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STOCK-BASED COMPENSATION AND CEO (DIS)INCENTIVES*

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The use of stock-based compensation as a solution to agency problems between shareholders and managers has increased dramatically since the early 1990s. We show that in a dynamic rational expectations model with asymmetric information, stock-based compensation not only induces managers to exert costly effort, but also induces them to conceal bad news about future growth options and to choose suboptimal investment policies to support the pretense. This leads to a severe overvaluation and a subsequent crash in the stock price. Our model produces many predictions that are consistent with the empirical evidence and are relevant to understanding the current crisis.

I. Introduction

Although a large theoretical literature views stock-based compensation as a solution to an agency problem between shareholders and managers, a growing body of empirical evidence shows that it may also 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 among the highest-paid executives in the United States, with huge equity-based personal profits realized when their firms' stock prices were high. Although the subsequent sharp decline of their firms' stock prices may have been due to exogenous systemic shocks to the economy, it is an important

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open question whether the extent of their 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 components in executives' compensation packages.[1]

In this paper, we show formally that although stock-based compensation induces managers to exert costly effort to increase their firms' investment opportunities, it also supplies incentives for suboptimal investment policies designed to hide bad news about the firm's 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 compensation is stock-based. 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 growth of the firm's investment opportunities slows down. The CEO is able to postpone 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 that whereas the CEO privately observes the slowdown 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

1. For instance, in January 2009 the U.S. government 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.

investors have no way of deducing this event, and equity becomes overvalued. To maintain the pretense over time, the CEO must design a suboptimal investment strategy: we assume that as long as the reported dividends over time are consistent with the high growth rate, the CEO keeps his or her job. Any deviation in dividends that follows a suboptimal investment policy leads to the CEO's dismissal.

We show that when a CEO's compensation is based on stock, and the range of possible growth rates is large, there exists 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 follows a suboptimal investment policy designed to maintain the pretense that investment opportunities are still strong. We solve for the dynamic pooling equilibrium in closed form and fully characterize the CEO's investment strategy. In particular, because the CEO is interested in keeping a high growth profile for as long as possible, he or she initially invests in negative–NPV projects as stores of cash, and later on foregoes positive–NPV projects in order to meet rapidly growing demand for dividends. In both cases, he destroys value. Because 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. Although the common wisdom of hidden-action models is to align the manager's objectives with those of investors by tying his compensation to the stock price, we show that stock-based compensation may lead the manager to invest suboptimally and destroy value to conceal bad news about future growth. The trade-off is made apparent by the fact that for most reasonable parameter values, and especially for medium- to high-growth companies, stock-based compensation indeed induces an equilibrium with high effort but also leads to a suboptimal 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, which eventually leads to undercapitalization and a stock price crash.

Although our analysis focuses on a linear stock-based compensation contract, we also consider alternative compensation schemes widely used in the industry. We analyze (i) flat wage contracts, (ii) deferred compensation, (iii) option-based compensation, (iv) bonuses, and (v) clawback clauses. We discuss the pros and cons of each of these contracts and show that these commonly used compensation schemes are not necessarily efficient either *ex ante* in inducing managerial effort, or *ex post* in forcing the manager to reveal the true state of the firm.

We then propose and analyze an optimal managerial compensation contract. We show that this double incentive problem (i.e., inducing high effort and revelation) can often be overcome by a firm-specific compensation scheme characterized by a combination of stock-based compensation and a bonus awarded to the CEO upon revelation of the bad news about long-term growth. Indeed, although stock-based compensation is necessary to induce the manager to exert costly effort and increase investment opportunities, it also implicitly punishes the CEO for truth telling, as the stock price will sharply decline. The contingent bonus, possibly in the form of a golden parachute or a generous severance package, is then necessary to compensate for the loss in the CEO stock holdings. However, we also show that a bonus contract alone would not work *ex ante*, because although it induces truth telling, it also provides an incentive not to exert effort, as this behavior anticipates the time of the bonus payment. The stock-based component ensures high effort.

An important implication of the model is that different types of firms need to put different levels of stocks in place in the compensation package. Specifically, we find that the CEOs' compensation packages of growth firms, that is, those with high investment opportunities growth and high return on capital, should have little stock-price sensitivity. Indeed, a calibration of the model shows that for most firms the stock-based compensation component should never be above 40% 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 both with an outright ban of stock-based compensation and 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], Ke [2005], Bergstresser and Philippon [2006], Burns and Kedia [2006], Johnson, Ryan, and

Tian [2009], and Kedia and Philippon [2010]). 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, Harvey, and Rajgopal (2005), according to which most managers state that they would forego a positive–NPV project if it caused them to miss on 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 a target. On the same note, our model's predictions are also consistent with Skinner and Sloan (2002), who show that the decline in firm value following a failure to meet analysts' forecasts is more pronounced in high-growth firms.

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], and Aghion and Stein [2008]). 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 firms. Similarly to Inderst and Mueller (2006) and Eisfeldt and Rampini (2008), 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 managers' incentives. Our paper is also related to Bolton, Scheinkman and Xiong (2006), Goldman and Slezak (2006), and Kumar and Langberg (2009), but it differs from them in that we emphasize the importance of firms' long-term growth options, which have a strong "multiplier" impact on the stock price and thus on CEO incentives to hide any worsening of investment opportunity growth.

Finally, our paper is also related to the recent literature on dynamic contracting under asymmetric information (e.g., Quadrini [2004], Clementi and Hopenhayn [2006], and 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. Although we also find the contract that induces full revelation and the first best, the main focus of our paper is 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's compensation and thus on the CEO's 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.

We organize the paper as follows. Section II presents the model setup. Section III presents the disincentives that stock-based compensation creates when there is information asymmetry. Section IV considers alternative compensation schemes. Section V provides the quantitative implications of our model. We discuss the broader implications of our results in Section VI.

II. The Model

We consider a firm run by a manager who (a) chooses an unobservable effort level 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 for the firm that is consistent with his or her public announcement. Our analysis focuses on the manager's trade-off between incentives to exert costly effort to maintain high growth of investment opportunities, and incentives to reveal to shareholders when investment opportunities growth slows down.

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

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

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 returns to scale up to the upper bound J_t, and then zero return for $K_t > J_t$. This simple specification of a decreasing–returns 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 a rate of δ.

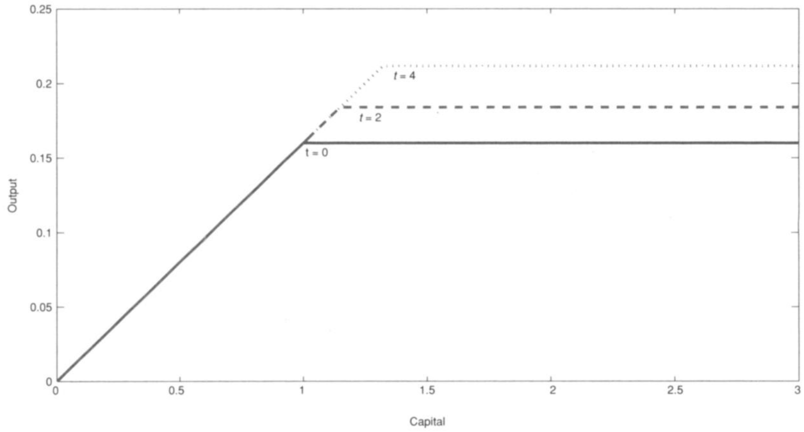

FIGURE I
Growth in Investment Opportunities
This figure reproduces the output (earnings) profile Y_t as a function of capital K_t for three different time periods, $t = 0$, $t = 2$, and $t = 4$.

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 for the firm. Because 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 I 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 initial public offering (IPO) or seasoned public offering (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 had 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 declines of the growth rate, as these are the times when the manager faces a hard decision as to whether to reveal the bad news to the public. Any firm may experience such a decline; thus our analysis applies 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^*, where τ^* is exponentially distributed with parameter λ. Formally,

$$\tilde{g} = \begin{cases} G & \text{for } t < \tau^* \\ g & \text{for } t \geq \tau^* \end{cases} \quad \text{where } f(\tau^*) = \lambda e^{-\lambda \tau^*}. \tag{3}$$

We assume that the manager's actions affect the time at which the decline occurs. After all, CEOs must actively search for investment opportunities and monitor markets and internal developments, all of which require time and effort. In our model, higher effort translates into a smaller probability of shifting to 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 declines. 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:

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

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

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

where w_u is the periodic wage of the CEO, and β is his or her discount rate.[2] We specify a cost of effort in a multiplicative fashion, which allows us to preserve scale invariance. Economically, this assumption implies 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 his or her pay w_t as much as possible.[3]

In (4), T is the time at which the manager leaves the firm, possibly $T = \infty$.[4] However, the departing date T may occur

2. Our results also hold with risk-averse managers, although analytical tractability is lost.

3. See Edmans, Gabaix, and Landier (2009).

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).

earlier, as the manager may be fired if the shareholders learn that he has followed a suboptimal investment strategy.

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 $r > G - \lambda^H$ and $r > g$. We also set $\beta > G$ to ensure that the total utility of the manager is finite. We also assume that $\beta \geq r$; that is, the manager has a higher discount rate than fully diversified investors.[5]

Although 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:

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

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

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

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

II.A. Investments and Stock Prices in the First Best

To build intuition, it is useful first to derive the optimal investment and the stock price dynamics under the first best. To maximize the firm value, the manager must invest to its fullest potential, that is, keep $K_t = J_t$ for all t. We solve for the investment rate I_t that ensures that this constraint is satisfied, and we obtain the following:

PROPOSITION 1. The first-best optimal investment policy given λ is

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

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

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

The top panel of Figure II plots the dynamics of the optimal dividend path for a firm with high growth in investment opportunities until τ^*, and low growth afterward. As the figure shows, the slowdown in the investment opportunities requires a decline in the investment rate, which initially increases the dividend payout rate: $D_{\tau^*}^g - D_{\tau^*}^G = (G-g)e^{G\tau^*}$.

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

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

$$P_{\text{fi},t}^{\text{before}} = E_t\left[\int_t^{\tau^*} e^{-r(s-t)} D_s^G ds + e^{-r(\tau^*-t)} P_{\text{fi},\tau^*}^{\text{after}}\right] = e^{Gt} A_\lambda^{\text{fi}} \quad \text{for } t < \tau^*, \tag{11}$$

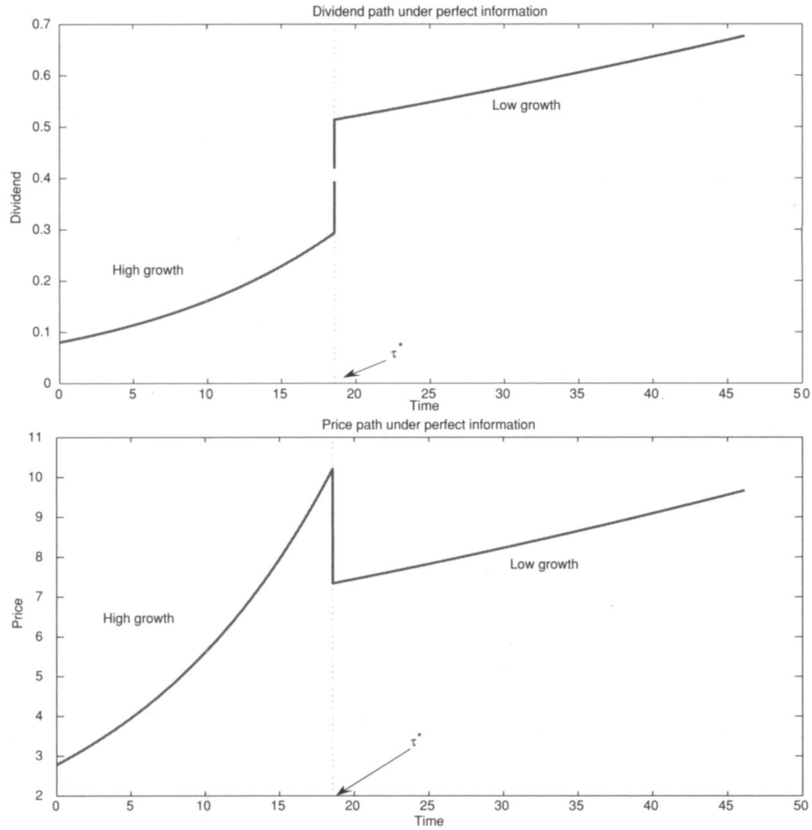

FIGURE II
A Dividend Path (Top Panel) and a Price Path (Bottom Panel) under Perfect Information
Parameter values are in Table I.

where

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

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

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

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

We finally 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,

$$P_{\text{fi},t}^{\text{before}}(\lambda^H) > P_{\text{fi},t}^{\text{before}}(\lambda^L). \tag{13}$$

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

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

which is always satisfied (see condition (5)).

