Product Market Competition, Incentives and Fraudulent Behavior*

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Abstract. The present paper investigates the role of product market competition in shaping incentive contracts and its effect on fraudulent behavior. We consider a framework where a manager, having private information about the company's market share, can influence the company's short-run market value exerting effort or through costly (fraudulent) signalling. We derive the optimal stock-based compensation contract which maximizes the expected long-run firm value in the presence of an imperfect monitoring technology and describe the shareholders trade-off between effort and fraud as the degree of product market competition varies.

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1 Introduction

The enormous increase in stock and stock-option based compensation experienced during the 1990s in the USA (Murphy, 1999) has initially been welcomed as a way to align managers' and shareholders' interests and to reduce agency costs (see Jensen and Meckling, 1976). Accounting scandals during the 1990s and early 2000s have brought compensation practices for CEOs under close scrutiny and stock based compensation has since been viewed as a double edged sword (Goldman and Slezak, 2006).

In this paper we study optimal incentive provision in a model where the manager can affect the firm's stock price by exerting unobservable effort and through costly, deceptive signalling. In this context, shareholders face a trade-off between effort and fraud and they may find eliminating fraudulent behavior too costly since it may curb effort. We investigate how product market competition (PMC) affects this trade-off. Common wisdom holds that competition has a positive influence on managerial behavior. While recent literature investigates the link between PMC and managerial effort (see, for example, Raith, 2003 and Vives, 2006), this literature neglects the possibility that incentives may also stimulate fraudulent behavior.

We consider a 2 period economy with a continuum of measure one of duopolistic sectors. Firm profits depend on an exogenously given industry-specific demand level, which, for simplicity, we consider to be either high or low, and which is unknown to shareholders and to the manager prior to his hiring (but private information once he got hired) and on managerial effort. The present model features both hidden action (managerial effort) and hidden information (exogenous demand shock). A manager, by exerting effort, is able to introduce quality improvements through which he can "steal" market share from others. On the other hand, he may also manipulate the company's short run stock price signalling an inflated demand level to the market, but decreasing in this way the firm's long run profits[1] . We assume that the manager pockets his compensation at the end

[1] Several paper document the negative relationship between earnings manipulation and its negative effects on the future stock price. Chan et al (2005) using accounting accruals as a proxy for the quality of reported earnings

of time 1 (that is, managers have a short time horizon) while the shareholders are paid dividends at the end of time period 2 (that is, shareholders have a long time horizon). Thus, the manager may try to manipulate the company's short term share price in order to boost his compensation at the expense of the company's long run performance.

We study incentives and fraudulent behavior as the degree of competition varies. We model PMC in a reduced form considering a business stealing effect and a rent reduction effect (see Baggs and De Bettignies, 2007 for a microfoundation). Business stealing effect is due to an increased product substitutability where the company's demand becomes more sensitive to managerial effort. The rent reduction effect, that is lower rents due to tougher competition, is modelled inversely by the degree to which firms in a sector are able to collude.

In providing incentives, shareholders face a trade-off between fraud and effort. Given that fraudulent managers face a constant expected penalty, we show that sufficiently weak incentives eliminate fraudulent behavior. Thus, shareholders are always able to enforce a separating equilibrium where managers truthfully signal the company's demand level. Enforcing a separating equilibrium may be too costly since it may provide to low incentives to exert effort. In this case a pooling equilibrium may be optimal where all managers signal a high demand level, and hence where shareholders allow for some amount of fraudulent behavior. We show that the threshold below which incentives do not lead to fraudulent behavior is increasing in the rent reduction effect of PMC and in the expected punishment. The intuition for this is that a higher expected punishment or a stronger rent reduction effect decrease the expected gains from fraudulent behavior, increasing as a consequence the region where incentives do not lead to fraudulent behavior.

We find that, given a constant business stealing effect, optimal incentives in terms of stock-based compensation are non-monotone in the strength of the rent reduction effect of PMC while

find a strong evidence of earnings manipulations in firms with the largest accruals and that accruals are negatively related to future stock market returns. Teoh, Welch and Wong (1998a) show how issuers of initial public offerings (IPOs) with unusually high accrual in the year of issue experience poor stock performance in the subsequent three years. Teoh, Welch and Wong (1998b) provide evidence that pre-issue earnings management by seasoned equity issuers, as reflected in discretionary accruals, explains future underperformance in stock returns. See also Jensen (2003).

equilibrium fraudulent behavior decreases as the rent reduction effect increases. This leads to a non-monotone relationship between incentives and fraudulent behavior. Consequently, it may happen that strong incentives do not lead to fraudulent behavior if these are associated with a sufficiently strong PMC while the same or weaker incentives lead to fraudulent behavior if PMC is sufficiently weak. Moreover, the non-monotone relationship between rent reduction effect of PMC and incentives implies that even in the absence of a business stealing effect, stronger PMC may lead to stronger incentives. The intuition for this result is the following. For a weak rent reduction effect, that is a large price-cost margin, effort is very important for the firm profits and hence shareholder provide strong incentives and tolerate some amount of fraudulent behavior. Increasing PMC, i.e. increasing the rent reduction effect, decreases the costs of enforcing a separation equilibrium since effort becomes less important, fraudulent behavior in equilibrium decreases and the threshold below which incentives do not lead to fraudulent behavior increases. Thus, for intermediate values of PMC it becomes optimal to enforce a separation equilibrium, that is to choose weak incentives in order to eliminate fraudulent behavior. Further increases in PMC now lead to an increase in incentives (without an increase in fraudulent activity) since the threshold which enforces the separation equilibrium is increasing in PMC.

We investigate also the role of business stealing effect of PMC on incentives and fraudulent behavior. We find that an increase in the business stealing effect leads to stronger incentives and more fraudulent behavior in equilibrium. The intuition is straightforward. As the business stealing effect increases so does the importance of managerial effort for the firm's performance and thus shareholders more willingly accept some fraudulent behavior.

