+h^*)}\left[1 + \left(e^{-(G-g)h^*} - 1\right)e^{(z-G-\delta)(t-t_1)} - e^{-(G-g)(t-t_1+h^*)}\right]$$

which again diverges to $-\infty$ as $t \to \infty$. From the condition $K_{T^{**}} - J_{T^{**}}\xi = 0$, and defining $h^{**} \equiv T^{**} - \tau^*$, we obtain the equation defining h^{**}:

$$0 \;\; = 1 + \left(e^{-(G-g)h^*} - 1\right)e^{(z-G-\delta)(h^{**}-h^*)} - e^{-(G-g)h^{**}}\xi \tag{37}$$

Q.E.D.

Proof of Proposition 5: Let $t > h^{**}$. If "default" has not been observed by t, then a shift cannot have occurred before $t - h^{**}$. Bayes formula implies that "default" time $T^{**} = \tau^* + h^{**}$ conditional on no "default" by time t has the following conditional distribution

$$F_{T^{**}}(t'|T^{**} > t) = Pr\left(\tau^* < t' - h^{**}|\tau^* > t - h^{**}\right) = \frac{e^{-\lambda(t-h^{**})} - e^{-\lambda(t'-h^{**})}}{e^{-\lambda(t-h^{**})}} = 1 - e^{-\lambda(t'-t)}$$

That is, T^{**} has the exponential distribution $f(T^{**}|\text{no default by } t) = \lambda e^{-\lambda(T^{**}-t)}$. The value of $P_{ai,t}$ for $t > h^{**}$ in (23) then follows from the pricing formula and integration by parts.

Let $t < h^{**}$, then the conditional distribution of T^{**} is zero in the range $[t, h^{**}]$, as even a shift at 0 would only be revealed at h^{**}. The density is then $f(T^{**}) = \lambda e^{-\lambda(T^{**}-h^{**})}1_{(T^{**}>h^{**})}$. Using this density to compute the expectation, we find

$$P_{ai,t} = (z-G-\delta)e^{Gt}\frac{1-e^{-(r-G)(h^{**}-t)}}{(r-G)} + e^{rt}e^{(G-r)h^{**}}A^{ai}_{\lambda} \tag{38}$$

Q.E.D

Proof of Proposition 6: If the manager decides to reveal (resp. conceal) $\tilde{g}_{\tau^*} = g$, the dividend path is given by D^g_t (resp. D^G_t until T^{**}). The expected utilities are, respectvely:

$$U^{reveal}_{Div,\tau^*} = \int_{\tau^*}^{\infty} e^{-\beta(t-\tau^*)}(\eta_d D^g_t)dt = \eta_d e^{G\tau^*}\left(\frac{z-g-\delta}{\beta-g}\right) \tag{39}$$

$$U^{conceal}_{Div,\tau^*} = \int_{\tau^*}^{T^*} e^{-\beta(t-\tau^*)}(\eta_d D^G_t)dt = \eta_d(z-G-\delta)e^{G\tau^*}\left(\frac{1-e^{-(\beta-G)h^{**}}}{\beta-G}\right) \tag{40}$$

A conceal equilibrium obtains if $U^{reveal}_{Div,\tau^*} < U^{conceal}_{Div,\tau^*}$, otherwise a reveal equilibrium obtains. Condition (25) follows from $U^{reveal}_{Div,\tau^*} > U^{conceal}_{Div,\tau^*}$ by rearranging terms. **Q.E.D.**

Proof of Proposition 7: Let $\tau^* > h^{**}$. There are two equilibria to consider: a reveal equilibrium and a conceal equilibrium. In both equilibria, if the manager reveals at τ^*, then her utility depends $P^{after}_{fi,t}$ in equation (11). In contrast, the price path is different under the conceal strategy, depending on the equilibrium: In a conceal equilibrium, investors' expect the manager to conceal and thus her utility depends on $P_{ai,t}$ in (23) until T^{**}. In a reveal equilibrium, then investors expect the manager to reveal and thus her utility under the conceal strategy depends on $P^{before}_{fi,t}$ in (11). We obtain:

$$U^{reveal}_{Stock,\tau^*} = \int_{\tau^*}^{\infty} e^{-\beta(t-\tau^*)}(\eta P^{after}_{fi,t})dt = \frac{e^{G\tau^*}}{(\beta-g)}\left(\frac{\eta_p(z-g-\delta)}{(r-g)}\right) \tag{41}$$

$$U^{conceal,ai}_{Stock,\tau^*} = \int_{\tau^*}^{T^*} e^{-\beta(t-\tau^*)}(\eta P_{ai,t})dt = \eta_p A^{ai}_{\lambda} e^{G\tau^*}\left(\frac{1-e^{-(\beta-G)h^{**}}}{\beta-G}\right) \tag{42}$$

$$U^{conceal,fi}_{Stock,\tau^*} = \int_{\tau^*}^{T^*} e^{-\beta(t-\tau^*)}(\eta P^{before}_{fi,t})dt = \eta_p A^{fi}_{\lambda} e^{G\tau^*}\left(\frac{1-e^{-(\beta-G)h^{**}}}{\beta-G}\right) \tag{43}$$

A reveal equilibrium obtains if $U^{reveal}_{Stock,\tau^*} > U^{conceal,fi}_{Stock,\tau^*}$ and a conceal equilibrium obtains if $U^{conceal,ai}_{Stock,\tau^*} > U^{reveal}_{Stock,\tau^*}$. The conditions in the claim are obtained by simple substitution.

Finally, if $\tau^* < h^{**}$, then $U^{conceal,ai}_{Stock,\tau^*}$ depends on the price in (38). Details are left to the technical appendix. **Q.E.D.**

Proof of Proposition 8: Let $t > h^{**}$. In a conceal equilibrium with high effort, $P_{ai,t}$ in (23) with $A^{ai}_{\lambda^H}$ determines the wage $w_t = \eta_p P_{ai,t}$. The expected utility under effort e is:

$$\begin{aligned} U_{Stock,t}(e) &= E\left[\int_t^{\tau^*} e^{-\beta(s-t)} w_s(1-c(e))ds + e^{-\beta(\tau^*-t)} U^{conceal,ai}_{Stock,\tau^*}\right] \\ &= e^{Gt}\eta_p A^{ai}_{\lambda^H}\frac{\left[1-c\left(e\right)+\lambda\left(e\right)H^{Stock}\right]}{\beta+\lambda\left(e\right)-G} \end{aligned}$$

where $\lambda(e)$ and $c(e)$ are the intensity and the cost of effort under effort choice e. The condition in the Proposition follows from the maximization condition $U_{Stock,t}\left(e^H\right) > U_{Stock,t}\left(e^L\right)$. Finally, given e^H chosen by the manager, then indeed λ^H applies in equilibrium, a conceal equilibrium obtains at τ^* and thus the price function is $P_{ai,t}$ in (23), concluding the proof.