It is intuitive that without a proper incentive scheme, the CEO won't exert high effort in this environment, even if τ^* is observable, because of the cost of effort. In our setting, shareholders cannot solve this incentive problem by simply "selling the firm to the manager":

COROLLARY 2. The manager's personal valuation of the firm before τ^* is as in (11), but with β substituted for r. Thus, a manager/owner exerts high effort, e^H, iff

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

where

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

Condition (15) is intuitive. First, when effort does not produce much increase in the expected τ^*, that is, 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 less intuitively, even when effort is costless ($c^H = 0$) the manager may still not choose high effort, even if he owns the firm. In this case, condition

(15) is satisfied iff[6]

$$z - \beta - \delta > 0, \tag{17}$$

which is similar to (14), but with the manager discount β taking the place of the shareholders' discount r. That is, if the manager is impatient, and the return on capital is low, so that $\beta > z - \delta$, then the manager/owner won't exert high effort. Because of this, the manager's personal valuation of the firm is much lower than the shareholders' valuation, a difference that goes beyond the simple difference due to discounting.

In line with previous work, stock-based compensation provides the incentive for the manager to exert costly effort. For simplicity, we focus first on the simplest compensation program, in which the manager receives shares at the constant rate η per period. Because of linear preferences, it is always optimal for the manager to sell the shares immediately;[7] therefore his or her effective compensation at time t is

$$w_t = \eta P_t. \tag{18}$$

PROPOSITION 3. In equilibrium with consistent beliefs where λ is the current intensity of τ^* and the stock price is $P_{\text{fi},t}^{\text{before}} = e^{Gt} A_\lambda^{\text{fi}}$, where A_λ^{fi} is in (12), the manager exerts high effort, e^H, under *stock-based compensation* (18) iff

$$\frac{\lambda^L + \beta - G}{\lambda^H + \beta - G} > \frac{A_\lambda^{\text{fi}} + \lambda^L H^{\text{Stock}}}{A_\lambda^{\text{fi}}(1 - c^H) + \lambda^H H^{\text{Stock}}}, \tag{19}$$

where

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

It follows that a *high-effort Nash equilibrium* occurs iff (19) is satisfied for $A_{\lambda^H}^{\text{fi}}$. A *low-effort Nash equilibrium* occurs iff (19) is not satisfied for $A_{\lambda^L}^{\text{fi}}$.

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

7. This is true in the full information equilibrium, as there is no signaling role of consumption. It is also true in a pooling asymmetric equilibrium, discussed next, as any deviation from this rule would reveal the manager's information and destroy the equilibrium.

We note that if the cost of effort is zero, $c^H = 0$, then condition (19) is always satisfied, as the price multiplier of the stock, largely due to future investment opportunities, is capitalized in the current salary, providing the proper incentive for the manager to exert high effort.

III. The (Dis)Incentives of Stock-Based Compensation

The preceding section shows that when τ^* is observable, a simple stock-based compensation will resolve the shareholders' incentive problem. Clearly the manager has much more information than the investors regarding the future growth opportunities of the firm, as well as its actual investments. Is this compensation scheme still optimal when τ^* is private information of the manager?

To build intuition, consider again the random time τ^* in the bottom panel of Figure II, and assume now that τ^* is private information of the manager. In this case, if the manager disclosed the information, his wage would drop from $w_t = \eta P_t^{\text{before}}$ to $w_t = \eta P_t^{\text{after}}$, depicted in the figure by the relatively sharp drop in price. That is, a pure form of stock-based compensation effectively implies that shareholders severely punish the manager for revealing bad news about the growth prospects of the firm. It is important to note that the bad news is only about the growth prospects—which we refer to as growth options, in line with the asset-pricing terminology—and not about the return on assets in place, which we assume constant and equal to z.

Given an opportunity, the manager will try to conceal this information. However, this *conceal* strategy is harder to implement than it seems at first, even if shareholders have no information about the firms' investment and capital dynamics. In reality, shareholders have only imprecise signals about the amount of economic capital and investment undertaken by the corporation. This is especially true for those industries characterized by high R&D expenditures, intellectual property, or a high degree of opacity in their operation (e.g., financial institutions), or in rapidly growing new industries, as the market does not know how to distinguish between investments and costs.

For tractability reasons, we assume that signals about the level of capital and investments have in fact infinite noise, and thus shareholders form beliefs about the manager's actions only by observing realized dividend payouts. Although this assumption is extreme, it reflects the lack of randomness of the return on capital z that we assume. A more realistic model would have both z stochastic and informative signals about capital and investments. Such a model is much more challenging to analyze, not only because shareholders' beliefs dynamics, which affect prices, are more complicated, but also because the CEO's optimal investment strategy would be extremely complex, as he or she would have to balance out the amount of information to reveal with the need to conceal the bad news for as long as possible. We note that although some information about investments and capital would make it easier for shareholders to monitor the manager, the presence of random return on capital z would also make it easier for the manager to conceal bad news longer, as he or she could blame low dividend payouts to temporary negative shocks on z rather than a permanent decline in investment opportunities. It is thus not obvious that our assumption of nonstochastic z but unobservable K and I make it easier for the manager to conceal τ^* than a more realistic setting.

Shareholders know that at $t = 0$ the firm has a given K_0 of capital and high growth rate G of investment opportunities. As long as the firm is of type G, they expect a dividend D_t^G, as described in (9).[8] We 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. This assumption is realistic, as only major changes in the firm's dividend policy may act as a coordination device across dispersed shareholders, who may then call for a possibly costly internal investigation on the firm. If the drop in dividend payouts does not correspond to the time of slowdown in investment opportunities (τ^*), the CEO is dismissed from the firm.

III.A. *Investment under Conceal Strategy*

If the CEO decides to conceal the truth, he or 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 a strategy cannot be held forever, as it will require more cash than the firm produces. We denote by T^{**} the time at which the

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

firm experiences a cash shortfall and must disclose the truth to investors. Because the firm's stock price will decline at that time, and the manager will lose his or 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 investment policy is to maximize the time until the cash shortfall T^{**}.

The next proposition characterizes 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. He or she employs all the existing capital stock: $K_{\tau^*} = K_{\tau^*-}$.
2. His or her investment strategy for $t > \tau^*$ is $I_t = z \min(K_t, J_t) - (z - G - \delta)e^{Gt}$.
3. The firm's capital dynamics is characterized as follows: Let h^* and h^{**} be the two constants defined in (49) and (50) in the Appendix, with $T^{**} = \tau^* + h^{**}$. Then
   a. For $t \in (\tau^*, \tau^* + h^*)$, the firm's capital K_t exceeds its optimal level J_t.
   b. For $t \in (\tau^* + h^*, T^{**}]$, the 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 point (2) of the proposition, 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 $t < \tau^* + h^*$), whereas eventually the capital stock must fall short of J_t (for $t \in (\tau^* + h^*, T^{**})$).

These dynamics are illustrated in Figure III for a parametric example. The top panel 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 initially invests in *negative*–NPV projects, as shown in the bottom panel. Indeed, although

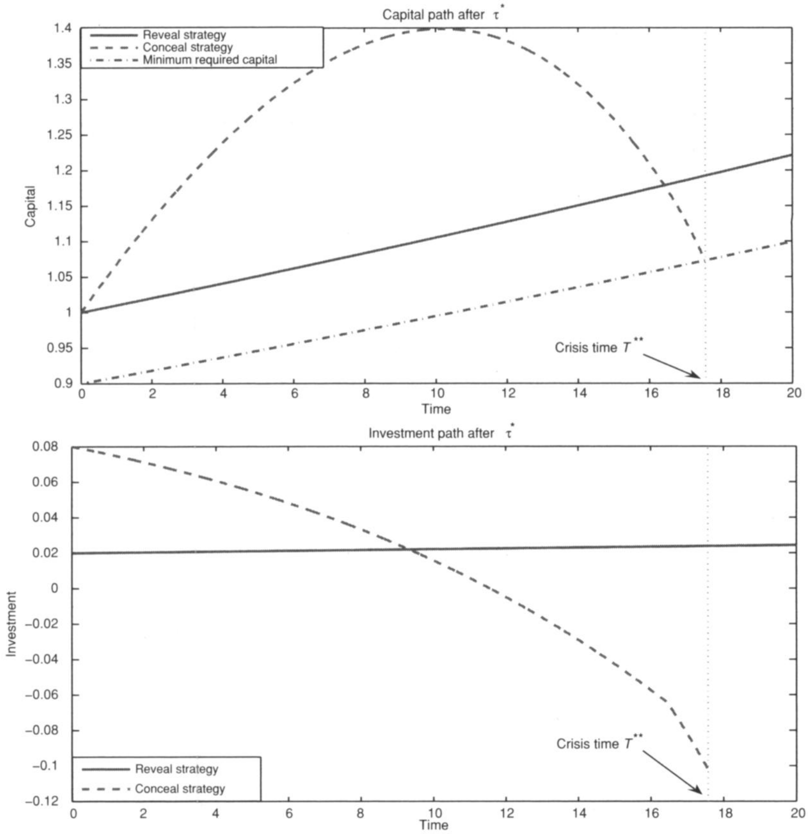

FIGURE III
The Dynamics of Capital and Investments under Reveal and Conceal Equilibrium after τ^* (Normalized to 0 in This Figure)

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 the liquidity crisis time T^{**}. Parameter values are in Table I.