We also investigate the role of the monitoring technology and find that if PMC is sufficiently weak, then optimal incentives are V-shaped in the manager's expected penalty. Strong incentives do not lead to fraudulent behavior if these are associated with a large expected penalty for the manager while the same incentives or even weaker one may lead to fraudulent behavior if the expected penalty is sufficiently low.

The paper contributes to the literature on PMC and managerial incentives[2] and to the literature on managerial incentives and fraudulent behavior[3] . In models investigating the relationship between PMC and managerial incentives, incentives of shareholders translate monotonically, via the incentive scheme of the manager, into the manager's incentives. We show that if fraudulent behavior is taken into account, then market driven incentives of shareholders are translated non-monotonically into managerial incentives. Moreover, we find that even in the absence of a business stealing effect, stronger PMC may lead the shareholder to provide the manager with stronger incentives. The literature on incentives and fraudulent behavior argues that the stronger are the incentives, the higher is the probability of observing fraudulent behavior, (Goldman and Slezak, 2006). We show that, once PMC is taken into account, a non-monotone relationship between incentives and fraudulent behavior exists. Stronger incentives may not lead to fraudulent behavior if PMC is sufficiently strong, while weaker incentives may lead to fraudulent behavior if PMC is weak.

The remaining part of the paper is organized as follows. In Section 2 we review the related literature. In Section 3 we introduce the model. In Section 4 we solve the model for the optimal incentive contract and state the main results of the paper. Section 5 investigates the role of monitoring technology. Section 6 concludes. All proofs are in the Appendix.

2 Related Literature

The present paper bridges two strands of literature. The first one investigates the relationship between competition and incentives while the second one investigates the relationship between incentives and fraudulent behavior.

Theoretical work on the relationship between product market competition and managerial incentives hints to an ambiguous relationship. Raith (2003) and Vives (2006) show that results vary

[2] See, for example, Hart (1983), Scharfstein (1988), Hermalin (1992), Schmidt (1997), Raith (2003), Baggs and De Bettignies (2007), Vives (2006), Beiner, Schmid and Wanzenried (2005), Graziano and Parigi (1998).

[3] See, for example, Goldman and Slezak (2006), Bebchuk and Bar-Gill (2003), Philippon and Kedia (2007), Crocker and Slemrod (2007), Povel, Sing and Winton (2007).

depending on the source of the variation in the degree of competition and also on the exogeneity or endogeneity of the industry structure. Raith (2003) considers a model of process innovation where the market structure is determined by free entry and exit of firms and where greater product substitutability, larger market size and lower entry costs imply more PMC. The author shows that more product substitutability and larger market size increase firm-level output and hence incentive provision, while lower entry costs reduce firm-level output and hence lead to lower incentive provision. Similar results are obtained in Vives (2006) who considers a general, reduced form model of product and process innovation with Bertrand and Cournot competition. Schmidt (1997) analyses the threat-of-liquidation effect of competition on managerial incentives. The threat-of-liquidation effect corresponds to a reduction in the cost of implementing a higher effort level as competition gets tougher. A second effect is related to the value of innovation: more competition reduces profits and possibly the benefits of inducing a higher level of effort leading, in general, to an ambiguous relationship between managerial incentives and PMC[4] . Baggs and De Bettignies (2007) propose a simple duopoly model where firms compete in quality and price and where competition is measured by the degree of substitutability between products. Increasing competition (i.e. the degree of product substitutability) in their model has two effects. Firstly, it increases the demand elasticity and thus the market share a company can "steal" from the other through quality improvements (business stealing effect). Secondly, it decreases the price-cost margin (rent reduction effect). While the former has a positive effect on incentive provision the latter has a negative effect. Moreover, if agency costs are present, both effects lead to a reduction in the firms' marginal costs of eliciting effort from agents. Since the theoretical model predicts an ambiguous result the authors test the model empirically and find that competition does have a positive direct pressure effect which is reinforced if agency costs are present. The effects of competition on the informational structure of the agency problem and hence on managerial incentives have been investigated by Hart (1983), Scharfstein (1988) and Hermalin (1992) showing

[4] See Funk and Wanzenried (2003) for an empirical implementation of the model.

an ambiguous relationship between competition and incentives.

A number of empirical papers investigate the relationship between PMC and incentives. Nickell (1996), studying a panel of 670 U.K. manufacturing companies, finds that lower monopoly rents and an increased number of competitors are associated with higher rates of total factor productivity growth. Cuñat and Guadalupe (2005) exploit the quasi-natural experiment of the Pound Sterling appreciation in 1996 to investigate the effect of an exogenous variation of competition on incentives. They find that competition increases the steepness of performance-related pay. Cuñat and Guadalupe (2004) use the deregulation of the banking and financial sectors in the 1990s as a quasi-natural experiment and find similar results. Karuna (2007) investigates the relationship between total equity incentives and a multi-dimensional characterization of competition, encompassing product substitutability, market size and entry costs, finding a positive relationship between PMC and managerial incentives. Santalo (2002) finds a negative correlation between the number of competitors and incentives. This result is difficult to interpret if market structure is endogenous (see Raith, 2003 and Vives, 2006). Kedia (2006) focuses on the type strategic interaction among firms (i.e. strategic complements vs strategic substitutes) and its interaction with CEO pay-for-performance incentives.

Incentives as a double-edged sword are modelled in Goldman and Slezak (2006) where it is shown that potential for information manipulation affects the equilibrium level of pay-for-performance sensitivity. The authors consider a principle/agent model with hidden action (unobservable effort) and study the "signal jamming" equilibrium whereby an agent takes a costly action that is intended to mislead but actually misleads no one in equilibrium. In their model without "naive investors" the firm value is adjusted to fully correct for the extent of the bias in the manipulated information, while "naive investors" are needed to generate fluctuations in the stock price.

Our paper is most closely aligned with Crocker and Slemrod (2007) who study a model where a manger's hidden action affects firm profits and where realized profits are hidden information known only to the manager. The authors show that compensation contracts contingent on reported earnings cannot provide managers with the incentive both to maximize profits and to report those profits honestly.

The real costs of fraudulent accounting in terms of investment and employment are studied in Philippon and Kedia (2007). The authors find that during periods of fraudulent behavior, firms invest and hire more than comparable matched firms.