A similar proof holds for $t < h^{**}$. The expressions are in the technical appendix. **Q.E.D.**

Proof of Corollary 2: Define

$$f(x) = \frac{1+\lambda^L x}{1-c^H+\lambda^H x}$$

which has $f'(x) > 0$ if and only if $(1 - c^H) > \lambda^H/\lambda^L$. Corollary 2 then follows from the fact from equation (25) we have

$$H_{ai}^{Stock} = \frac{1 - e^{-(\beta-G)h^{**}}}{\beta - G} < \frac{(z - g - \delta)}{(z - G - \delta)(\beta - g)} = H^{Div}.$$

and thus, from $f'(x) > 0$, we have

$$\frac{1 + \lambda^L H^{Div}}{1 - c^H + \lambda^H H^{Div}} > \frac{1 + \lambda^L H_{ai}^{Stock}}{1 - c^H + \lambda^H H_{ai}^{Stock}},$$

which in turn implies that there are parameter values for which

$$\frac{1 + \lambda^L H^{Div}}{1 - c^H + \lambda^H H^{Div}} > \frac{\lambda^L + \beta - G}{\lambda^H + \beta - G} > \frac{1 + \lambda^L H_{ai}^{Stock}}{1 - c^H + \lambda^H H_{ai}^{Stock}}. \tag{44}$$

The statement of Corollary 2 then follows from Propositions 3 and 8. **Q.E.D.**

Proof of Proposition 9: First, we need to compute the condition that guarantees a reveal strategy at time τ^*. The equilibrium price function to use in this calculation is $P_{fi,t}^{before}(\lambda^H)$ if conceal (i.e. the manager deviates), and $P_{fi,t}^{after}$ if it reveals. We obtain

$$U_{comb,\tau^*}^{reveal} = \left(\omega\eta_p \frac{1}{r-g} + (1-\omega)\,\eta_d\right) e^{G\tau^*}\left(\frac{z-g-\delta}{\beta-g}\right)$$
$$U_{comb,\tau^*}^{conceal} = \left(\omega\eta_p A_{\lambda}^{fi} + (1-\omega)\,\eta_d\,(z-G-\delta)\right) e^{G\tau^*}\left(\frac{1-e^{-(\beta-G)h^{**}}}{\beta-G}\right)$$

Let $\eta_d = \eta_p/(r-g)$. At τ^*, (32) follows from $U_{comb,\tau^*}^{reveal} > U_{comb,\tau^*}^{conceal}$, where

$$\mathcal{L}_2 = \frac{z-g-\delta}{(\beta-g)(r-g)}$$

Before τ^*, the expected utility under the combined package depends on both a dividend component and a stock component. For given effort e, the dividend-based component is

$$\begin{aligned} U_{Div,t}(e) &= E\left[\int_t^{\tau^*} e^{-\beta(u-t)}\left(w_u\left(1-c\left(e_u\right)\right)\right)du + e^{-\beta(\tau^*-t)}U_{Div,\tau^*}^{reveal}\right] \\ &= \frac{e^{Gt}}{\beta+\lambda(e)-G}\eta_d\left((z-G-\delta)\left(1-c\left(e_u\right)\right)+\lambda\left(e_u\right)\left(\frac{z-g-\delta}{\beta-g}\right)\right) \end{aligned}$$

The stock-based component, conditional on a reveal equilibrium and thus price $P_{fi,t}^{before}(\lambda^H)$:

$$\begin{aligned} U_{Stock,t}(e) &= E\left[\int_t^{\tau^*} e^{-\beta(u-t)}\left(w_u\left(1-c(e)\right)\right)du + e^{-\beta(\tau^*-t)}U_{Stock,\tau^*}^{reveal}\right] \\ &= \frac{e^{Gt}}{\beta+\lambda-G}\eta_p\left(A_{\lambda^H}^{fi}(1-c(e)) + \frac{\lambda}{r-g}\left(\frac{z-g-\delta}{\beta-g}\right)\right) \end{aligned}$$

Thus, the total combined utility before τ^* is $U_{Comb,t}(e) = \omega U_{Stock,t} + (1-\omega) U_{Div,t}$. Tedious computations show that (33) follows from $U_{Comb}\left(e^H\right) > U_{Comb}\left(e^L\right)$, where

$$\mathcal{L}_1(\omega) = \omega A^{fi}_{\lambda^H} + (1-\omega)\left(\frac{z-G-\delta}{r-g}\right)$$

and $A^{fi}_{\lambda^H}$ is in (12). Finally, given the behavior of the manager (High Effort/Reveal), the price function is $P^{before}_{fi,t}$ for $t < \tau^*$ and $P^{after}_{fi,t}$ $t \geq \tau^*$. **Q.E.D.**

Formulas for Cost of CEO Compensation: We report here the expected discounted value of the compensation costs. The derivations are left to the technical appendix. Consider first the pure dividend-based compensation under full revelation and low effort. In this case, $w_t = \eta_d D_t$ and therefore

$$V^{Reveal,L}_{Div} = E\left[\int_0^\infty e^{-rt}\eta_d D_t dt\right] = \eta_d A^{fi}_{\lambda^L} \tag{45}$$

where $A^{fi}_{\lambda^L}$ is given in (12). Similarly, the present value of all payments to the CEO under the high-effort, stock-based compensation and conceal equilibrium, requires $w_t = \eta_p P_{ai,t}$, where $P_{ai,t}$ is given by (23). We obtain

$$V^{Conceal,H}_{Stock} = \eta_p (z-G-\delta)\left(\frac{1-e^{-(r-G)h^{**}}}{r-G}\right)^2 + \ \eta_p A^{ai}_{\lambda^H} e^{-(r-G)h^{**}}\left(h^{**} + \frac{z-G-\delta}{r+\lambda-G}\right) \tag{46}$$

where A^{ai}_{λ} is given in (24). Finally, the total costs under the full revelation / high effort equilibrium obtained from the combined compensation is given by:

$$V^{Reveal,H}_{Comb} = \omega\eta_p\left(A^{fi}_{\lambda^H} + \lambda^H \frac{z-g-\delta}{(r-g)^2}\right)\frac{1}{(r-G+\lambda^H)} + (1-\omega)\,\eta_d A^{fi}_{\lambda^H} \tag{47}$$

where $A^{fi}_{\lambda^H}$ is given in (12).