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 II). Instead, if the CEO pretends that nothing has happened, he or she will invest this extra cash in negative–NPV projects as a storage of value to delay T^{**} as much as possible. The bottom panel of Figure III shows that eventually the pretending firm engages in disinvestments 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, the condition $K_{T^{**}} = \underline{K}_{T^{**}}$ determines T^{**}.[9]

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

III.B. 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 operate at its full potential; thus it needs to recapitalize. Because at T^{**} the firm's capital equals the minimum employable capital level, $K_{T^{**}} = \underline{K}_{T^{**}}$, whereas 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

$$\begin{aligned} P^L_{\mathrm{ai},T^{**}} &= \int_{T^{**}}^{\infty} D_t^g e^{-r(t-T^{**})} dt - J_{T^{**}}(1-\xi) \\ &= e^{(G-g)\tau^* + gT^{**}} \left(\frac{z-r-\delta}{r-g} + \xi \right). \end{aligned} \tag{20}$$

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

$$P_{\mathrm{ai},t} = E_t \left[\int_t^{T^{**}} e^{-r(s-t)} D_s^G ds + e^{-r(T^{**}-t)} P^L_{\mathrm{ai},T^{**}} \right]. \tag{21}$$

The subscript "ai" in (21) stands for "asymmetric information." Expression (21) 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 $P^{\mathrm{after}}_{\mathrm{fi},\tau^*}$ is replaced with the much lower price $P^L_{\mathrm{ai},T^{**}}$. We are able to obtain an analytical solution:

PROPOSITION 5. Let shareholders believe that λ is the current intensity of τ^*. Under asymmetric information and conceal

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

strategy equilibrium, the value of the stock for $t \geq h^{**}$ is[10]

$$P_{\mathrm{ai},t} = e^{Gt} A_\lambda^{\mathrm{ai}}, \tag{22}$$

where

$$A_\lambda^{\mathrm{ai}} = \frac{(z - G - \delta)}{(r + \lambda - G)} + \lambda e^{-(G-g)h^{**}} \left(\frac{z - r - \delta + (r - g)\xi}{(r - g)(r + \lambda - G)} \right). \tag{23}$$

Comparing the pricing formulas under asymmetric and symmetric information, (22) and (11), we observe that the first terms in the constants A_λ^{fi} and A_λ^{ai} are identical. However, the second term is smaller in the case of asymmetric information: the reason is that under asymmetric information, rational investors take into account two additional effects. First, even if the switch time τ^* has not been declared yet, it may already have taken place, and the true investment opportunities may be growing at a lower rate g for a while (up to h^{**}). The adjustment $e^{-(G-g)h^{**}} < 1$ takes this possibility into account. Second, at time T^{**}, the firm must recapitalize 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 IV illustrates the value loss associated with the conceal strategy. Because 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 gotten 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 the reveal strategy, the conceal strategy pays lower dividends for a while, as the manager pretends to actively invest, and then must pay higher dividends, which arise from allegedly high cash flow. These higher dividend payouts come at the expense of investment, and 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 up the pretense, and thus the higher the recapitalization that is required when the firm experiences a cash shortfall. This also implies lower dividends forever after the T^{**}.

How does the information asymmetry affect the price level? The bottom panel of Figure IV plots price dynamics under the conceal equilibrium and compares them with prices under the

10. The case $t < h^{**}$ does not yield additional intuition, yet it is much more complex. For this reason, we leave it to equation (51) in the Appendix.

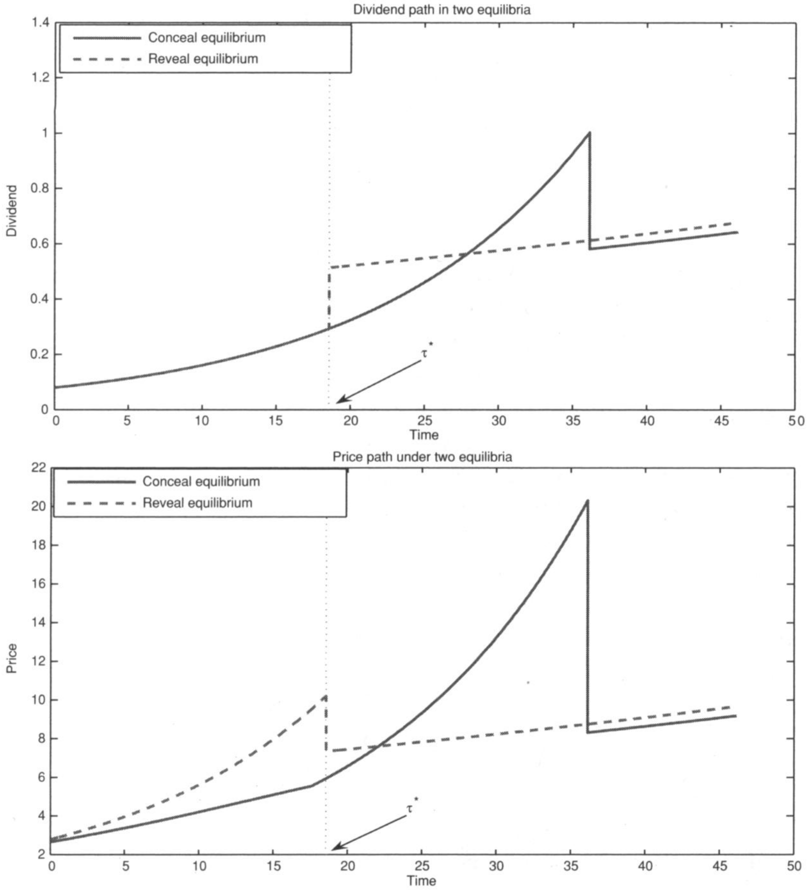

FIGURE IV

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. Parameter values are in Table I.

reveal equilibrium. Rational investors initially reduce prices in the conceal equilibrium, as they correctly anticipate the manager's suboptimal 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 sizes of underpricing and price drop depend on parameter values, as further discussed in Section V.

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

III.C. Equilibrium Strategy at $t = \tau^*$

We now consider the manager's incentives at time τ^* to conceal or reveal the true growth rate. Because 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), and thus the two utility levels can be computed exactly.

The rational-expectations, pure-strategies Nash equilibrium must take into account investors' beliefs about the manager's strategy at time τ^*, because 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 $P^{\text{after}}_{\text{fi},t}$ in equation (10) if at τ^* the manager decides to reveal. In contrast, if the manager decides to conceal, his or her utility is determined by the price function $P^{\text{before}}_{\text{fi},t}$ 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 $P_{\text{ai},t}$ in equation (22). If instead, the manager reveals at τ^* the true state of the firm, the price function reverts back to the full information price $P^{\text{after}}_{\text{fi},t}$ in equation (10). These three utility levels are

(24)
$$U^{\text{reveal}}_{\text{Stock},\tau^*} = \int_{\tau^*}^{\infty} e^{-\beta(t-\tau^*)}\left(\eta P^{\text{after}}_{\text{fi},t}\right)dt = \frac{\eta e^{G\tau^*}}{(\beta-g)}\left(\frac{z-g-\delta}{r-g}\right),$$
(25)
$$U^{\text{conceal,ai}}_{\text{Stock},\tau^*} = \int_{\tau^*}^{T^*} e^{-\beta(t-\tau^*)}\left(\eta P_{\text{ai},t}\right)dt = \eta A^{\text{ai}}_{\lambda} e^{G\tau^*}\left(\frac{1-e^{-(\beta-G)h^{**}}}{\beta-G}\right),$$
(26)
$$U^{\text{conceal,fi}}_{\text{Stock},\tau^*} = \int_{\tau^*}^{T^*} e^{-\beta(t-\tau^*)}\left(\eta P^{\text{before}}_{\text{fi},t}\right)dt = \eta A^{\text{fi}}_{\lambda} e^{G\tau^*}\left(\frac{1-e^{-(\beta-G)h^{**}}}{\beta-G}\right).$$

The following proposition provides the equilibrium conditions:

PROPOSITION 6. Let $\tau^* \geq h^{**}$.[11] A necessary and sufficient condition for a conceal equilibrium under stock-based compensation is

$$(27) \qquad \frac{A_\lambda^{\mathrm{ai}}}{(\beta - G)}\left(1 - e^{-(\beta - G)h^{**}}\right) > \frac{(z - g - \delta)}{(r - g)(\beta - g)},$$

where the constant A_λ^{ai} is given in equation (23). Similarly, a necessary and sufficient condition for a reveal equilibrium under stock-based compensation is

$$(28) \qquad \frac{A_\lambda^{\mathrm{fi}}}{(\beta - G)}\left(1 - e^{-(\beta - G)h^{**}}\right) < \frac{(z - g - \delta)}{(r - g)(\beta - g)},$$

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

Intuitively, the right-hand sides of both conditions (27) and (28) are the discounted utility under the reveal strategy. Because the compensation is stock-based, the stock multiplier "$1/(r - g)$" enters the formula. The left-hand sides of both conditions are the discounted utility values under the conceal strategy. In particular, now the stock multiplier A_λ^{ai} appears under the conceal equilibrium, whereas the stock multiplier A_λ^{fi} appears under the reveal equilibrium. Because $A_\lambda^{\mathrm{fi}} > A_\lambda^{\mathrm{ai}}$, conditions (27) and (28) 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.

III.D. Rational Expectations Equilibrium with the Choice of Effort

We now move back to $t < \tau^*$ and obtain conditions for Nash equilibrium that include 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

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

11. The solution for the case $\tau^* < h^{**}$ is cumbersome and thus is relegated to the Appendix.

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

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

PROPOSITION 7. Let $t \geq h^{**}$ and let λ^H be such that a conceal equilibrium is obtained at τ^*. Then high effort e^H is the equilibrium strategy iff

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

where

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

Condition (30) is similar to condition (19) in the benchmark case, and it has the same intuition (see discussion after Proposition 3).

To summarize, Propositions 6 and 7 show that under conditions (27) and (30), pure stock-based compensation induces a high effort/conceal equilibrium: The CEO exerts high effort to increase the firm's growth options but will not disclose bad news about growth options when the time comes. Section V shows that these conditions hold for a wide range of parameters.

IV. Alternative Simple Compensation Schemes

The preceding section focused on a simple, linear stock-based compensation scheme. In this section we consider alternative simple compensation schemes widely used in the industry. The final section also discusses the properties of an optimal contract.

IV.A. Flat Wage

Suppose the manager simply gets a wage w_t that is not contingent on anything. For simplicity, assume $w_t = w$, a constant. In this case, it is intuitive that the manager at time τ^* prefers to reveal the decrease in investment opportunities to shareholders, as he would get w for a longer period. The drawback, of course, is that the manager has no incentive to exert costly effort, because it would bear the effort cost c^H. Thus, the resulting Nash equilibrium is a low effort/reveal equilibrium, as shareholders expect that the manager will not exert effort, and prices adjust to $P_{\text{fi},t}^{\text{before}} = e^{Gt} A_{\lambda^L}^{\text{fi}}$ in (11).

From the shareholders' point of view, the interesting question is whether it is better to induce a low effort/reveal equilibrium through a simple flat wage, or a high effort/conceal equilibrium through stock-based compensation. Because each of the two equilibria has one positive and one negative feature, the question is which one is better. The next corollary answers this question, whereas Section V contains a quantitative assessment of this corollary.

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, $P_{\text{ai},0} > P_{\text{fi},0}^{\text{before}}$.

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

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 recapitalization as a delayed cost to provide incentives for longer-term growth.

This fact implies that it is not necessarily true that finding *ex post* managers who 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 V below shows that stock-based compensation is *ex ante* optimal for a wide range of reasonable parameters.

IV.B. Deferred Compensation: Vesting

A popular incentive scheme is to delay the compensation of managers for a few years. Indeed, there is a conventional wisdom that delayed stock-based compensation provides the incentives both to exert high effort and to reveal any bad news about the company. Unfortunately, this conventional wisdom is not warranted, as we now show.