Povel, Sing and Winton (2007) study in a model of financing and investment equilibrium fraud and monitoring decision. The authors show that incentives to commit fraud are highest towards the end of booms and that this link becomes stronger as monitoring costs decrease.

Several empirical studies try to relate pay-performance sensitivity with fraudulent behavior. Erickson, Hanlon and Maydew (2006) study a sample consisting of 50 firms accused of accounting fraud by the SEC during January 1996 to November 2003 and compare the fraud firms with a matched and unmatched sample of firms to examine whether executive equity incentives are positively associated with accounting fraud. The authors find that controlling for corporate governance, the desire for external financing, financial performance and firm size, this association becomes insignificant. Burns and Kedia (2005) comparing earning restatements of 215 firms with a control sample of firms matched by industry and size find that equity, restricted stock and LTIP do not have any significant impact on the propensity and magnitude to misreport but find strong evidence that higher incentives from stock options are associated with a higher propensity to misreport and also with a higher magnitude of misreporting. Bergstresser and Philippon (2005) consider accruals-based measures of earnings management and find that periods of high accruals coincide with unusually large options exercise of CEOs and with sale of large quantities of shares by other insiders. Gao and Shrieves (2002) investigate the relationship between earnings management intensity, as measured by the absolute value of discretionary current accruals scaled down by asset size, and managers' compensation package. They find a positive relationship between earnings management and stock option based compensation, while they find a weaker support for a positive association between earnings management and restricted stock study a sample of firms subject to SEC's Accounting and Auditing Enforcement Releases (AAER). The authors find that executives at fraud firms face significantly greater financial incentives stemming from stock and options holdings. Moreover they find that during the fraud period, executives exercise also a larger fraction of vested options than do executives at control firms.

3 The model description

We consider a two period model, where time 1 is the short run and time 2 the long run.

Firms are run by managers. Each firm issues one share and all earnings are paid out as dividends at the final date. We consider a continuum of measure one of sectors and a continuum of measure two of identical managers. In each sector two firms produce a homogeneous good, employing the same technology with unit costs β. Given the unit production cost β and p^j the price of good j, we define $\varepsilon^j \equiv \frac{1}{2}\frac{p^j-\beta}{p^j}$, $\varepsilon^j \in \left(0, \frac{1}{2}\right)$. Following Aghion et al. (2005), we model the degree of product market competition inversely by the degree to which the two firms in a sector are able to collude. For $\varepsilon^j = 0$ the two firms are unable to collude and thus Bertrand competition drives profits to zero, while the larger is ε^j, the weaker is the competition between the two firms.

We assume that a firm's market share depends on exogenous as well as endogenous factors. In particular, we assume that managerial effort may lead to quality improvements which in turn lead to increases in the company's market share. We assume that demand of firm i of sector j is $q_i^j = \frac{1}{2}\frac{\phi_i^j}{\phi}\frac{R}{p^j}$ for $i = 1, 2$ and $j \in [0, 1]$, where $\frac{\phi_i^j}{\phi}R = \theta^j + \left(e_i^j - \overline{e}\right)\eta$ and R is aggregate income. θ^j is an exogenous sectoral demand shock, which takes value θ^H with probability $\frac{1}{2}$ and θ^L with probability $\frac{1}{2}$, where $2\theta^L > \theta^H > \theta^L$ and $\frac{1}{2}\left(\theta^H + \theta^L\right) = R$. e_i^j denotes managerial effort of the manager of company i of sector j, $\overline{e}$ is the average managerial effort, where the average is taken over all firms in the economy and η the impact of managerial effort on the firm's market share. We implicitly assume that managerial activity has no direct spill-over effect on other firms and in particular on the rival firm of the same sector. There still exists an indirect effect through the average effort level.

Demand of companies producing good j may be either low or high according to the realization of θ^j and may be affected by managerial effort. We assume that θ^j is unknown to the company and to the manager prior to his hiring. η is a "business stealing" parameter indicating the manager's ability to increase the firm's market share at the expense of other firms.

Without loss of generality we assume that $\varepsilon^j = \varepsilon$ for each $j \in [0,1]$. True firm profits can be written as

$$\pi = \varepsilon \left[\theta^j + (e - \overline{e})\,\eta\right] - W\,(S) \quad \text{for} \;\; j \in \{H, L\} \tag{1}$$

where $W\,(S) = \omega_0 + \omega_1 S$ is the manager's compensation package, being a function of the company's stock price S. Given that there is a continuum of measure one of sectors in the economy we exclude the possibility that firms choose managerial incentives in a cooperative way. We also exclude the possibility of whistle blowing within each sector.

Variations in ε represent the rent reduction effect of competition while variations in η represent the business stealing effect of competition. An increased PMC reduces the price-cost margin and hence ε (rent reduction effect). At the same time, an increase in PMC may also lead to an increase in the degree of product substitutability and hence to an increase in the impact of quality improvements on the company's market share η (business stealing effect, see Baggs and Bettignies, 2007)[5] . We are interested in how parameters (ε, η) affect the shareholders' decision of optimal incentive provision.

3.1 Information, signals and timing

The timing is as follows. At the beginning of time period 1 the company offers the manager a compensation package (ω_0, ω_1). The manager accepts the contract if he obtains a positive utility across all possible states of nature. Since all mangers are offered the same contract and no one has private information about θ^j, managers are randomly matched with firms. After having accepted

[5] The linear formulation of the business stealing effect in (1) can be interpreted as a first order approximation of a more general model where second order terms have been neglected.

the contract the manager learns θ^j, chooses effort e and a signal $x \in \left\{\theta^H, \theta^L\right\}$ whose cost we normalize for simplicity to $c^j(x) = x - \min\left\{\theta^j, x\right\}$. A truthful signal is costless $c^i\left(\theta^i\right) = 0$ for $i \in \left\{\theta^H, \theta^L\right\}$, while an untruthful signal is costly $c^L\left(\theta^H\right) = \theta^H - \theta^L \equiv \Delta$. Note that all managers are offered the same incentive contract and hence exert the same effort. At the end of time 1 the executive pockets his compensation. Managers of a $L-$type company may have an incentive to pool with a $H-$type company. Pooling occurs if a manager of a $L-$type firm signals the same sales as a $H-$type firm, inflating in this way the short run stock price at the cost of a reduced long run stock price. In particular, a manager signalling untruthfully high sales benefits at time 1 from the same stock price as a $H-$type company, while at time 2 the company's profits will be reduced because of the costly signal. At time 2 products are sold and dividends are paid to shareholders.