Corollary A1: *Let λ be the equilibrium intensity. Then:*

1. *Let $C^{fi} = \left(\frac{z-g-\delta}{r-g}\right)$. Under perfect information the average market decline at τ^* is*

$$E_0\left[\frac{P_{\tau^*} - P_{\tau^*-}}{P_{\tau^*-}}\right] = \frac{\frac{(r-G)}{(z-G-\delta)}C^{fi} - 1}{\frac{\lambda}{(z-G-\delta)}C^{fi} + 1}$$

2. *Under asymmetric information the average market decline at T^{**} is*

$$E_0\left[\frac{P_{T^*} - P_{T^*-}}{P_{T^*-}}\right] = \frac{\frac{(r-G)}{(z-G-\delta)}C^{ai} - 1}{\frac{\lambda}{(z-G-\delta)}C^{ai} + 1}$$

where $C^{ai} = e^{-(G-g)h^{**}}C^{fi} - (1-\xi)\, e^{-(G-g)h^{**}} < C^{fi}$

Proof of Corollary A1: See technical appendix. **Q.E.D.**

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Table 1: Calibration Parameters

Cost of capital	r	10%	Return on capital	z	20%
Depreciation rate	δ	1%	CEO discount rate	β	20%
Low growth rate	g	0%	Expected τ^* (high effort)	$E[\tau^*\|e^H] = 1/\lambda^H$	15 years
High growth rate	G	6%	Expected τ^* (low effort)	$E[\tau^*\|e^L] = 1/\lambda^L$	2 years
Minimal capital level	ξ	80%	CEO Cost of Effort	c^H	2%

Table 2: Stock-based Compensation or Dividend-based Compensation?

	Stock-based Compensation (High Effort / Conceal) Eq.		Dividend-based Compensation (Low Effort / Reveal) Eq.		Combined Compensation (High Effort / Reveal) Eq.	
Panel A: Investment Opportunities Growth						
G	$P_{ai,0}$	$E\left[\frac{P_{T^{**}}}{P_{T^{**}_-}}-1\right]$	$P^{before}_{fi,0}(\lambda^L)$	$E\left[\frac{P_{\tau^*}}{P_{\tau^*_-}}-1\right]$	$P^{before}_{fi,0}(\lambda^H)$	$E\left[\frac{P_{\tau^*}}{P_{\tau^*_-}}-1\right]$
5.00%	2.24	-49.28%	1.98	-4.12%	2.28	-16.85%
7.00%	2.46	-61.43%	2.02	-5.88%	2.55	-25.50%
9.00%	2.80	-72.07%	2.06	-7.70%	2.95	-35.68%
Panel B: Expected τ_L under Low Effort						
$E[\tau_L]=1/\lambda_L$	$P_{ai,0}$	$E\left[\frac{P_{T^{**}}}{P_{T^{**}_-}}-1\right]$	$P^{before}_{fi,0}(\lambda^L)$	$E\left[\frac{P_{\tau^*}}{P_{\tau^*_-}}-1\right]$	$P^{before}_{fi,0}(\lambda^H)$	$E\left[\frac{P_{\tau^*}}{P_{\tau^*_-}}-1\right]$
4.00	2.34	-55.55%	2.08	-8.91%	2.40	-21.00%
6.00	2.34	-55.55%	2.16	-12.07%	2.40	-21.00%
8.00	2.34	-55.55%	2.22	-14.67%	2.40	-21.00%
Panel C: Return on Investment						
z	$P_{ai,0}$	$E\left[\frac{P_{T^{**}}}{P_{T^{**}_-}}-1\right]$	$P^{before}_{fi,0}(\lambda^L)$	$E\left[\frac{P_{\tau^*}}{P_{\tau^*_-}}-1\right]$	$P^{before}_{fi,0}(\lambda^H)$	$E\left[\frac{P_{\tau^*}}{P_{\tau^*_-}}-1\right]$
18.00%	2.02	-57.29%	1.78	-4.37%	2.09	-18.77%
20.00%	2.34	-55.55%	2.00	-4.99%	2.40	-21.00%
22.00%	2.66	-54.11%	2.22	-5.49%	2.71	-22.73%
Panel D: Shareholders Discount Rate						
r	$P_{ai,0}$	$E\left[\frac{P_{T^{**}}}{P_{T^{**}_-}}-1\right]$	$P^{before}_{fi,0}(\lambda^L)$	$E\left[\frac{P_{\tau^*}}{P_{\tau^*_-}}-1\right]$	$P^{before}_{fi,0}(\lambda^H)$	$E\left[\frac{P_{\tau^*}}{P_{\tau^*_-}}-1\right]$
6.00%	5.03	-59.84%	3.43	-7.59%	5.12	-38.11%
10.00%	2.34	-55.56%	2.00	-5.00%	2.41	-21.04%
14.00%	1.45	-54.36%	1.39	-2.65%	1.50	-9.72%
Panel E: Depreciation Rate δ						
δ	$P_{ai,0}$	$E\left[\frac{P_{T^{**}}}{P_{T^{**}_-}}-1\right]$	$P^{before}_{fi,0}(\lambda^L)$	$E\left[\frac{P_{\tau^*}}{P_{\tau^*_-}}-1\right]$	$P^{before}_{fi,0}(\lambda^H)$	$E\left[\frac{P_{\tau^*}}{P_{\tau^*_-}}-1\right]$
0.00%	2.50	-55.07%	2.11	-5.26%	2.56	-21.92%
2.00%	2.18	-56.08%	1.89	-4.70%	2.25	-19.97%
4.00%	1.85	-57.27%	1.66	-3.99%	1.93	-17.38%
Panel F: Minimum Capital Requirement ξ						
ξ	$P_{ai,0}$	$E\left[\frac{P_{T^{**}}}{P_{T^{**}_-}}-1\right]$	$P^{before}_{fi,0}(\lambda^L)$	$E\left[\frac{P_{\tau^*}}{P_{\tau^*_-}}-1\right]$	$P^{before}_{fi,0}(\lambda^H)$	$E\left[\frac{P_{\tau^*}}{P_{\tau^*_-}}-1\right]$
40.00%	2.33	-66.99%	2.00	-4.99%	2.40	-21.00%
60.00%	2.34	-61.55%	2.00	-4.99%	2.40	-21.00%
80.00%	2.34	-55.55%	2.00	-4.99%	2.40	-21.00%

Notes: Column 1 reports the value of the parameter that is changed from its base value in Table 1. Columns 2 and 3 report the firm value at $t = 0$ and the average stock decline at T^{**}, respectively, under the (High Effort/Conceal) equilibrium induced by stock-based compensation. Column 4 and 5 report the firm value at $t = 0$ and the average stock decline at τ^*, respectively, under the (Low Effort/Reveal) equilibrium induced by dividend-based compensation. The last two columns report the same quantities under the (High Effort/Reveal) equilibrium induced by the combined compensation.