To see the problem with the argument, consider the case in which the firm pays the managers at a rate of η_t shares per period, which are vested for k years. Because of linear preferences, it is optimal for the manager to sell off all of the shares that are becoming eligible for vesting, and consume out of the proceeds.[12] Thus, at time t, the manager's consumption is

$$w_t = \eta_{t-k} P_t.$$

As in the preceding section, we study the case in which the firm always awards the same number of shares per period, $\eta_t = \eta$, which makes the consumption at time t simply $w_t = \eta P_t$. Assume that if the CEO conceals at τ^*, he will lose all the nonvested shares at the time of the cash shortfall T^{**}. It is immediate then that if $\tau^* > k$, the intertemporal utilities at τ^* under either a reveal or a conceal equilibrium are given by the expressions (24)–(26). Thus, in this case, the incentive problem of the manager is *identical* to the one examined earlier in Proposition 7. That is, delayed stock-based compensation is completely ineffective in inducing the manager to reveal bad news about growth options. Intuitively, if $\tau^* > k$, then at τ^* the manager has accumulated enough shares becoming eligible for vesting per period so that the revelation of bad news about growth options would undermine. The manager will then retain the information.

What if $\tau^* < k$? The only change in the expressions for the intertemporal utilities (24)–(26) is that the integral will start from k instead of τ^*, and thus the expressions have to be modified accordingly. In this case, indeed, for k long enough the intertemporal utility under the conceal strategy always decreases to zero more quickly than the one under the reveal strategy, and thus a large vesting period k would provide the correct incentives *if* $\tau^* < k$. However, relying on this event ($\tau^* < k$) to provide the proper incentives to the CEO is misguided, as the lower utility under stock-based compensation only stems from the fact that the CEO has not had enough time to accumulate shares before τ^*. This logic is problematic for two reasons: First, shareholders actually want τ^*

12. See footnote 7.

to occur as far in the future as possible, and thus hoping also to have $\tau^* < k$ is against their desire to push the manager to exert high effort, unless the delay k is unreasonably high. Second, the argument relies on $t = 0$ being the time at which the CEO starts accumulating shares, which is also problematic. In our model, $t = 0$ is any time at which there is full disclosure about both the capital K_0 and the company growth rate $\tilde{g} = G$. For instance, if this time reflects the time of an IPO, it is typically the case that the owner selling the firm becomes the CEO of the new company while initially retaining a large fraction of the firm's ownership. Similarly, managers who are promoted from within the firm have already accumulated shares during their time at the firm. Thus, if we assume that at time $t = 0$ the manager is already endowed with shares becoming eligible for vesting, then $\tau^* < k$ can never happen, and the equilibrium is effectively identical to the one in the preceding section.

We finally note that when the manager decides at τ^* to conceal the bad news about future investment opportunities, he or she does so in the full knowledge that at the later time T^{**} he or she will lose all of the nonvested shares (ηk), suffering an effective loss at T^{**} equal to $\eta k P_{T^{**}}$. This amount can be quite substantial, as $P_{T^{**}}$ is very high (see Figure IV), and thus it may appear at first that a CEO who loses a massive amount of wealth at the time of the firm's liquidity crisis (i.e., T^{**}) cannot be responsible for the crisis itself, as he or she is the first to lose. But this conclusion is not warranted, because the price reached the large level $P_{T^{**}}$ exactly because of the (misleading) behavior of the CEO. Had the CEO behaved in the best interest of the shareholders, such a high value of the stock would have been not realized in the first place, as shown by the dashed line in Figure IV. This analysis therefore cautions against reaching any type of conclusion on the behavior of CEOs based on personal losses of wealth at the time of the firm's liquidity crisis.

IV.C. Deferred Compensation: Delayed Payments

The main problem with vesting is that the effective compensation at t still depends on the stock price at t. A popular variation of deferred compensation is to delay the payment only to k years in the future, so that the consumption at time t is

$$w_t = \eta_{t-k} P_{t-k}$$

if the manager acts in the best interest of the shareholders, or zero after the cash shortfall T^*, if it happens. This compensation scheme is equivalent to placing the cash equivalent of the pure stock-based compensation in an escrow account, and paying it k years later if the CEO has not been caught misbehaving. The next proposition characterizes the equilibrium:

PROPOSITION 8. *a*. Let $\underline{k}$ be defined by the equation

$$A_{\lambda}^{\text{fi}}\left(\frac{1-e^{-(\beta-G)(h^{**}-\underline{k})}}{\beta-G}\right)=\frac{z-g-\delta}{(r-g)(\beta-g)}. \tag{31}$$

Then the manager reveals at τ^* iff $k \geq \underline{k}$.

b. Let $t \geq k = \underline{k}$ and let τ^* not have been realized yet.[13] Then the manager exerts high effort e^H iff

$$c^H\left[\frac{\beta+\lambda^L-G}{\beta+\lambda^H-G}\right] < (\lambda^L-\lambda^H)e^{-(\beta-G)h^{**}}. \tag{32}$$

Thus, there exists a constant $\underline{c}^H$, such that if $c^H < \underline{c}^H$, then high effort/reveal is a Nash equilibrium.

This proposition shows that the stock-based delayed-payment compensation scheme may effectively achieve the first best, as the CEO exerts high effort (b) and reveals the true state at τ^* (a). This is good news, and it matches the intuition that the stock component of the compensation still provides the incentive to work hard, and the delayed payment provides the incentive to reveal any bad news about the long term. However, the proposition also highlights two facts: First, the delay must be sufficiently long ($k > \underline{k}$), and second, the cost of effort must be sufficiently low ($c^H < \underline{c}^H$). Unfortunately, if either of these requirements is not satisfied, the equilibrium breaks down. In our basic calibration, we find that the minimum delay to induce truth revelation is $\underline{k} \approx 11.8$ years, which we find unrealistically long. In addition, we also find that the lower bound to the managerial cost is $\underline{c}^H \approx 1.8\%$, which is below the parameter range we use in our calibration. The optimal contract in Section IV.G and its implementation through a stocks-plus-bonus compensation scheme in Section V.C provide a solution that works across a large range of parameter values.

13. We assume $t \geq k$ to sidestep the issue of having already accumulated shares by τ^*, as discussed in the preceding section.

IV.D. Option-Based Compensation

How does an option-based contract affect the incentive to conceal bad news about growth options? We now show that such a contract amplifies the incentive to conceal. Let η_t denote the number of options awarded at time t, and let k be their time to maturity. As is standard practice, we assume that these options are issued at the money, with strike price $H_t = P_t$. Thus, the consumption of the manager at t is given by

$$w_t = \eta_{t-k} \max(P_t - H_{t-k}, 0) = \eta_{t-k} \max(P_t - P_{t-k}, 0).$$

Consider again time τ^*. In this case, the intertemporal utilities under the reveal and conceal strategy in the reveal Nash equilibria[14] are given by

$$(33)\quad U^{\text{Reveal,fi}}_{\text{Option},\tau^*} = \int_{\tau^*}^{\tau^*+k} e^{-\beta(t-\tau^*)}\eta_{t-k} \max\left(P^{\text{after}}_{\text{fi},t} - P^{\text{before}}_{\text{fi},t-k}, 0\right)dt + \int_{\tau^*+k}^{\infty} e^{-\beta\left(t-\tau^*\right)}\eta_{t-k} \max\left(P^{\text{after}}_{\text{fi},t} - P^{\text{after}}_{\text{fi},t-k}, 0\right) dt,$$

$$(34)\quad U^{\text{Conceal,fi}}_{\text{Option},\tau^*} = \int_{\tau^*}^{\tau^*+h^{**}} e^{-\beta(t-\tau^*)}\eta_{t-k} \max\left(P^{\text{before}}_{\text{fi},t} - P^{\text{before}}_{\text{fi},t-k}, 0\right) dt.$$

The intertemporal utilities under these two strategies in the conceal equilibrium are identical but with the asymmetric information price $P_{\text{ai},t}$ substituted in place of $P^{\text{before}}_{\text{fi},t}$ in both (33) and (34). The next proposition shows that the leverage implied by option like contracts in fact makes the conceal strategy more likely.

PROPOSITION 9. *a*. Let k^*_{fi} be defined by

$$(35)\quad k^*_{\text{fi}} = \frac{1}{G} \log\left(\frac{r-g}{z-g-\delta} A^{\text{fi}}_{\lambda}\right).$$

Then for $k < k^*_{\text{fi}}$ a reveal equilibrium at τ^* holds iff

$$(36)\quad \frac{(e^{gk}-1)}{(1-e^{-Gk})}\left(\frac{\beta-G}{\beta-g}\right) > e^{Gk^*_{\text{fi}}} e^{\beta k}\left(1-e^{-(\beta-G)h^{**}}\right).$$

There exists $\underline{g} > 0$ such that this condition is always violated for $g < \underline{g}$. Thus, a reveal equilibrium cannot be supported when g is small.

14. See notation and discussion in Section III.C.

b. Let k^*_{ai} be defined as in (35) but with $A^{\mathrm{ai}}_{\lambda}$ in place of $A^{\mathrm{fi}}_{\lambda}$, and let $\tau^* > h^{**} + k$. Then, for $k < k^*_{\mathrm{ai}}$, a conceal Nash equilibrium at τ^* occurs if

$$\frac{(e^{gk}-1)}{(1-e^{-Gk})}\left(\frac{\beta - G}{\beta - g}\right) < e^{Gk^*_{\mathrm{ai}}}e^{\beta k}\left(1 - e^{-(\beta - G)h^{**}}\right).$$

There exists $\underline{g} > 0$ such that this condition is always satisfied for $g < \underline{g}$. Thus, a conceal equilibrium can always be supported when g is small.

The intuition behind this proposition is straightforward. Consider the case in which $g = 0$. In this case, the pricing formula in (11) shows that when the information is revealed, the price drops to $P^{\mathrm{after}}_{\mathrm{fi},t}$, which is a constant. The value of k^*_{fi} in (35) is the time lag that ensures that the price at revelation, $P^{\mathrm{after}}_{\mathrm{fi},\tau^*}$, equals the price before revelation while it was still increasing, $P^{\mathrm{before}}_{\mathrm{fi},\tau^*-k^*_{\mathrm{fi}}} = P^{\mathrm{after}}_{\mathrm{fi},\tau^*}$. Clearly, for $k < k^*_{\mathrm{fi}}$, it follows that the price after revelation is always smaller than the strike price $H_{\tau^*-k} = P^{\mathrm{before}}_{\mathrm{fi},\tau^*-k}$, pushing the option out of the money. The case in which $g = 0$ also implies that the manager cannot expect that his future options will ever be in the money. Thus, in this case, by revealing the CEO gets intertemporal utility equal to zero. By concealing, in contrast, he always receive positive utility. It follows from this argument that optionlike payoffs tend to increase the incentive to conceal bad news compared to the case in which the manager has a linear contract. If $k > k^*_{\mathrm{fi}}$ calculations are less straightforward, but because the simple stock-based compensation can be considered a special type of option-based contract with strike price equal to $H = P_0$, it follows that increasing the strike price only decreases the payoff if the manager reveals information, decreasing his incentive to reveal.

IV.E. Cash Flow–Based (Bonus) Compensation

One alternative to stock-based compensation is a profit-based compensation contract. In the spirit of our simple neoclassical model with no frictions, we assume the firm pays out its output net of investments in the form of dividends. From an accounting standard, these should be considered the firm's free cash flow,[15] which coincides with dividends and earnings in our model, but

15. We thank Ray Ball for pointing this out.

that in reality they are different and subject to different degrees of manipulation. Free cash flows are arguably harder to manipulate and thus we consider a simple compensation defined on cash flows.