We assume rational expectations and rational inference, that is Bayes' law, and normalize the risk free interest rate to zero. Moreover, we assume that both shareholders and managers are risk neutral and that managers are effort averse.

3.2 Asset prices

Given that the company signals high sales $x = \theta^H$, that, in equilibrium, a fraction $\lambda > 0$ of executives managing a $L-$type company signal high sales and using Bayes' law, the asset price at time 1 is

$$S^P \equiv E\left(\pi \left| x = \theta^H, \lambda\right.\right) = \varepsilon\left[\frac{\lambda}{1+\lambda}\left(\theta^L - \Delta\right) + \frac{1}{1+\lambda}\theta^H + (e - \overline{e})\,\eta\right] - \omega_0 - \omega_1 S^P$$

which, after rearranging terms, reads as

$$S^P = (1-\alpha)\left\{\varepsilon\left[\frac{\lambda}{1+\lambda}\left(\theta^L - \Delta\right) + \frac{1}{1+\lambda}\theta^H + (e - \overline{e})\,\eta\right] - \omega_0\right\} \tag{2}$$

where $\alpha = \frac{\omega_1}{1+\omega_1}$. Note that α is increasing in ω_1 and therefore we will consider α as a proxy for the pay-for-performance sensitivity.

Given that a manager at time 1 signals low sales ($x = \theta^L$), the asset price at time 1 is

$$S_{L,L} \equiv E\left(\pi_2 \left| x = \theta^L \right.\right) = \varepsilon \left[\theta^L + (e - \overline{e})\,\eta\right] - \omega_0 - \omega_1 S_{L,L}$$

which, after rearranging terms, reads as

$$S_{L,L} = (1-\alpha)\left\{\varepsilon\left[\theta^L + (e-\overline{e})\,\eta\right] - \omega_0\right\} \tag{3}$$

If $\lambda = 0$, then no pooling occurs; for $\lambda > 0$ we have that the market undervalues $H-$type companies while it overvalues some $L-$type companies.

3.3 Optimal effort and the equilibrium level of fraud

Manager's expected utility function is

$$E\left(U\left(S\right)\right) = \omega_0 + \omega_1 E\left(S\right) - \frac{1}{2}e^2 \tag{4}$$

All managers in equilibrium are offered the same contract (ω_0, ω_1). A manager of an $i-$type firm mimicing a $j-$type firm obtains an expected utility $E\left(U_{i,j}\right)$. Substituting (2) and (3) into (4) we have

$$E\left(U_{L,H}\right) = E\left(U_{H,H}\right) = (1-\alpha)\,\omega_0 + \alpha\varepsilon\left[\frac{\lambda}{1+\lambda}\left(\theta^L - \Delta\right) + \frac{1}{1+\lambda}\theta^H + (e-\overline{e})\,\eta\right] - \frac{1}{2}e^2 \tag{5}$$

and

$$E\left(U_{L,L}\right) = (1-\alpha)\,\omega_0 + \alpha\varepsilon\left[\theta^L + (e-\overline{e})\,\eta\right] - \frac{1}{2}e^2 \tag{6}$$

Managers choose effort maximizing expected utility. From (5) and (6), optimal effort is $e^* = \alpha\varepsilon\eta$. Thus, the stronger are the incentives provided by the company (α), the stronger will be the effort. Moreover, stronger PMC reduces, due to the rent reduction effect, effort, while it increases effort due to the business stealing effect.

A manager caught signalling fraudulently high sales suffers a punishment whose expected value we assume to be $\gamma > 0$. The equilibrium value λ is given by

$$E\left(U_{L,H}\right) - \gamma = E\left(U_{L,L}\right) \tag{7}$$

Using (5) and (6), (7) yields the equilibrium level of fraud

$$\lambda = \max\left\{\frac{\alpha\varepsilon\Delta - \gamma}{\alpha\varepsilon\Delta + \gamma}, 0\right\} \tag{8}$$

λ is increasing in α and ε and decreasing in γ. Thus, as PMC and/or the expected punishment increase, the equilibrium level of fraud decreases. The intuition for this is straightforward. A stronger PMC, lower incentives or a higher expected punishment decrease the expected gains from fraudulent behavior, reducing fraudulent behavior in equilibrium. Moreover, by choosing a sufficiently low value of α, the company is always able to induce a separating equilibrium. Enforcing a separating equilibrium may be too costly since a low α leads to a low effort level. Note that λ is unaffected by managerial effort since managers exert the same amount of effort independently of their signalling choice (i.e. the firm's profit function is assumed to be linear in managerial effort). Hence, λ depends only on the rent reduction effect of PMC. Consequently, while stronger PMC may have an ambiguous effect on effort, it unambiguously decreases fraud. For $\alpha \leq \frac{\gamma}{\varepsilon\Delta}$, $\lambda = 0$ and thus fraud and effort are independent variables. Thus, the stronger is PMC (i.e. the lower ε) and/or the larger is the expected punishment, the larger is the region where incentives do not lead to fraudulent behavior. For $\alpha \geq \frac{\gamma}{\varepsilon\Delta}$, since $e^* = \alpha\varepsilon\eta$, fraud and effort are, in terms of incentives, positively related and consequently the company faces a trade-off between effort and fraud. γ affects the effectiveness of α in changing λ: the larger (lower) is γ, the stronger (weaker) is the effectiveness of α in influencing λ (i.e. $\frac{\partial^2}{\partial\alpha\partial\gamma}\lambda > 0$ for each $\alpha \geq \frac{\gamma}{\varepsilon\Delta}$).