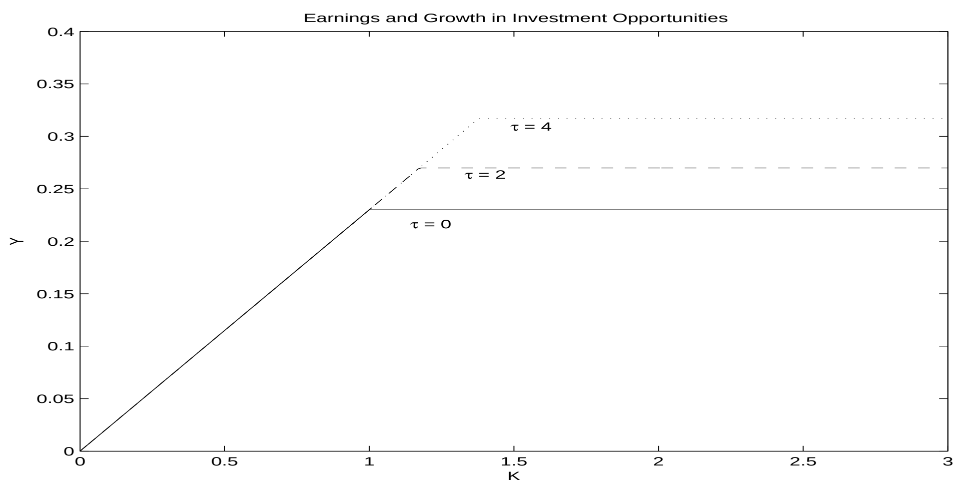

Figure 1: Growth in Investment Opportunities. This figure reproduces the earnings profile Y_t as a function of capital K_t, for three different time periods $t = 0$, $t = 1$ and $t = 2$.

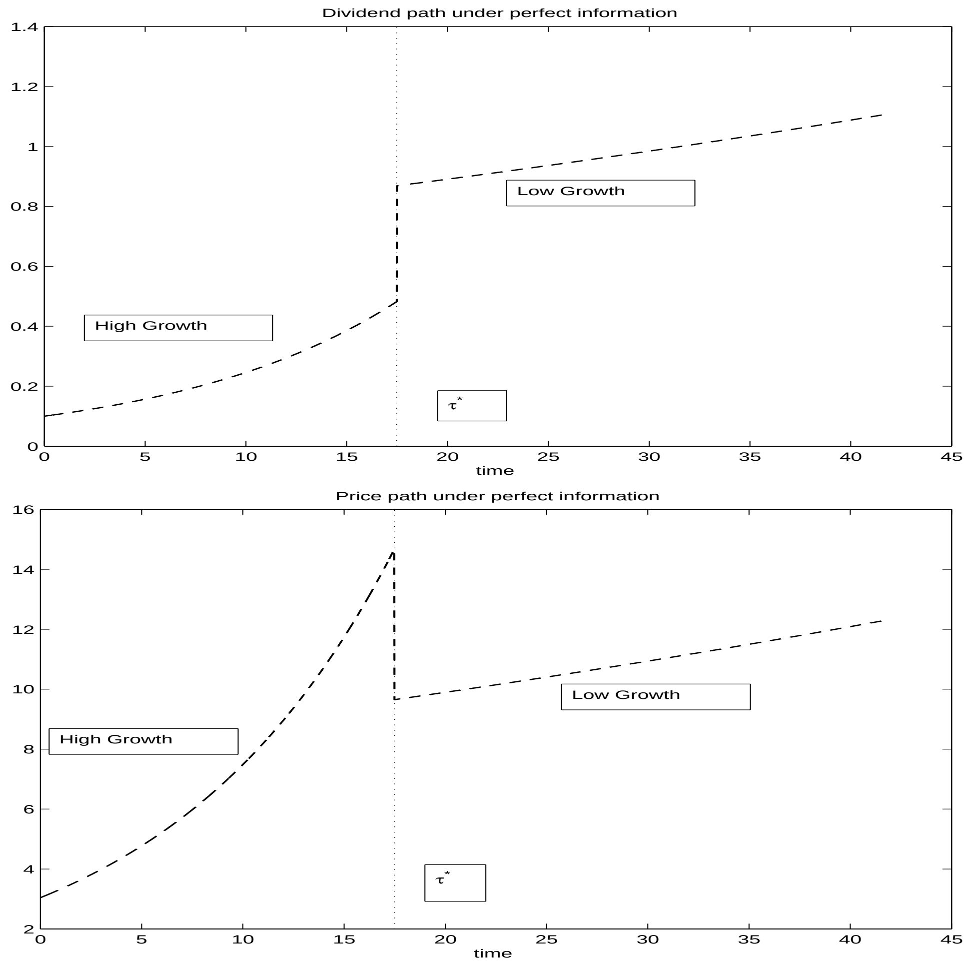

Figure 2: A dividend path (top panel) and a price path (bottom panel) under perfect information. We use the following parameters: $r = 10\%$, $z = 20\%$, $g = 1\%$, $G = 9\%$, $\delta = 1\%$.