Let then the compensation be given by $w_t = \eta_d D_t$. In this case, we obtain the following:

PROPOSITION 10. Under cash flow–based compensation, a necessary and sufficient condition for a "reveal" equilibrium at $t = \tau^*$ is

$$\left(\frac{z-G-\delta}{\beta-G}\right)\left(1-e^{-(\beta-G)h^{**}}\right) < \left(\frac{z-g-\delta}{\beta-g}\right). \tag{37}$$

In addition, the manager exerts high effort, e^H, iff

$$\frac{\lambda^L+\beta-G}{\lambda^H+\beta-G} > \frac{1+\lambda^L H^{\mathrm{Div}}}{1-c^H+\lambda^H H^{\mathrm{Div}}}, \tag{38}$$

where

$$H^{\mathrm{Div}} = \frac{(z-g-\delta)}{(z-G-\delta)(\beta-g)}. \tag{39}$$

A *Nash equilibrium* with high (low) effort obtains iff (38) is (is not) satisfied.

This compensation strategy can achieve first best under some parameterizations. In particular, we find that condition (37) is satisfied for most parameter configurations. This result is in fact intuitive, and leads us to the optimal compensation discussed later. Referring to the top panel of Figure II, we see that when the manager optimally reveals, he or she has to increase the payout to shareholders, as there are no longer any investment opportunities available. Effectively, by doing so, the manager also increases his or her own compensation. That is, this cash flow–based compensation resembles a "bonus" contract in which the revelation of bad news leads to a higher cash payment and thus higher utility.

Of course, a drawback of this compensation scheme is that it provides an incentive to pay out too high dividends and thus sacrifice investments. In fact, because the manager is impatient, $\beta > r$, he or she prefers to have τ^* occur as soon as possible, thus decreasing his or her incentive to exert high effort. Indeed, we find that condition (38) is satisfied only under some extreme parameterizations, in which both the return on capital z and the growth rate G are large. In this case, the higher discount β is compensated by (much) larger cash flows in the future if the manager invests heavily, that is, if he or she exerts high effort. In all the other cases, the cash flow–based compensation leads to low effort and revelation, thereby generating the same type of conundrum already discussed in Section IV.A

IV.F. Clawback Clauses

One final popular incentive scheme is to insert clawback clauses into the CEO compensation package. Such clauses establish that the CEO has to return part or all of the compensation he or she received during a given time if he or she is found guilty of misconduct. In our model, in a conceal equilibrium the CEO is not disclosing all the information to shareholders, which can be considered reasonable cause for shareholders or regulators to proceed against the CEO. Clearly, if the difference between τ^* and T^{**} is verifiable in court, then by imposing a sufficiently large penalty at T^{**} we can always ensure that the manager discloses. The clawback clause is just such a penalty.

Our model, however, suggests that shareholders and regulators have to be careful even with clawback clauses. For instance, suppose that the distinction between τ^* and T^{**} is observable but not verifiable, meaning that it would be hard to effectively prove in court that the manager has misbehaved. Although in our stylized model it is simple to detect misbehavior of the CEO, in reality the nonoptimal investment strategy of the CEO is much harder to detect, let alone to prove in court. In this case, one may decide to make the clawback clause contingent on some measure of performance. Consider, for instance, that shareholders move against the manager to claw back the salary paid when the price drops. In this case it is intuitive that the manager has no incentive to reveal his or her information at time τ^*, as it would induce a price decline. By concealing, the manager can push the price decline further back in the future, and thus maximize his or her utility.

Another possibility is to set up a clawback clause contingent on a (large) recapitalization, which is the main difference between τ^* and T^{**}. This clause would indeed solve the problem within our model,[16] although it relies on the fact that in our model the firm never needs to go to the capital markets. In an extension of the

16. The clawback clause must require the CEO to return the actual compensation received. As shown in Section IV.B, losing only the shares ηk not yet vested at T^{**}, for instance, would not alleviate the incentive to conceal the bad news at τ^*.

model in which the firm may need to raise more capital for investment purposes, for instance to open a new identical firm with the same technology that allows to increase the size, then again there is the risk that by putting a clawback clause the shareholders would not be inducing the optimal CEO behavior.

IV.G. The Optimal Contract

The preceding sections considered relatively standard simple compensation packages, adapted to our stylized model, and discussed their pros and cons. In this final section we briefly discuss the characteristics of the optimal contract, and compare them to the previous contracts. As in our dynamic model all quantities increase at an exponential rate, we restrict our attention to contracts of the form

$$w_t = \begin{cases} w_t^b = A_b\, e^{B_b t} & \text{if } t < \tau^* \\ w_t^a = A_a\, e^{B_a t + C_a \tau^*} & \text{if } t \geq \tau^* \end{cases},$$

where the subscript a stands for "after τ^*" and the subscript b stands for "before τ^*." We assume for simplicity that although τ^* is not *ex ante* observable by shareholders, they are able to observe whether τ^* has been realized or not once the announcement is made. As discussed earlier, the manager may produce convincing evidence that investment opportunities deteriorated at τ^*, whereas he or she may refrain from producing this information in a conceal equilibrium. This simplifying assumption allows us to make the contract's payoff contingent on the announcement itself.[17] All bargaining power is with the firm, but the manager has an outside option, given by $U_t^O = A_O e^{B_O t}$, which may be growing over time.

Because in our model the resources to pay the manager are outside the model (do not come from dividends themselves), effectively the firm solves

$$\min E\left[\int_0^\infty e^{-rt} w_t\, dt\right]$$

17. For simplicity, we sidestep here the issue of truthfull revelation, that is, the incentive to have the manager announce τ^* when it actually happens.

conditional on the following incentive compatibility constraints:

(40) (Reveal at τ^*) $U_{\tau^*}^{\text{Reveal}} \geq U_{\tau^*}^{\text{Conceal}}$ for all τ^*,

(41) (High effort before τ^*) $U_t^H \geq U_t^L$ for all $t \leq \tau^*$,

(42) (Outside option) $U_t \geq U_t^O$ for all t,

where $U_{\tau^*}^{\text{Reveal}} = \int_{\tau^*}^{\infty} e^{-\beta(t-\tau^*)} w_t^a dt$, $U_{\tau^*}^{\text{Conceal}} = \int_{\tau^*}^{T^{**}} e^{-\beta(t-\tau^*)} w_t^b dt$, and for $i = H, L$,

$$U_t^i = E_t\left[\int_t^{\tau^*} e^{-\beta(s-t)} w_s^b (1 - c_s^i) ds + e^{-\beta(\tau^* - t)} U_{\tau^*}^{\text{Reveal}} | i\right].$$

Note that we assume that by concealing, the *manager loses the outside option.* That is, there is a serious penalty for concealing. This is realistic. Adding back the outside option after concealing is possible at the cost of additional complications, but without much change in intuition. This assumption skews the manager against concealing. Because we find that with stock-based compensation concealing is widespread, adding the outside option even after (being caught) concealing would just make it even more frequent.[18]

Finally, to ensure that $E[\int_0^{\infty} e^{-rt} w_t dt]$ is finite, we must assume that $r + \lambda > B^b$ and $r > B^a$. That is, the compensation does not grow at a higher rate than the cost of capital.

PROPOSITION 11. The incentive compatibility constraints are satisfied iff the following constraints are met:

(43) (Reveal at τ^*)

$$A_a \geq A_b \frac{(\beta - B_a)}{(\beta - B_b)} \left(1 - e^{-(\beta - B_b)h^{**}}\right);$$

$$(B_a + C_a) \geq B_b;$$

(44) (High effort before τ^*)

$$A_a \leq A_b \frac{(\beta - B_a)}{(\beta - B_b)} \left(1 - \frac{c^H(\beta + \lambda^L - B_b)}{[\lambda^L - \lambda^H]}\right);$$

$$B_b \geq (C_a + B_a);$$

18. Although we did not mention any outside option in preceding sections, as the compensation was assumed exogenous, it is necessary here to ensure that the manager has a positive lower bound to his or her payment (the firm has all the bargaining power). The analysis here is nonetheless consistent with the previous one so long as B_O is small enough, and the free parameter η is set to equalize the manager's expected utility at time 0 with the value of the outside option.

(45) (Outside option)

$$\left[A_b\left(1-c^H\right)+\frac{\lambda^H A_a}{(\beta-B_a)}\right]\frac{1}{(\beta+\lambda^H-B_b)}\geq A_O;$$

$$B_b \geq B_O;$$

(46) $$\frac{A_a}{\beta-B_a}\geq A^O;\quad C_a\geq 0;\quad B_a\geq B_O.$$

Subject to these constraints, the firm then minimizes

$$V=E\left[\int_0^{\infty}e^{-rt}w_t dt\right]=\left[A_b+\frac{\lambda^H A_a}{(r-B_a)}\right]\left[\frac{1}{(r+\lambda^H-B_b)}\right].$$

Constraint (43) shows that after τ^*, the level A_a of the compensation has to be above some value to induce the manager to reveal the bad news. Similarly, constraint (44) shows that the level of compensation cannot be too high after τ^*; otherwise the manager prefers not to exert effort and increase his or her payoff sooner. These two constraints combined imply that $B_a + C_a = B_b$ and

$$A_b\frac{(\beta-B_a)}{(\beta-B_b)}\left(1-\frac{c^H(\beta+\lambda^L-B_b)}{(\lambda^L-\lambda^H)}\right)$$
$$\geq A_a \geq A_b\frac{(\beta-B_a)}{(\beta-B_b)}\left(1-e^{-(\beta-B_b)h^{**}}\right).$$

This last constraint determines a feasibility region for A_a. This region is not empty iff the cost to exert high effort is below a threshold:

$$c^H\leq\frac{[\lambda^L-\lambda^H]e^{-(\beta-B_b)h^{**}}}{(\beta+\lambda^L-B_b)}.$$

Because the right-hand side is increasing in B_b, this constraint implies a lower bound on the growth rate of the CEO compensation before τ^*. We further discuss the properties and the intuition of the optimal contract in our calibration analysis in Sections V.B and V.C. There we also compare the stock-based compensation to the optimal contract and illustrate how the optimal contract can be approximated by using an appropriate stock-plus-bonus compensation. It is worth emphasizing immediately, however, that because of the simplicity of the model, we are able here to make the contract only contingent on time t and τ^*. This is useful to gauge the characteristics of the contract. In its implementation, however, one must use a better proxy than t for the firm's growth. We return to this issue below.

TABLE I
PARAMETER VALUES

Cost of capital	r	8%	Return on capital	z	16%
High growth rate	G	7%	CEO discount rate	β	18%
Low growth rate	g	1%	Expected τ^* (high effort)	$E[\tau^* \mid e^H] = 1/\lambda^H$	15 years
Depreciation rate	δ	1%	Expected τ^* (low effort)	$E[\tau^* \mid e^L] = 1/\lambda^L$	2 years
Minimal capital level	ξ	90%	CEO cost of effort	c^H	5%

V. QUANTITATIVE IMPLICATIONS

In this section we examine when stock-based compensation generates a high effort/conceal equilibrium. For comparison, and to pave the way for the discussion of the optimal contract in Section V.C, we also consider the equilibrium induced by a cash flow–based (bonus) type of contract discussed in Section IV.E. The base parameter values are in Table I.

Figure V shows the partition of the parameter space of (z, G) into regions corresponding to various equilibria.[19] 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 a cash-flow (bonus) type of contract achieves the first best, as in this case he or she also reveals the bad news to investors, and maximizes firm value. This region consists of firms characterized by high returns on 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 bonus compensation no longer induces high effort, whereas stock-based compensation does, although in a conceal equilibrium. This is indeed the most interesting region, where we observe a trade-off between effort inducement and truth-telling inducement. 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, whereas cash flow–based bonus compensation still induces a low effort equilibrium. This is a region where a stock-compensated manager would prefer to conceal if he or she chose high effort, but would no longer choose high effort if he or she

19. Online Technical Appendix B shows that stock-based compensation indeed induces a conceal equilibrium for most parameter values in the spaces (g, G) and $(E[\tau], G)$ as well. The implications are similar and omitted for brevity.