4 Optimal incentive contract

At the beginning of time period 1, the shareholders' problem is to find the optimal compensation package (ω_0, ω_1), or equivalently (ω_0, α), that maximizes the company's expected long run stock price. The optimal compensation package trades off gains from inducing a separating equilibrium (i.e. achieved by setting a low value of α) against its costs, represented by a lower effort level.

We normalize the outside option of managers to zero ($U_0 = 0$) and thus the participation constraint is $E\left(U_{L,L}\right)=0$, which yields $\omega_0=-\frac{1}{1-\alpha}\varepsilon\left[\alpha\left(\theta_L-\overline{e}\eta\right)+\frac{1}{2}\alpha^2\varepsilon\eta^2\right]$.

Given that in equilibrium a fraction λ of managers of $L-$type companies engage in fraudulent behavior and that $\frac{1}{2}$ of the companies are $L-$type and $\frac{1}{2}$ are $H-$type, the expected long run stock price reads

$$E\left(S\right)=\frac{1}{2}\left[\left(1+\lambda\right)S^P+\left(1-\lambda\right)S_{L,L}\right] \tag{9}$$

Using S^P and $S_{L,L}$ defined in (2) and (3), respectively, and the expression for ω_0, we can rewrite (9) as

$$E\left(S\right)=\varepsilon\left[R-\overline{e}\eta+\alpha\left(1-\frac{1}{2}\alpha\right)\varepsilon\eta^2-\alpha\frac{1}{2}\Delta-\left(1-\alpha\right)\frac{1}{2}\lambda\Delta\right] \tag{10}$$

where λ is given by (8).

The first three terms of (10) represent the expected stock price in absence of asymmetric information and fraudulent behavior. The fourth term represents agency costs due to hidden information (i.e. asymmetric information over types). Managers of $H-$ and $L-$ type companies are offered the same contract (ω_0,ω_1), where ω_0 is such that the participation constraint of an $L-$type manager is binding. Consequently, a manager of an $H-$type company benefits from informational rents. The last term of (10) represents agency costs due to fraudulent behavior (fraud rents).

Observe that the long run stock price (10) is decreasing in λ and, moreover, using the envelope theorem, it is increasing in γ. Thus, the larger is the expected punishment γ, the lower is, in equilibrium, the fraction of firms engaging in fraud, and hence the larger is the long run stock price.

Throughout the remaining part of the paper we make use of the following assumption.

Assumption 1 *Parameters η, γ and Δ are such that $k\eta^2>1$, where $k\equiv\frac{4\gamma}{\Delta^2}$.*

The derivative of $E\left(S\right)$ as in (10) with respect to α is

$$\frac{\partial}{\partial\alpha}E\left(S\right)=\varepsilon^2\eta^2\left(1-\frac{\Delta}{2\varepsilon\eta^2}-\alpha\right) \qquad \text{if } \alpha<\frac{\gamma}{\varepsilon\Delta} \tag{11}$$

$$\frac{\partial}{\partial \alpha} E\left(S\right) = \varepsilon \left[\varepsilon \eta^2 \left(1-\alpha\right) - \Delta \gamma \frac{\gamma + \varepsilon \Delta}{\left(\gamma + \alpha \varepsilon \Delta\right)^2} \right] \qquad \text{if } \alpha \geq \frac{\gamma}{\varepsilon \Delta} \tag{12}$$

For $\alpha < \frac{\gamma}{\varepsilon \Delta}$ managers never commit fraud and hence the expected long run value of the company is a concave function of α. In this case the company trades off gains from incentives against their costs due to asymmetric information (i.e. minimizing informational rents). For $\alpha \geq \frac{\gamma}{\varepsilon \Delta}$ a fraction λ of managers engage in fraudulent behavior. The first term of (12) represents marginal gains from incentives while the second term represents marginal costs of incentives.

Let us define $\alpha_{\max} \equiv \arg\max_{\alpha \in [0,1]} E\left(S\right)$ and thresholds $\overline{I} \equiv \left\{ \left(\varepsilon, \eta^2\right) \in \Re^2_+ : \varepsilon = \frac{\gamma}{\Delta} \frac{\eta^2 k + 1}{\eta^2 k - 1} \right\}$, $\underline{I} \equiv \left\{ \left(\varepsilon, \eta^2\right) \in \Re^2_+ : \varepsilon = \frac{\gamma}{\Delta} \left(\sqrt{\frac{27}{\eta^2 k}} - 1 \right), \text{ with } \eta^2 \leq \frac{3}{k} \right\}$ and $I^* \equiv \left\{ \left(\varepsilon, \eta^2\right) \in \Re^2_+ : \varepsilon = \frac{\gamma}{\Delta} \left(1 + \frac{2}{\eta^2 k}\right) \right\}$. In the following proposition we describe the optimal incentive contract as a function of ε.

Proposition 1
(i) If $\left(\varepsilon, \eta^2\right) < I^*$, then there exists a unique $\alpha_{\max} = \alpha^* \equiv 1 - \frac{\Delta}{2\varepsilon\eta^2}$ with $\lambda = 0$;
(ii) if $I^* \leq \left(\varepsilon, \eta^2\right) \leq \underline{I}$, then there exists a unique $\alpha_{\max} = \frac{\gamma}{\varepsilon \Delta}$ and $\lambda = 0$;
(iii) if $\underline{I} < \left(\varepsilon, \eta^2\right) < \overline{I}$, then there exist two local maxima, at $\alpha = \frac{\gamma}{\varepsilon \Delta}$ with $\lambda = 0$ and at $\alpha = \widehat{\alpha} > \frac{\gamma}{\varepsilon \Delta}$ with $\lambda > 0$;
(iv) if $\left(\varepsilon, \eta^2\right) > \overline{I}$, then there exists a unique $\alpha_{\max} = \widehat{\alpha} > \frac{\gamma}{\varepsilon \Delta}$ and $\lambda > 0$;
where $\frac{\partial}{\partial \varepsilon} \widehat{\alpha} > 0$, $\frac{\partial}{\partial \eta^2} \widehat{\alpha} > 0$ and $\frac{\partial}{\partial \gamma} \widehat{\alpha} < 0$.