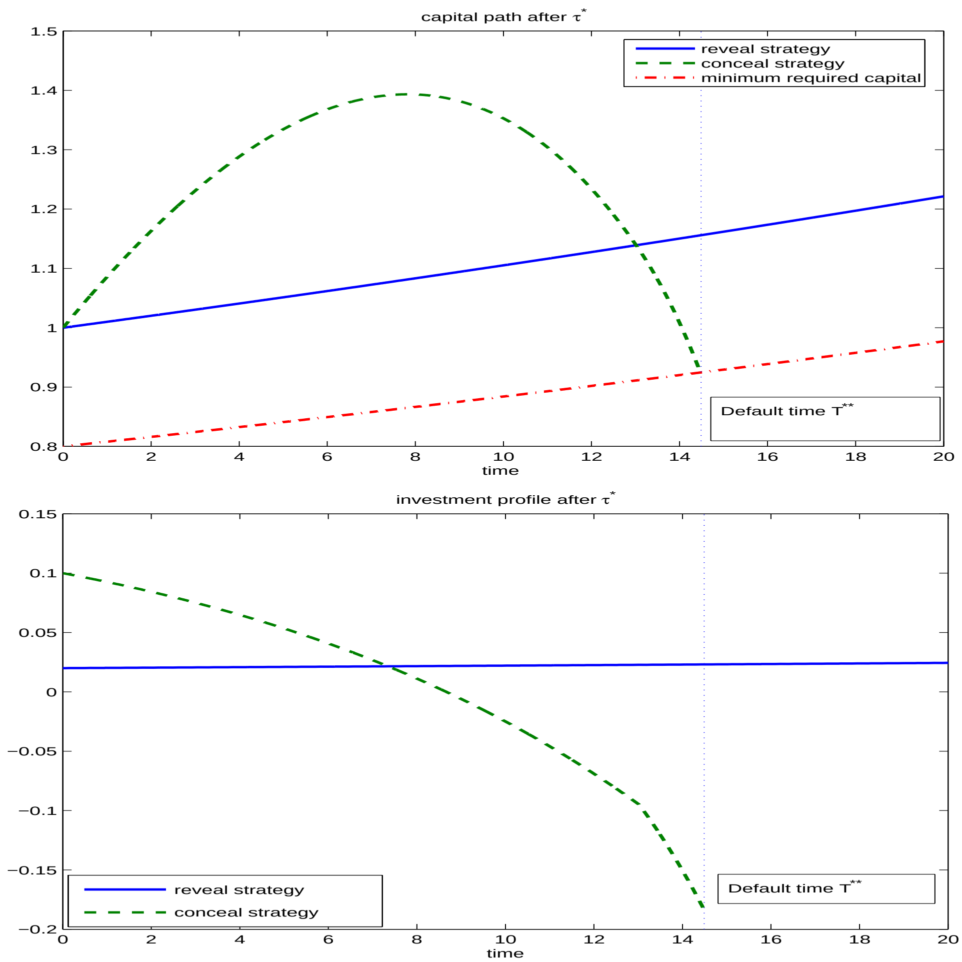

Figure 3: The dynamics of capital and investments under reveal and conceal equilibrium after τ^* (normalized to 0 in this figure). This figure shows the capital dynamics (top panel) and investment dynamics (bottom panel) for a g firm pretending to be a G firm (dashed line), relative to the revealing strategy (solid line). The vertical dotted line denotes "default" time T^{**}. The following parameters are used: $r = 10\%$, $z = 20\%$, $g = 1\%$, $G = 9\%$,$\delta = 1\%$, $\lambda = 1/15$, $\xi = .8$.

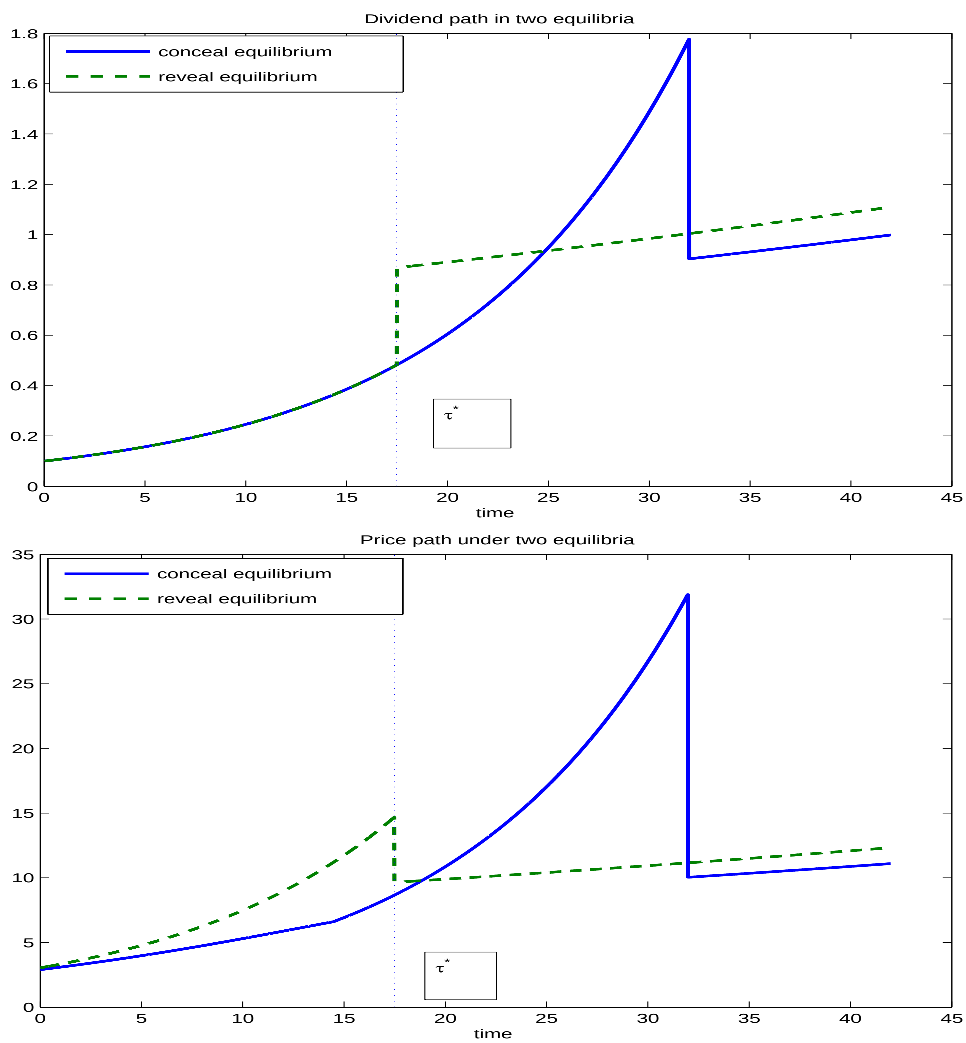

Figure 4: Dividend dynamics and price dynamics in reveal and conceal equilibria. The vertical dotted line denotes time τ^* of the growth change from G to g. The following parameters are used: $r = 10\%$, $z = 20\%$, $g = 1\%$, $G = 9\%$, $\delta = 1\%$, $\xi = .8$, $\lambda = 1/15$.