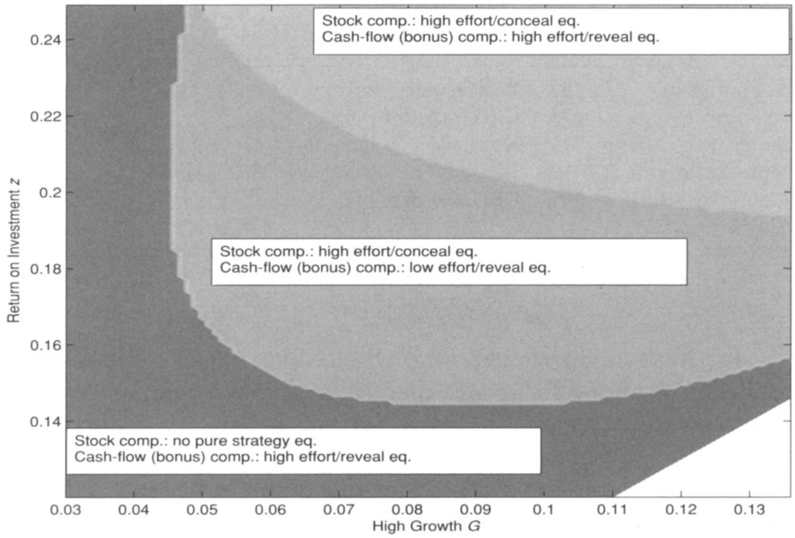

FIGURE V

Equilibrium Areas under Stock-Based Compensation and Cash Flow–Based Compensation

In the (z, G) space, the figure shows the areas in which the following equilibria are defined: (a) the high effort/reveal equilibrium under dividend-based compensation; (b) the low effort/reveal equilibrium under dividends-based compensation; and (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 25%, whereas G ranges between 3% and 14%. The remaining parameters are in Table I.

concealed. 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 these 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.

V.A. *High Effort or Truthful Revelation?*

The preceding section shows a large area in the parameter space in which a high effort/conceal equilibrium and a low effort/reveal equilibrium may coexist. 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.

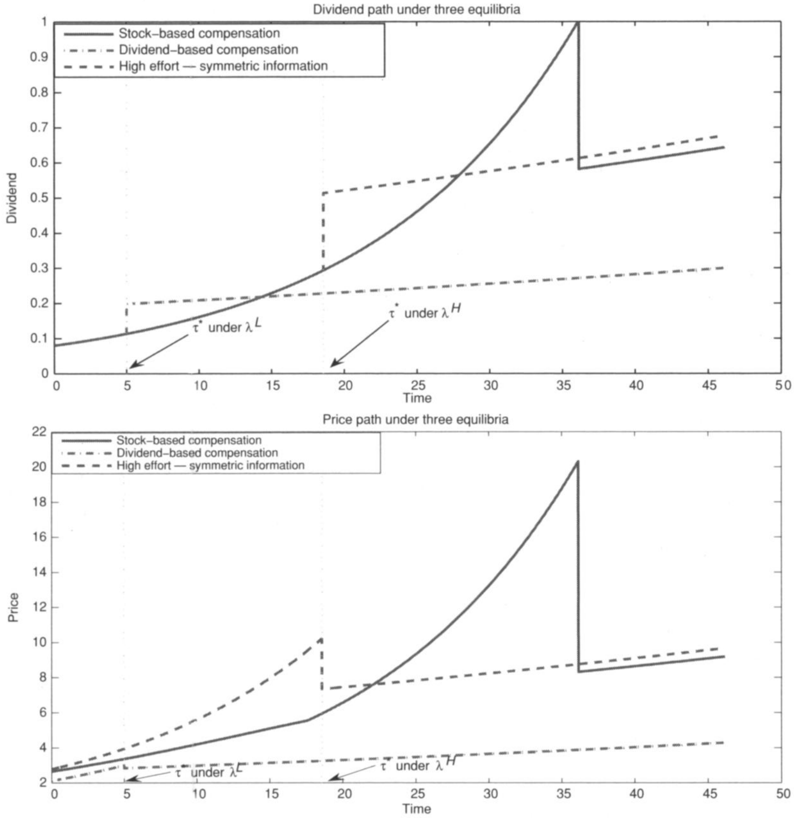

FIGURE VI
Dividend and Price Paths in Three Equilibria

The figure plots hypothetical dividend (top panel) and price (bottom panel) paths in the cases of "stock-based compensation" (solid line); "dividend-based compensation" (dotted line); and the first best benchmark case with symmetric information and optimal investment (dashed line). Parameter values are in Table I.

To illustrate the trade-off, Figure VI plots the hypothetical price and dividend paths under the high effort/conceal and low effort/reveal equilibriua. For comparison, it also reports the first best, featuring high effort and the optimal investment after τ^*. As shown in Corollary 3, the low effort/reveal equilibrium induced, for instance, by a flat wage or cash flow–based (bonus) compensation may induce too low an effort, and this loss outweighs the benefits of optimal investment behavior at τ^*. The high effort/conceal equilibrium, induced by stock-based compensation, in contrast, gets closer to the first best, yet also leads to suboptimal investment behavior, which generates the bubblelike pattern in dividend payouts and prices.

To gauge the size of the trade-off between the two equilibria under various parameter choices, Table II reports the firm value at time $t = 0$, $P_{\mathrm{ai},0}$, and $P_{\mathrm{fi},0}^{\mathrm{before}}$, 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 high effort/conceal equilibrium (column (3)) and at τ^* in the low effort/reveal equilibrium (column (5)). Online Technical Appendix A 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 I. The last two columns report the value and the expected decline in the first-best case.

Panel A of Table II shows that even when the high growth rate G is relatively low, $G = 6\%$, the high effort/conceal equilibrium achieves a higher firm value ($P_{\mathrm{ai},0} = 2.48$) than the low effort/reveal equilibrium ($P_{\mathrm{fi},0}^{\mathrm{before}}(\lambda^L) = 2.10$), even though the former equilibrium induces a substantial expected market crash $E[P_{T^{**}}/P_{T^{**}_-} - 1] = -51.49\%$ at T^{**}, against a milder decline of only $E[P_{\tau^*}/P_{\tau^*_-} - 1] = -4.59\%$ in the latter case. The last two columns show that the first best achieves an even higher firm value, $P_{\mathrm{fi},0}^{\mathrm{before}}(\lambda^H) = 2.58$, although this value is not so much higher than the one under asymmetric information. Note that even in the first-best case there is a market decline at revelation (-22.38%), although it is far smaller than in the asymmetric information case.

The remainder of Table II (Panels B–F) shows that a similar pattern is realized for a wide range of parameter choices.[20] 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 $E[\tau^*|e^L]$ is as high as eight years, a similar result applies, as $P_{\mathrm{fi},0}^{\mathrm{before}}(\lambda^L)$ is always lower than $P_{\mathrm{ai},0}$. Panel C shows that a higher return on investments z leads to an increase in prices (across equilibria) and a mild decline in the size of the crash at T^{**} for the asymmetric information case. Panel D shows that the 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 that on the

20. In Panels B and F we set the cost $c^H = 2\%$ instead of $c^H = 5\%$ assumed throughout to ensure that all three equilibria exist under the parameter choices in column (1).

TABLE II
HIGH EFFORT OR TRUTHFUL REVELATION?

	High effort/conceal eq.		Low effort/reveal eq.		High effort/reveal eq.	
Panel A: Investment opportunities growth						
G	$P_{\text{ai},0}$	$E[\frac{P_{T^{**}}}{P_{\underline{T}^{**}}}-1]$	$P_{\text{fi},0}^{\text{before}}(\lambda^L)$	$E[\frac{P_{\tau^*}}{P_{\underline{\tau}^*}}-1]$	$P_{\text{fi},0}^{\text{before}}(\lambda^H)$	$E[\frac{P_{\tau^*}}{P_{\underline{\tau}^*}}-1]$
6.00%	2.48	−51.49%	2.10	−4.59%	2.58	−22.38%
8.00%	2.85	−66.24%	2.14	−6.54%	3.05	−34.42%
10.00%	3.48	−78.99%	2.19	−8.57%	3.93	−49.08%
Panel B: Expected τ_L under low effort						
$E[\tau_L]$	$P_{\text{ai},0}$	$E[\frac{P_{T^{**}}}{P_{\underline{T}^{**}}}-1]$	$P_{\text{fi},0}^{\text{before}}(\lambda^L)$	$E[\frac{P_{\tau^*}}{P_{\underline{\tau}^*}}-1]$	$P_{\text{fi},0}^{\text{before}}(\lambda^H)$	$E[\frac{P_{\tau^*}}{P_{\underline{\tau}^*}}-1]$
4.00	2.65	−59.11%	2.23	−10.34%	2.78	−28.12%
6.00	2.65	−59.11%	2.34	−14.51%	2.78	−28.12%
8.00	2.65	−59.11%	2.44	−18.18%	2.78	−28.12%
Panel C: Return on investment						
z	$P_{\text{ai},0}$	$E[\frac{P_{T^{**}}}{P_{\underline{T}^{**}}}-1]$	$P_{\text{fi},0}^{\text{before}}(\lambda^L)$	$E[\frac{P_{\tau^*}}{P_{\underline{\tau}^*}}-1]$	$P_{\text{fi},0}^{\text{before}}(\lambda^H)$	$E[\frac{P_{\tau^*}}{P_{\underline{\tau}^*}}-1]$
16.00%	2.65	−59.11%	2.12	−5.55%	2.78	−28.12%
18.00%	3.19	−57.52%	2.44	−6.21%	3.29	−30.56%
20.00%	3.71	−56.26%	2.76	−6.71%	3.80	−32.35%
Panel D: Shareholders' discount rate						
r	$P_{\text{ai},0}$	$E[\frac{P_{T^{**}}}{P_{\underline{T}^{**}}}-1]$	$P_{\text{fi},0}^{\text{before}}(\lambda^L)$	$E[\frac{P_{\tau^*}}{P_{\underline{\tau}^*}}-1]$	$P_{\text{fi},0}^{\text{before}}(\lambda^H)$	$E[\frac{P_{\tau^*}}{P_{\underline{\tau}^*}}-1]$
7.00%	3.38	−60.66%	2.49	−6.42%	3.53	−33.96%
8.00%	2.65	−59.11%	2.12	−5.55%	2.78	−28.12%
9.00%	2.15	−57.89%	1.84	−4.71%	2.26	−22.88%
Panel E: Depreciation rate δ						
δ	$P_{\text{ai},0}$	$E[\frac{P_{T^{**}}}{P_{\underline{T}^{**}}}-1]$	$P_{\text{fi},0}^{\text{before}}(\lambda^L)$	$E[\frac{P_{\tau^*}}{P_{\underline{\tau}^*}}-1]$	$P_{\text{fi},0}^{\text{before}}(\lambda^H)$	$E[\frac{P_{\tau^*}}{P_{\underline{\tau}^*}}-1]$
0.00%	2.92	−58.69%	2.28	−5.90%	3.04	−29.44%
1.00%	2.65	−59.11%	2.12	−5.55%	2.78	−28.12%
2.00%	2.37	−59.58%	1.96	−5.15%	2.53	−26.53%
Panel F: Minimum capital requirement ξ						
ξ	$P_{\text{ai},0}$	$E[\frac{P_{T^{**}}}{P_{\underline{T}^{**}}}-1]$	$P_{\text{fi},0}^{\text{before}}(\lambda^L)$	$E[\frac{P_{\tau^*}}{P_{\underline{\tau}^*}}-1]$	$P_{\text{fi},0}^{\text{before}}(\lambda^H)$	$E[\frac{P_{\tau^*}}{P_{\underline{\tau}^*}}-1]$
60.00%	2.64	−66.70%	2.11	−5.55%	2.78	−28.12%
70.00%	2.64	−64.35%	2.11	−5.55%	2.78	−28.12%
80.00%	2.64	−61.85%	2.11	−5.55%	2.78	−28.12%

Notes. Column (1) reports the value of the parameter that is changed from its base value in Table I. 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. Columns (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, for example, by flat wage compensation or cash flow–based (bonus) compensation. The last two columns report the same quantities under the high effort/reveal equilibrium induced by the optimal contract. Panels B and F use $c^H = 2\%$ instead of $c^H = 5\%$ to ensure that all three types of equilibria exist under the parameters in column (1).