The results stated in Proposition 1 are best commented on by looking at Figure (1) where thresholds $\overline{I}$ (black line), $\underline{I}$ (dotted line) and I^* (dashed line) are depicted.

The last part of the proposition states that if the rent reduction effect of PMC is sufficiently weak (large ε) and/or the business stealing effect is sufficiently strong (large η), i.e. values of $\left(\varepsilon, \eta^2\right)$ above the set $\overline{I}$, then it is optimal to increase α beyond the threshold $\frac{\gamma}{\varepsilon \Delta}$ and thus to tolerate some amount of fraud. This holds for each $\left(\varepsilon, \eta^2\right)$ above the continuous line in Figure 1. The intuition for this result is straightforward. The larger is ε and/or the larger is η, the more important is effort for the company's performance and thus the stronger are incentives, even though this may lead to some amount of fraudulent behavior.

The first part of Proposition 1 considers values of $\left(\varepsilon, \eta^2\right)$ below the set I^* (dashed line in Figure 1), that is very low price-cost margin (low ε) and/or low business stealing effect (low η),

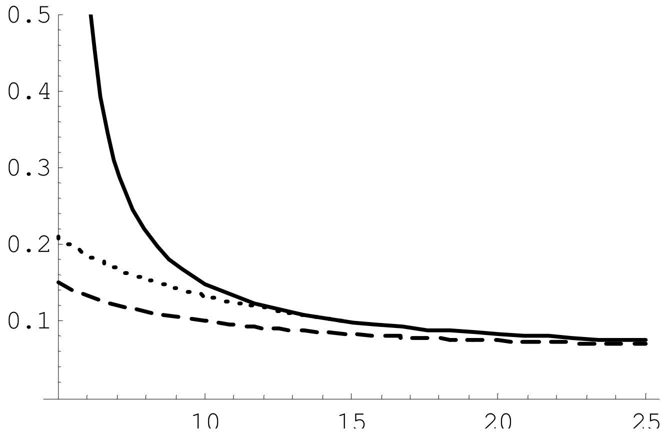

Figure 1: $\overline{I}$ (black line), $\underline{I}$ (dotted line) and I^* (dashed line) in the (η^2, ε)-space; $\Delta = 1$, $\gamma = 0.05$ and $\eta > 2.236$.

where α^* with $\lambda = 0$ is optimal. This result states that if the optimal contract without fraud (α^*) is such that engaging in fraud is not optimal, that is $\alpha^* \leq \frac{\gamma}{\varepsilon\Delta}$, then this contract is optimal. Two effects are at play. Firstly, the stronger is the rent reduction effect and/or the weaker is the business stealing effect, the less important is effort for firm profits. Secondly, a stronger rent reduction effect increases the threshold below which incentives do not lead to fraudulent activity. Both effects decrease the cost of implementing a separation equilibrium.

For values of (ε, η^2) between the set I^* and $\overline{I}$ there exists another set $\underline{I}$, represented in Figure 1 by the dotted line, such that for each (ε, η^2) between the continuous and the dotted line two local maxima exist and thus the company may choose between a weak-incentives-without-fraud equilibrium ($\alpha_{\max} = \frac{\gamma}{\varepsilon\Delta}$ and $\lambda = 0$) and a strong-incentives-with-fraud equilibrium ($\alpha_{\max} = \widehat{\alpha} > \frac{\gamma}{\varepsilon\Delta}$ and $\lambda > 0$). The weaker is the rent reduction effect (i.e., larger is ε) and/or the stronger is the business stealing effect (i.e. the larger is η), the more likely it is that the company chooses the latter equilibrium. For (ε, η^2) between the dotted and the dashed line, $E(S)$ is decreasing for each $\alpha \in \left[\frac{\gamma}{\varepsilon\Delta}, 1\right]$ and hence the maximum is achieved in $\frac{\gamma}{\varepsilon\Delta}$ where $\lambda = 0$. The intuition for this result is the same as above: the stronger is the rent reduction effect and/or the weaker is the business stealing effect, the less important is effort for firm profits; a stronger rent reduction effect increases the threshold below which incentives do not lead to fraudulent activity. In other words, as the rent reduction effect becomes stronger and/or the business stealing effect becomes weaker, enforcing a separation equilibrium becomes less costly.

Finally, note that the weaker is the rent reduction effect and/or the stronger is the business stealing effect, the larger is $\widehat{\alpha}$ and λ. A weaker rent reduction effect reduces the marginal costs of incentives while increasing their marginal gains and thus it is optimal to increase incentives. A stronger business stealing effect increases the marginal gains from incentives and thus it is optimal to strengthen incentives, which in turn leads in equilibrium to a larger amount of fraud. Moreover, an increase in the expected punishment γ, increases the effectiveness of α in reducing fraudulent behavior and as a consequence it increases the marginal costs of incentives and thus it is optimal to decrease $\widehat{\alpha}$.