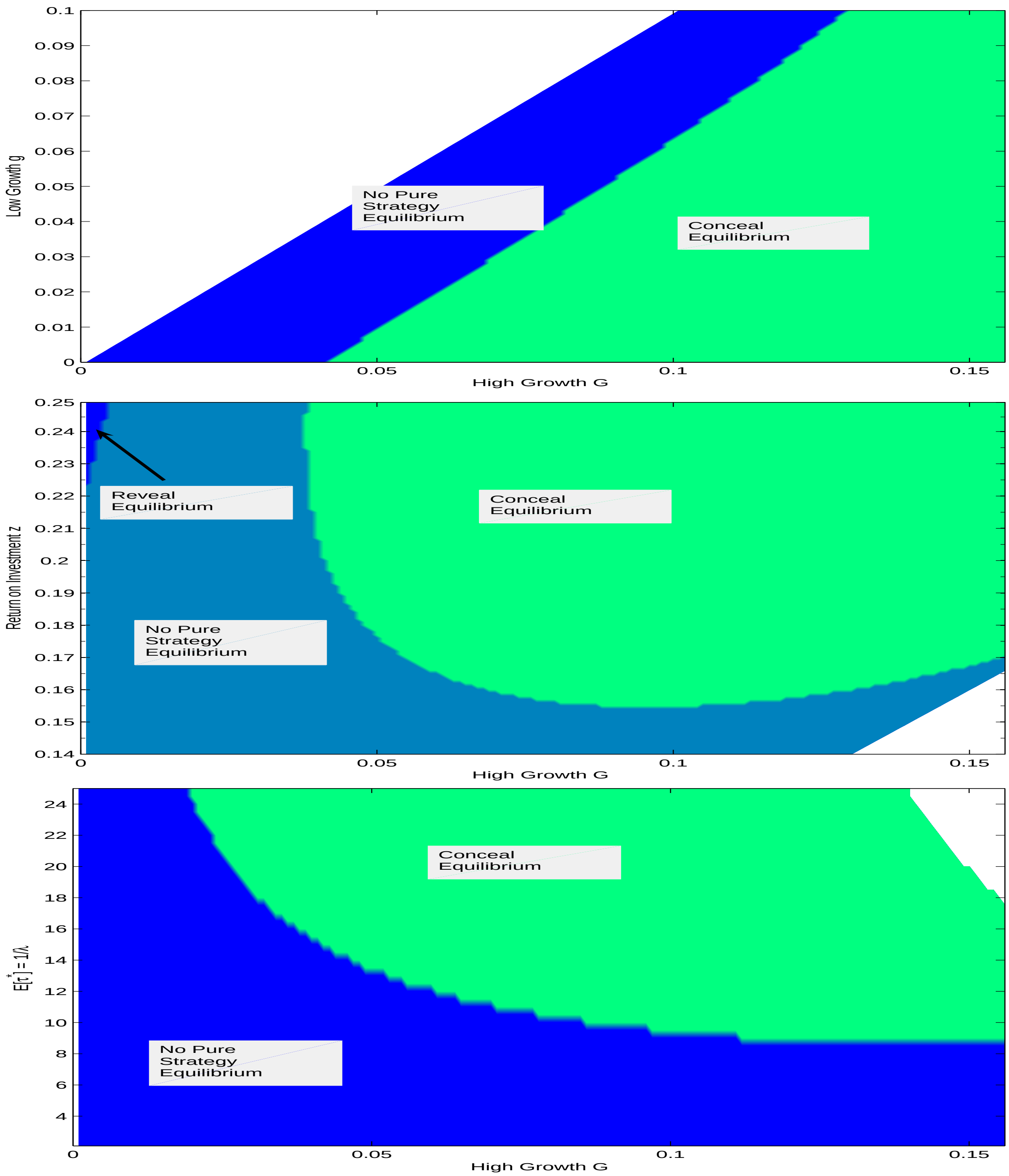

Figure 5: Conceal equilibrium under stock compensation The figure reports the conceal and reveal equilibria areas under stock compensation. In all figures, the $x-$axis reports the initial high growth G. In the top panel, the $y-$axis is the low growth g, in the middle panel, the $y-$axis is the return on capital z; and in the bottom panel, the $y-$axis is given by the expected time to maturity $E[\tau^*] = 1/\lambda$. The base parameters are in Table 1.

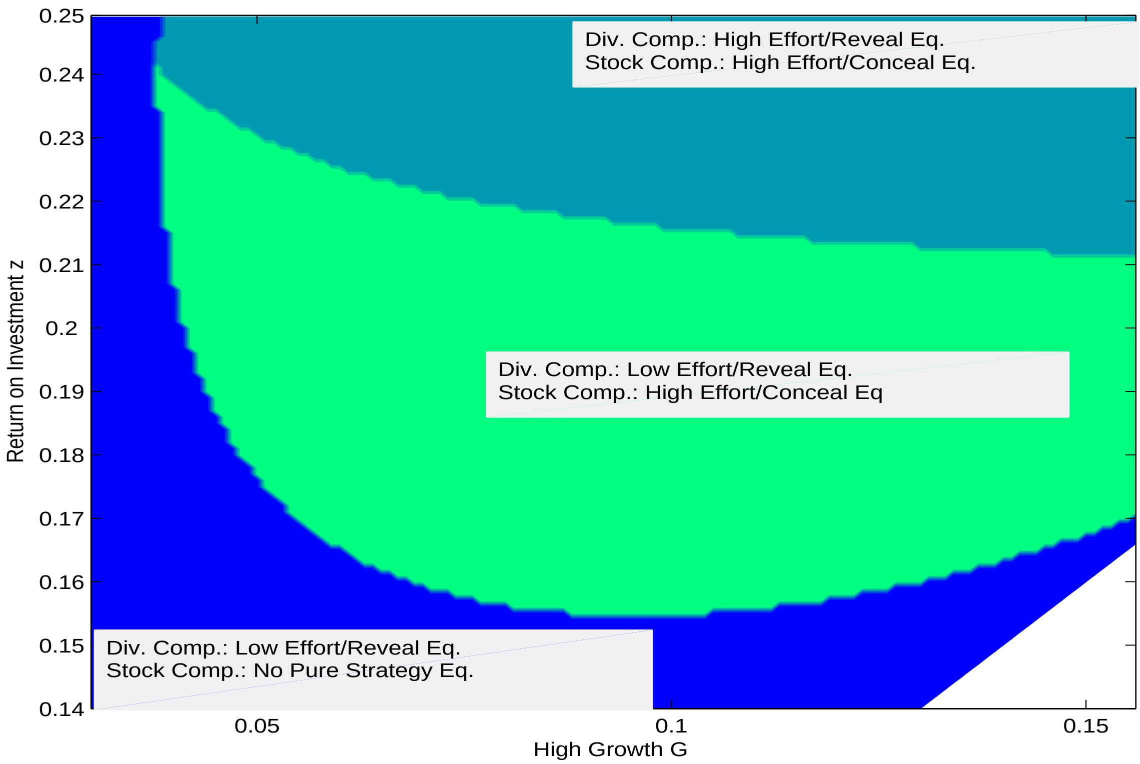

Figure 6: Equilibrium Areas under Stock Compensation and Dividend Compensation. In the (z, G) space, the figure shows the areas in which the following equilibria are defined: (a) the high effort / revealing equilibrium under dividend-based compensation; (b) the low effort / revealing equilibrium under dividends based compensation; (c) the high effort / conceal equilibrium under stock-based compensation. For all combination of parameters, dividend compensation generates a reveal equilibrium. z ranges between 12% and 30%, while G ranges between 6% and 16%. The remaining parameters are in Table 1.