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, 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^{**}.[21]

The results in Table II highlight that if the shareholders' choice is between a contract that induces a low effort/reveal equilibrium and one that induces a high effort/conceal equilibrium, they should choose the latter, as firm value is much higher in this case and in fact rather close to the first-best high effort/reveal equilibrium. This finding may also explain why stock-based compensation is so widespread in the real world: If there is any difficulty in implementing an optimal contract that induces the first best, then a simple stock-based compensation achieves a second best that is not too far from the first best, as can be seen by comparing the value of the assets in columns (2) and (6) of Table II. Erring on the side of inducing truth revelation but low effort, instead, has a much worse impact on the value of the firm than erring on the side of providing incentives to increase investment opportunities.

V.B. *The Optimal Contract*

What does the optimal contract look like? Figure VII compares the optimal contract established in Section IV.G to the stock-based compensation, for a hypothetical realization of τ^*, under the assumption that at τ^* there is full revelation in both cases. This is the relevant scenario to understand why the CEO is reluctant to reveal information under stock-based compensation. The figure contains six panels: The left hand–side panels plot the optimal contract (dashed line) and the stock-based contract. Each of the three panels corresponds to a different level of the cost of effort c^H. In all cases, the payoffs have been scaled to ensure that the CEO receives the same expected utility at time 0. Of course, the optimal contract is cheaper for the firm, as it minimizes the

21. We note that some parameters do not affect the comparative statics: for instance, the manager discount rate β or the cost of effort c^H affects only whether a conceal equilibrium or reveal equilibrium is obtained. But because the CEO strategy conditional on concealing is just to push the time of cash shortfall T^{**} as far into the future as possible, the latter depends only 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.

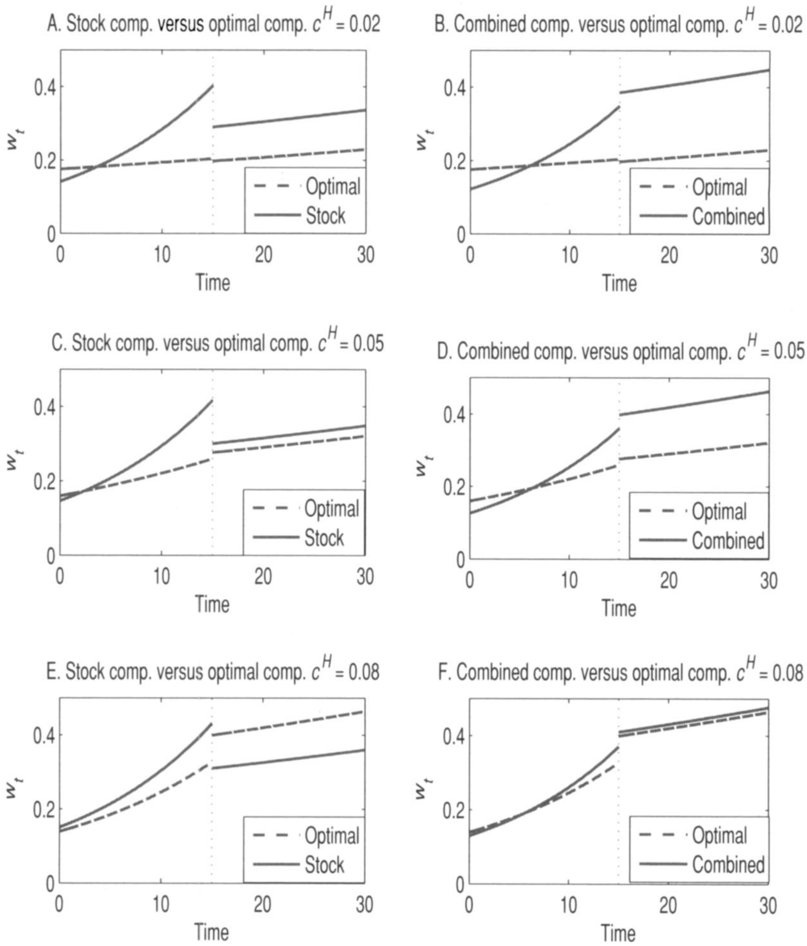

FIGURE VII

Optimal Contract versus Stock-Based Compensation

The figure plots compensation paths under the optimal contract and simple stock-based compensation (left panels) and a combined compensation with both stocks and cash-flow (bonus) components (right panels). The vertical dotted bar corresponds to a hypothetical occurrence of τ^*. The figure reports three sets of panels, each pair corresponding to a different effort cost c^H. The remaining parameters are in Table I. The stock-based compensation and combined compensation are normalized to provide the same intertemporal utility to the CEO as the optimal contract at time 0, conditional on full revelation.

discounted expected future cash payouts. Finally, we assume the outside option has $A_O = 1$ and $B_O = 1\%$, which reflects the fact that in our baseline case in Table I the growth of the firm also shifts to $g = 1\%$ at τ^*.

It is convenient to start from the middle panel (Panel C) which contains our base case $c^H = 5\%$ (see Table I). We see two noteworthy features of the optimal contract: First, the payoff to the manager is increasing over time, and it jumps up at τ^* upon revelation. The latter discrete increase is a bonus compensation that the manager must receive to provide the incentive to reveal the bad news about investment opportunities. Because the manager must be compensated for telling when τ^* occurs, the impatient manager has an incentive to work little in order to anticipate τ^* (which is *ex post* observable) as much as possible. An increasing payoff provides the incentive to the manager to push τ^* into the future.

These characteristics of the optimal contract, namely, an increasing pattern plus a bonus to reveal bad news, strongly contrast with the payoff implicit in stock-based compensation, which is depicted by the solid line. Indeed, the latter implies a fast-growing payoff, which provides the incentive to work hard and increase investment opportunities. At the same time, however, the payment to the CEO drops substantially at τ^* if he or she reveals the bad news about growth opportunities. That is, a stock-based contract implicitly punishes the CEO for good behavior of truth revelation. It follows that this implicit punishment provides an incentive to conceal the bad news as discussed in Section III.A

We see an additional interesting characteristics of the optimal contract by comparing Panel C with Panels A and E, which use a different effort cost c^H: The higher the effort cost c^H the stronger must be the increasing pattern in the optimal contract to ensure the manager is willing to exert high effort for longer, and thus the larger must be the bonus when he or she reveals the bad news. Indeed, when c^H is small (top panel), then the overall compensation of the manager drops at τ^*. Still, even in this case, the drop is far smaller than the one implied by the stock-based compensation.

V.C. The Stock-Plus-Bonus Contract

This discussion shows that indeed optimal compensation is in general rising over time to provide the incentive for high effort and has a bonus component to provide the incentive to reveal bad news. Whereas stock-based compensation implies a drop at τ^*, we recall from Section IV.E that a compensation $w_t = \eta_d D_t$ generates a bonus type of compensation at time τ^*. However, we also recall that this compensation has a bonus that is too generous, and thus the manager has an incentive to work less to anticipate its payment. A possibility is combining stock-based compensation with cash flow–based compensation to mimic the optimal contract, using variables that are observable in the firm.

The right hand–side panels of Figure VII report the contract obtained by combining stock-based compensation $w_t = \eta P_t$ with the cash flow–based compensation $w_t = \eta_d D_t$, where we normalize $\eta_d = \eta/(r-g)$, a value that ensures that the expected utility under stock-based and cash flow–based compensation is the same. We emphasize that we use dividend D_t to be consistent with the model, but the interpretation of D_t could also be as a cash payment over time with the same characteristics as dividends in our model, in particular, with a bonus component at revelation. We let ω be the weight on the stock-based compensation, so that the combined compensation is

$$w_t = \omega\eta P_t + (1-\omega)\eta_d D_t. \tag{47}$$

The compensation is only linked to variables in the firm, and they do not depend any more on time t, nor on τ^* itself. We must choose ω to ensure that under compensation (47) the manager has an incentive both to exert high effort *and* to reveal at τ^*. Proposition A1 in Online Technical Appendix A contains the formal conditions. We find that $\omega = 30\%$ works for all three right hand–side panels in Figure VII.[22] Consider first the base case in Panel D. In this case, the combined compensation is similar to the optimal contract, in that it implies both a rising compensation over time and a bonus at τ^*. When the cost of effort is higher, as $c^H = 8\%$ in Panel F, the match between the optimal contract and the combined stock-plus-bonus contract is very accurate. Instead, the combined compensation is not close to the optimal in the case in which the cost is small, such as $c^H = 2\%$ as in Panel B.

The stock-plus-bonus contract resembles real contracts that include golden parachutes and generous severance packages as a way of compensating the manager for revealing bad news at τ^*.

An important question pertains to the weight to give to stock in combined compensation to ensure that the manager exerts effort and reveals bad news (recall that this discussion applies also to deferred compensation; see Section IV.B). Section B.2 in the

22. Again, we rescaled η to ensure that in all cases, the expected utility at time 0 from the optimal contract and from the combined compensation is the same.

Online Technical Appendix shows that in our numerical exercises, the weight on stock ω in (47) is always below 40% for reasonable parameter values. In addition, unless the return on capital z is excessively high, we also find that ω is strictly positive, showing that some of the CEO's compensation must be in stocks to ensure high effort.

Our analysis abstracts from the costs that different incentive schemes impose on the firm itself. 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 hard to obtain. Nevertheless, 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, and comparing the value of the firm net of these costs across the various incentive schemes. Our analysis (see Section B.3 in the Online Technical Appendix), although approximate, shows that the combined optimal compensation plan discussed earlier achieves the first best without imposing too high a burden on the company.

VI. Discussion and Conclusions

Our paper contributes to the debate on executive compensation.[23] On 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 incentive to misreport the true state of the firm and in fact even to engage at times in outright fraudulent behavior. This paper sheds new light on the debate by analyzing the *ex ante* incentive problem of inducing managers to exert costly effort to maximize the firms' investment opportunities, and simultaneously inducing managers to reveal the true outlook for the firm *ex post* and follow an optimal investment rule.

We show that a combined compensation package that uses both stock-based performance and a cash flow–based bonus type of compensation reaches the first best, inducing the manager to

23. See Murphy (1999), Hall and Murphy (2003), Bebchuk and Fried (2004), Gabaix and Landier (2008), and Edmans and Gabaix (2009) for recent discussions.

exert costly effort and reveal any worsening of the investment opportunities, if it happens. Firm value is then maximized in this case. Each component (stock and bonus) 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, whereas compensating managers with bonuses when they reveal bad news about long-term growth significantly reduces their incentives to engage in value-destroying activities to support the inflated expectations. Thus, our model supports the inclusion of a golden parachute or a generous severance package in the stock-based compensation package of the CEO.