4.1 Rent reduction and optimal incentives

In this section we consider a constant business stealing effect and study optimal incentive provision ($\alpha_{\max}$) as the rent reduction effect varies. For values of (ε, η) below the set I^*, i.e. PMC is sufficiently strong, we know from Proposition 1 that $\alpha_{\max} = \alpha^*$ and $\lambda = 0$. Since α^* is increasing in ε, decreasing PMC leads the shareholder to provide the manager with stronger incentives (see the continuous black line in Figure 2). Note that a weaker PMC increases the importance of effort and at the same time reduces the threshold for α below which incentives do not lead to fraudulent behavior. Once $I^* \leq (\varepsilon, \eta^2) \leq \underline{I}$ (i.e. (ε, η^2) between the dashed and the dotted line in Figure 1), $\alpha_{\max} = \frac{\gamma}{\varepsilon \Delta}$ where the company provides the maximum of incentives compatible with no fraudulent behavior in equilibrium. For $I^* \leq (\varepsilon, \eta^2) \leq \underline{I}$, increases in ε lead to a reduction in $\alpha_{\max}$ since the threshold below which no fraudulent behavior occurs decreases as PMC weakens (dotted line in Figure 2). Note that the company prefers to eliminate fraudulent behavior even though the importance of effort for the company's performance increases as PMC weakens. For low values of η^2, threshold $\overline{I}$ exists and thus once $\underline{I} < (\varepsilon, \eta^2) < \overline{I}$ (i.e. (ε, η^2) is between the dotted and the continuous line in Figure 1), two local maxima emerge. For low values of ε it is still optimal to eliminate fraudulent behavior (weak-incentives-without-fraud equilibrium), where $\alpha_{\max} = \frac{\gamma}{\varepsilon\Delta}$, $\lambda = 0$, while for larger values of ε the company switches to the strong-incentives-with-fraud equilibrium, where $\alpha_{\max} = \widehat{\alpha}$, $\lambda > 0$ (dashed line in Figure 2). For $(\varepsilon, \eta^2) > \overline{I}$, $\alpha_{\max} = \widehat{\alpha}$, $\lambda > 0$ and thus further increases in ε increase $\widehat{\alpha}$ (thin line in Figure 2). For large values of η^2 there exists always a unique maximum and consequently for $\underline{I} < (\varepsilon, \eta^2)$, the company provides the manager with strong incentives ($\alpha_{\max} = \widehat{\alpha}$) enduring some amount of fraudulent behavior $\lambda > 0$ (see gray line in Figure 2).

This result is summarized in the following proposition.

Proposition 2 *Optimal incentives ($\alpha_{\max}$) are non-monotone in ε, while λ is increasing in ε.*

Proof. The result follows from the argument in the text above and the results stated in Proposition 1. ■

A consequence of this result is that, even in the absence of a business stealing effect, stronger PMC may lead to stronger incentives.

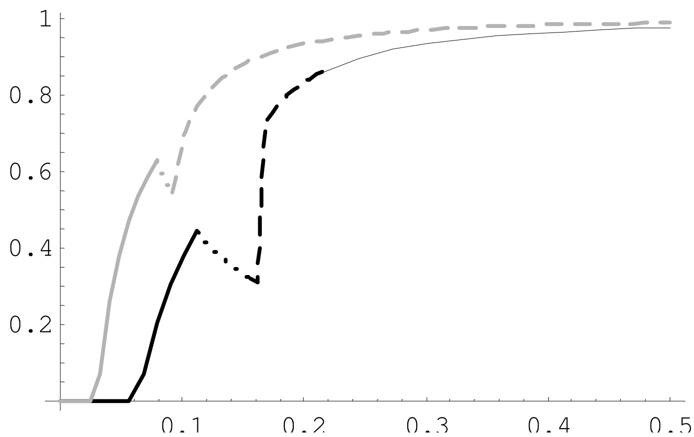

Figure 2: $\alpha_{\max}$ as a function of ε for low values of η^2 (black line) and large values of η^2 (gray line). Numerical example based on the one depicted in Figure 1.

A further result concerns the relationship between managerial incentives and fraudulent behavior. Let $\alpha_{\max}(\varepsilon)$ be the optimal incentive contract as a function of ε and $\lambda(\varepsilon)$ the associated equilibrium level of fraud. From Figure 2 we observe that it may happen that $\alpha_{\max}(\varepsilon') > \alpha_{\max}(\varepsilon'')$ and $0 = \lambda(\varepsilon') < \lambda(\varepsilon'')$ with $\varepsilon'' > \varepsilon'$. In other words, strong PMC (low ε) is associated with strong incentives and no fraudulent behavior while weak PMC (large ε) is associated with weak incentives and some fraudulent behavior in equilibrium. This result can be summarized as follows.

Corollary 3 *There exists a non-monotone relationship between incentives ($\alpha_{\max}$) and fraudulent behavior (λ).*

Proof. Follows directly from Proposition 2. ■

4.2 Business stealing and optimal incentives

In this section we investigate the relationship between optimal incentive provision ($\alpha_{\max}$) and business stealing effect (η), for a constant rent reduction effect. Let us start with values of (ε, η) below the set I^*, that is a business stealing effect, where $\alpha_{\max} = \alpha^*$ with $\lambda = 0$. Within this region $\alpha_{\max}$ is increasing in η^2 and hence as the business stealing effect increases it is optimal to strengthen incentives (see the continuous line in Figure 3). As the business stealing effect increases so does the importance of effort for firm profits. For $I^* \leq (\varepsilon, \eta^2) \leq \underline{I}$, it is optimal to enforce a separating equilibrium and hence to set $\alpha_{\max} = \frac{\gamma}{\varepsilon\Delta}$ (dotted line in Figure 3). Once $\underline{I} < (\varepsilon, \eta^2) < \overline{I}$, two local maxima emerge. For low values of η^2 it is still optimal to eliminate fraudulent behavior (weak-incentives-without-fraud equilibrium), where $\alpha_{\max} = \frac{\gamma}{\varepsilon\Delta}$, $\lambda = 0$, while for larger values of η^2 the company switches to the strong-incentives-with-fraud equilibrium, where $\alpha_{\max} = \widehat{\alpha}$, $\lambda > 0$ (dashed line in Figure 3). For $(\varepsilon, \eta^2) > \overline{I}$, further increases in η^2 increase $\widehat{\alpha}$ (thin line in Figure 3).

This result can be summarized as follows.

Proposition 4 *Optimal incentives ($\alpha_{\max}$) and equilibrium fraudulent behavior (λ) are increasing in η^2.*

Proof. The result follows from the argument in the text above and the results stated in Proposition 1. ■

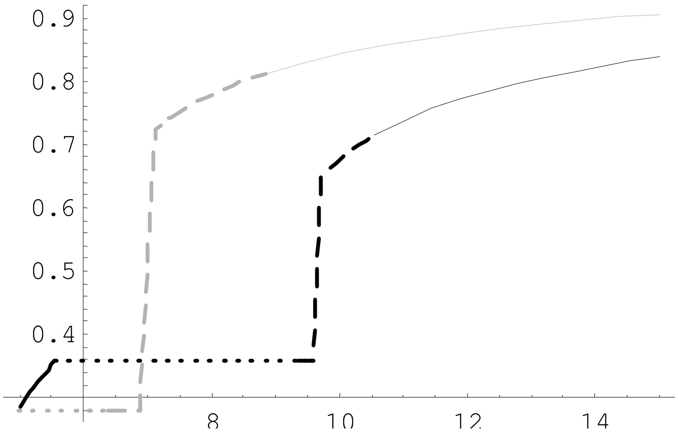

Figure 3: $\alpha_{\max}$ as a function of η^2 for $\varepsilon = 0.14$ (black line) and $\varepsilon = .18$ (gray line).