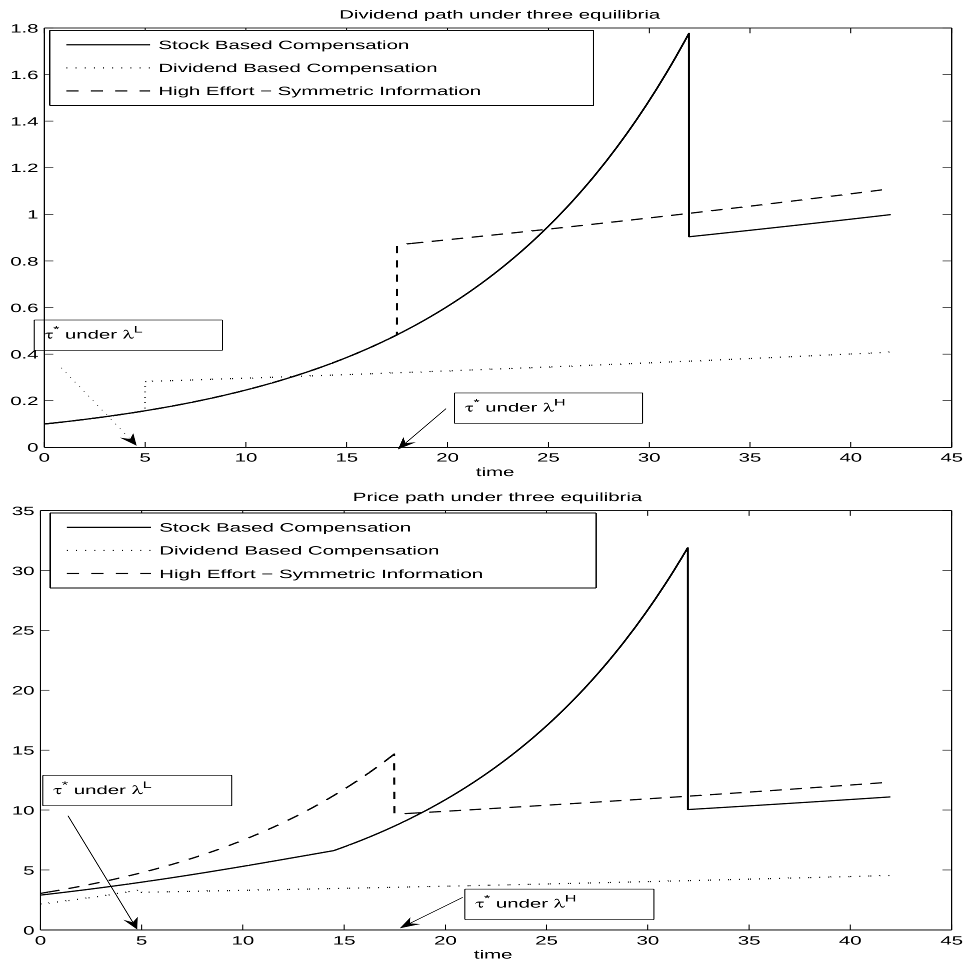

Figure 7: Dividend and Price Paths in Three Equilibria. The Figure plots hypothetical dividend (top panel) and price (bottom panel) paths under the case of "Stock-Based Compensation" (solid line); "dividend-based Compensation" (dotted line); and the first best Benchmark Case with Symmetric Information and Optimal Invemstment (dashed line). The parameters are in Table 1.