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 packages, whereas the opposite is true for low-growth firms. That is, there is no fixed rule that works for every type of firm. As a consequence, generalized regulatory decisions that ban stock-based compensation, or board of directors' decisions on CEO compensation that are based on "conventional wisdom," are particularly dangerous, as they do not consider that each firm needs a different incentive scheme.

Interestingly, our calibrated model also shows that if for any reason implementing the first-best contract is not possible, then it is better for shareholders to compensate CEOs with too much stock rather than too little. In fact, for most parameter specifications firm value under a high effort/conceal equilibrium is much closer to the first best than under a low effort/reveal equilibrium. This finding may explain the widespread use of stock-based compensation in the real world, even in situations where *ex post* it may appear that it was not optimal for shareholders. Indeed, our model helps shed light on the incentives and disincentives of CEOs when their compensation is too heavily tilted toward stock. The 1990s high-tech boom and collapse and the 2007–2008 financial-crisis offer interesting examples of the mechanism discussed in our model. The 1990s high-tech boom was characterized by expectations of high growth rates and high uncertainty, coupled with high-powered, stock-based executive compensation. Firms with high perceived 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 high-powered incentives induce the pretense of high-growth firms and lead eventually to the crash of the stock price.

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 a serious lack of transparency of banks' investment behavior (e.g., complicated derivative structures) as well as of the available investment opportunities. Moreover, banks, and especially investment banks, employ high-powered, stock-based incentives, or contracts that are effectively stock-based. 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 investors, return some 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 subprime mortgages, if the mortgage rate charged does not correspond to the riskiness of the loan.[24]

Moreover, to keep up the pretense for as long as possible, the manager also has 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 managers' investment *ex post*. Nevertheless, too little stock sensitivity has a potentially even worse effect, providing the CEO with no incentives to search for good investment opportunities.

24. Laeven and Levine (2009) provide empirical evidence that bank risk taking is positively correlated with ownership concentration. Fahlenbrach and Stulz (2009), however, conclude that bankers' incentives "cannot be blamed for the credit crisis or for the performance of banks during the crisis" (p. 18), basing their conclusion on evidence on CEOs' personal losses during the crisis. On this last point, however, see our discussion at the end of Section IV.B

Appendix

This Appendix contains only sketches of the proofs of the propositions. Details can be found in a separate Online Technical Appendix available on the authors' Web pages.

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

$$\frac{dK_t}{dt} = I_t - \delta K_t. \tag{48}$$

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 (48) the optimal investment policy is given by (8). From (7), the dividend stream is (9). QED

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

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

Proof of Corollary 2. The first part immediately follows the fact that a manager/owner values the firm as the present value of future dividends discounted at β. The second part follows from the utility of the manager at τ^* and $t < \tau^*$. First, after τ^*, there is no benefit from exerting effort. Thus the manager/owner's utility is

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

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

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

Given H^{Div} in (16), the condition $U_{\text{Div},t}(e^H) > U_{\text{Div},t}(e^L)$ translates into (38). QED

Proof of Proposition 3. As in Corollary 2, from τ^* onward the manager will not exercise high effort, resulting in a utility level at τ^* given by

$$U_{\text{Stock},\tau^*} = \int_{\tau^*}^{\infty} e^{-\beta(s-t)}(\eta P_{\text{fi},s}^{\text{after}})ds = \frac{\eta(z-g-\delta)}{(r-g)(\beta-g)}e^{G\tau^*}.$$

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

$$U_{\text{Stock},t}(e) = E\left[\int_t^{\tau^*} e^{-\beta(s-t)}(\eta P_{\text{fi},s}^{\text{before}})(1-c(e))\,ds + e^{-\beta(\tau^*-t)}U_{\text{Stock},\tau^*}\right]$$
$$= \frac{\eta e^{Gt}}{\beta+\lambda(e)-G}\left[A_\lambda^{\text{fi}}(1-c(e)) + \lambda(e)\left(\frac{z-g-\delta}{(r-g)(\beta-g)}\right)\right].$$

Let e^H be the optimal strategy in equilibrium. The price function is then $P_{\text{fi},t}^{\text{before}}$ with $A_{\lambda^H}^{\text{fi}}$. We then obtain the condition $U_{\text{Stock},t}(e^H) > U_{\text{Stock},t}(e^L)$ iff (19) holds. The Nash equilibrium follows. Similarly, if e^L is the optimal strategy in equilibrium, then the price function is $P_{\text{fi},t}^{\text{before}}$ with $A_{\lambda^L}^{\text{fi}}$. Thus, $U_{\text{Stock},t}(e^H) < U_{\text{Stock},t}(e^L)$ iff (19) does not hold. QED

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 him or her lose his or her job. Because he or she cannot affect the stock price, after τ^* his or her utility only depends on the length of his or her tenure. Because we normalize the manager's outside options to zero, his or her optimal choice is to maximize T^{**}. QED

Proof of Proposition 4. Point (1). The CEO must mimic D_t^G for as long as possible. From (7), this target determines the investments I_t (in point (2) of the proposition) and thus the evolution of capital $dK_t/dt = I_t - \delta K_t$ for given initial condition $\widehat{K}_{\tau^*}$. From the monotonicity property 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.

Point (3). At time τ^* we have $K_{\tau^*} = J_{\tau^*} = e^{G\tau^*}$, which implies $dK_t/dt|_{\tau^*} = Ge^{G\tau^*} > dJ_t/dt|_{\tau^*} = ge^{G\tau^*}$. Thus, the trajectory of capital at τ^* is above J_t. By continuity, there is a $[0, t_1]$ in which $K_t > J_t$. Solving explicitly for the capital evolution shows that as t increases, $K_t - J_t \to -\infty$. Because $K_{\tau^*+dt} - J_{\tau^*+dt} > 0$, there must be a t_1 at which $K_{t_1} - J_{t_1} = 0$. Define $h^* \equiv t_1 - \tau^*$, and substituting in $K_{t_1} - J_{t_1} = 0$, h^* must satisfy

$$(49)\quad 0 = \left(\frac{z-g-\delta}{\delta+g}\right)e^{-Gh^*}\left(e^{gh^*} - e^{-\delta h^*}\right) + \left(e^{-(\delta+G)h^*} - 1\right)\left[\frac{z-G-\delta}{\delta+G}\right].$$

For $t > t_1$, $K_t < J_t$. Solving explicitly for the capital evolution shows that $K_t - J_t$ 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^{**}:

$$(50) \qquad 0 = 1 + \left(e^{-(G-g)h^*} - 1\right) e^{(z-G-\delta)(h^{**}-h^*)} - e^{-(G-g)h^{**}}\xi.$$

QED

Proof of Proposition 5. Let $t > h^{**}$. If a cash shortfall has not been observed by t, then a shift cannot have occurred before $t - h^{**}$. Bayes' formula implies that time $T^{**} = \tau^* + h^{**}$ conditional on not observing a cash shortfall by time t has the 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 $f(T^{**}|\text{no cash shortfall by } t) = \lambda e^{-\lambda(T^{**}-t)}$. The value of $P_{\text{ai},t}$ for $t > h^{**}$ in (22) then follows from the pricing formula (21).

Let $t < h^{**}$; then the conditional distribution of T^{**} is zero in the range $[t, h^{**}]$, as even a shift at 0 would be revealed only 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

$$(51) \quad P_{\text{ai},t} = (z - G - \delta)e^{Gt}\frac{1 - e^{-(r-G)(h^{**}-t)}}{(r - G)} + e^{rt}e^{(G-r)h^{**}}A_{\lambda}^{\text{ai}}.$$

QED

Proof of Proposition 6. Let $\tau^* > h^{**}$. There are two equilibria to consider: a reveal equilibrium and a conceal equilibrium. Expressions (24), (25), and (26) contain the expected utilities at τ^* under conceal and reveal strategies in the two possible equilibria. A reveal equilibrium occurs iff $U^{\text{reveal}}_{\text{Stock},\tau^*} > U^{\text{conceal,fi}}_{\text{Stock},\tau^*}$ and a conceal equilibrium occurs iff $U^{\text{conceal,ai}}_{\text{Stock},\tau^*} > U^{\text{reveal}}_{\text{Stock},\tau^*}$. The conditions in the claim are obtained by simple substitution.

Finally, if $\tau^* < h^{**}$, then $U^{\text{conceal,ai}}_{\text{Stock},\tau^*}$ depends on the price in (51). Details are left to the Online Technical Appendix. QED

Proof of Proposition 7. Let $t \geq h^{**}$. In a conceal equilibrium with high effort, $P_{\text{ai},t}$ in (22) with $A^{\text{ai}}_{\lambda_H}$ determines the wage $w_t = \eta P_{\text{ai},t}$. Using expression (29) with $U_{\tau^*} = U^{\text{conceal,ai}}_{\text{Stock},\tau^*}$, the expected utility under effort e is

$$U_{\text{Stock},t}(e) = e^{Gt}\eta A^{\text{ai}}_{\lambda^H}\frac{\left[1-c\,(e)+\lambda\,(e)\,H^{\text{Stock}}\right]}{\beta+\lambda\,(e)-G},$$

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 $U_{\text{Stock},t}(e^H) > U_{\text{Stock},t}(e^L)$. Finally, given e^H chosen by the manager, indeed λ^H applies in equilibrium, a conceal equilibrium occurs at τ^*, and thus the price function is $P_{\text{ai},t}$ in (22), concluding the proof.

A similar proof holds for $t < h^{**}$. The expressions are in the Online Technical Appendix. QED

Proof of Propositions 8, 9, *and* 10. See the Online Technical Appendix.

Proof of Proposition 11. *a*. The two utilities under reveal and conceal strategies are

$$U^{\text{Reveal}}_{\tau^*} = \frac{A_a e^{(B_a+C_a)\tau^*}}{\beta-B_a}; \quad U^{\text{Conceal}}_{\tau^*} = A_b e^{B_b\tau^*}\frac{1-e^{-(\beta-B_b)h^{**}}}{(\beta-B_b)}. \tag{52}$$

It follows that $U^{\text{Reveal}}_{\tau^*} \geq U^{\text{Conceal}}_{\tau^*}$ for all τ^* iff conditions (43) are satisfied.

b. For $i = H, L$ and $t < \tau^*$ we can compute

$$U^i_t = \frac{A_b e^{B_b t}\left(1-c^i\right)}{\left(\beta+\lambda^i-B_b\right)} + \frac{\lambda^i A_a e^{(C_a+B_a)t}}{\left(\beta-B_a\right)\left(\beta+\lambda^i-(C_a+B_a)\right)}.$$

Tedious algebra shows that $U^H_t \geq U^L_t$ is satisfied for all t iff conditions (44) are satisfied.

c. For all t and τ^* we must have $U_t \geq U^O_t$. For $t < \tau^*$, the constraints obtained above imply that U^H_t is the relevant utility. Imposing $B_b = C_a + B_a$, $U^H_t \geq A_O e^{Bot}$ iff

$$\left[A_b(1-c^H)+\frac{\lambda^H A_a}{(\beta-B_a)}\right]\frac{e^{B_b t}}{\left(\beta+\lambda^H-B_b\right)} \geq A_O e^{Bot}.$$

This condition is satisfied for all t iff conditions in (45) are satisfied.

Similarly, for $t \geq \tau^*$ the constraints above imply that $U_t = U^{\text{Reveal}}_t$, given by (52). Thus, the outside option condition is

$$\frac{A_a}{\beta-B_a}e^{C_a\tau^*}e^{B_a t} \geq A_O e^{Bot},$$

which is satisfied for all t and τ^* iff conditions (45) are satisfied. QED

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