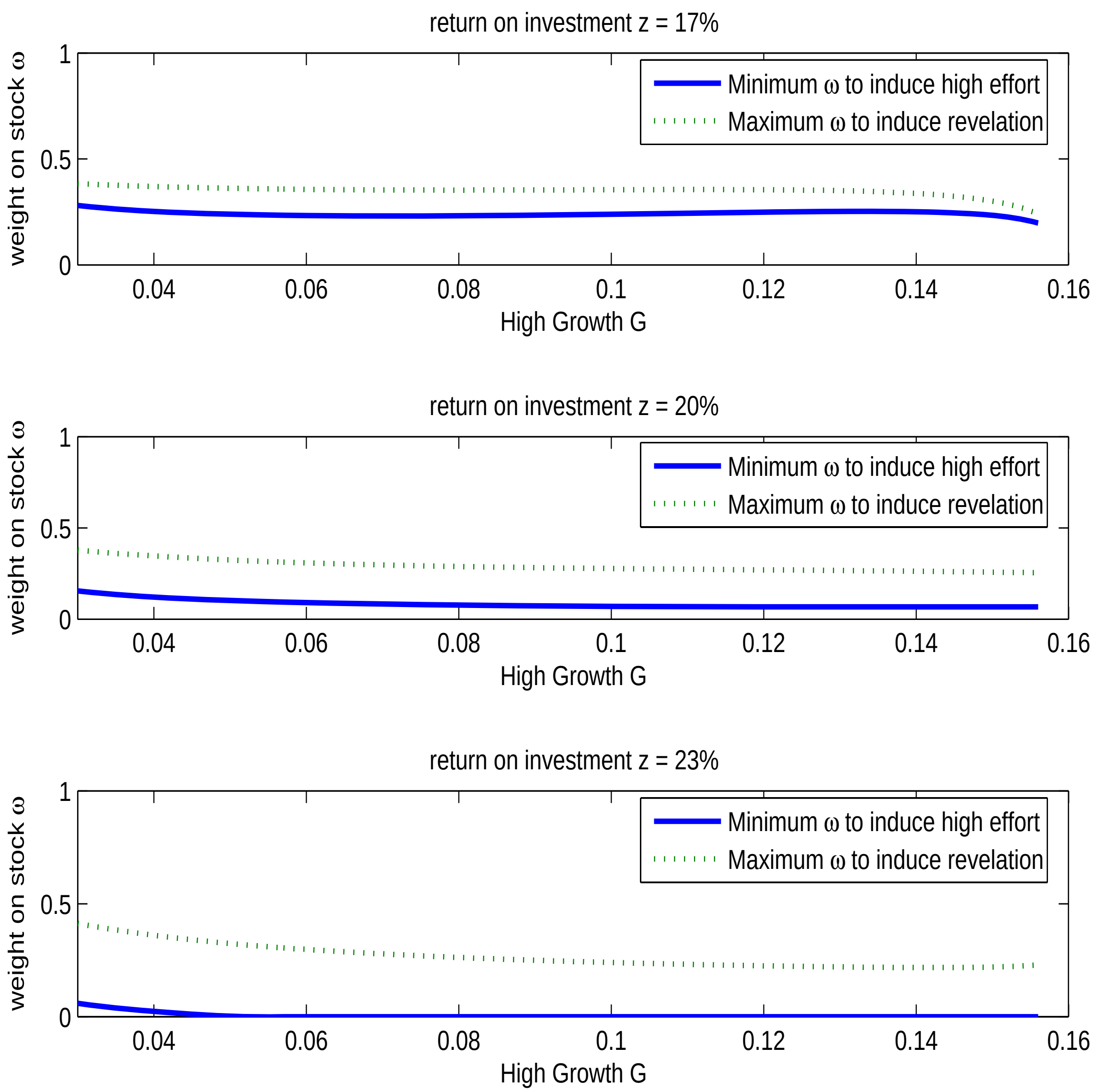

Figure 8: Optimal Weight ω on Stocks in Compensation Package. This figure reports the range of weights on the stock component of the combined compensation package that induces the first best for shareholders, that is, the high effort / reveal equilibrium. In each panel, which only differ for the level of return on capital z, the top line is the maximum ω that still induces the manager to reveal the shift in investment opportunuties, while the bottom line is the minimum ω that induces the manager to exert high effort. The remaining parameters are in Table 1.

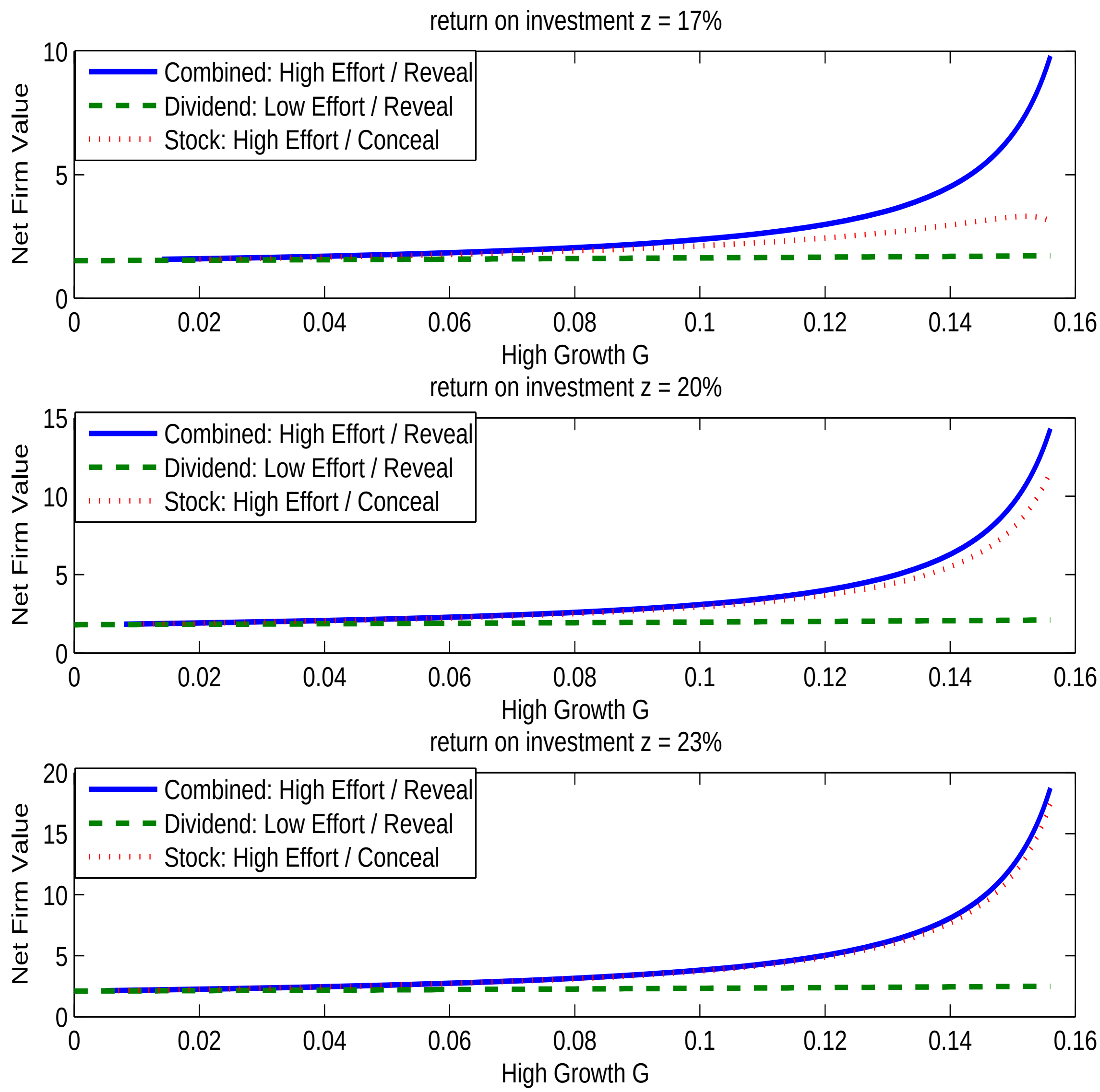

Figure 9: Firm Value Net of CEO's Incentive Contract Cost. This figure compares the firm value net of the CEO incentive contract costs in the first best equlibrium under the combined compensation package (solid line) to the firm value under (a) dividend compensation when CEO exerts low effort (dashed line), and (b) stock-based compensation when CEO exerts high effort but conceals the worsening of investment opportunities at τ^* (dotted line). Each panel corresponds to a different return on capital z. The combined package in each panel is the one corresponding to the minimum weight ω to stock that still induces the CEO to exerts high effort. $\eta_d = 5\%$ while for each panel η_p is chosen so that the cost to the firm under case (a) and (b) is the same, and thus differens across G and z cases. The remaining parameters are in Table 1.