4.3 PMC, rent reduction, business stealing and fraud

An increase in PMC is likely to increase the rent reduction effect as well as the business stealing effect. The effect of PMC on fraud and optimal incentives is thus a combination of the two effects analyzed in Sections 4.1 and 4.2. In this Section we briefly put the two effects together.

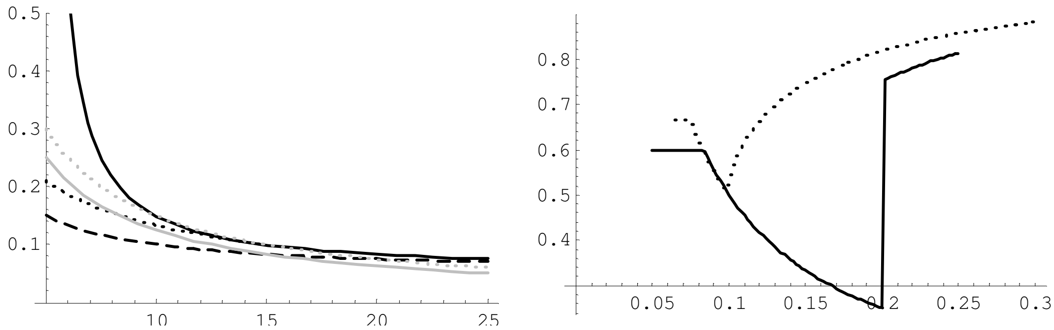

Figure 4. LHS: Thresholds $\overline{I}$ (black line), $\underline{I}$ (dotted line) and I^*(dashed line) and $\varepsilon = \frac{c}{\eta^2}$ in the (η^2, ε)-space for $c = 1.25$ (continuous gay line) and $c = 1.5$ (dashed gray line). RHS: $\alpha_{\max}$ as a function of ε, with $\varepsilon = \frac{c}{\eta^2}$ for $c = 1.25$ (continuous line) and $c = 1.5$ (dotted line).

In Figure 4 we plot a representative example where an increase in PMC reduces ε and increases η^2 according to the relation $\varepsilon = \frac{c}{\eta^2}$, with c a positive constant (variations in the degree of PMC correspond to movements along gray lines in Figure 4 LHS). Notice that, in this example, changes in the degree of PMC have no direct effect on the manager's optimal effort choice, but only an indirect effect through the pay-for-performance sensitivity parameter α. In Figure 4 RHS we plot optimal incentives as a function of ε. From Figure 4 RHS we observe that optimal incentives ($\alpha_{\max}$) are non-monotone in PMC and that the equilibrium level of fraud (λ) is decreasing in the strength of PMC. As a consequence, there exists a non-monotone relationship between incentives ($\alpha_{\max}$) and fraudulent behavior (λ).

5 Discussion

A final issue concerns the effect of the monitoring technology and thus the expected punishment on optimal incentives. In order to address this problem it is useful to plot $\overline{I}$, $\underline{I}$, and I^* in the (γ, ε)-space (see Figure 5 for an example).

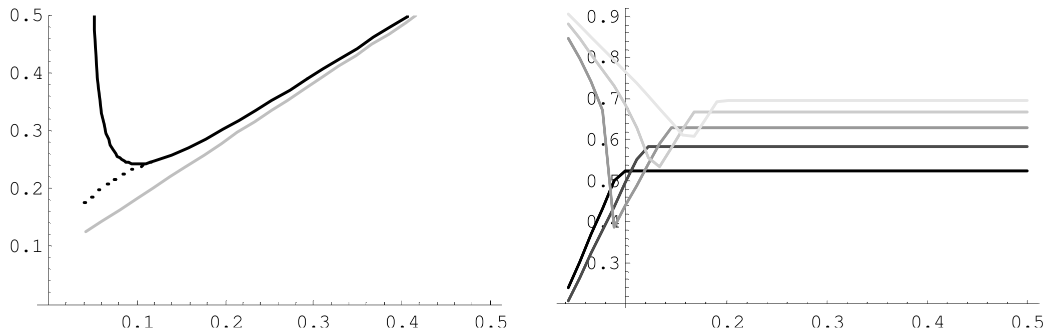

Figure 5. LHS: Thresholds $\overline{I}$ (black continuous-line), $\underline{I}$(dotted line)and I^* (gray line) in the (γ, ε)-space; $\eta^2 = 6$ and $\gamma \in [\underline{\gamma}, 0.5]$. RHS: $\alpha_{\max}$as a function of γ. Increased brightness corresponds to increased values of ε ($\varepsilon = 0.175$, 0.2, 0.225, 0.25 and 0.275).

Using the result stated in Proposition 1 we are able to study how, for a given rent reduction effect, optimal incentives vary as γ changes. In Figure 5 RHS we plot $\alpha_{\max}$ as a function of γ for different values of ε.

Consider first the case of a strong rent reduction effect (i.e. low values of ε). In this case incentives are low for low values of γ and monotonically increasing in γ. The intuition for this result is the following: managerial effort is relatively unimportant while fraud has a strong negative effect. Consequently, it is optimal to eliminate fraudulent behavior, i.e. $\alpha_{\max} = \frac{\gamma}{\varepsilon\Delta}$. Increasing γ increases also the threshold for α below which incentives do not lead to fraudulent behavior. For larger values of γ we have $\alpha_{\max} = \alpha^*$ which is independent of γ, and $\lambda = 0$.

Weakening the rent reduction effect leads to a non-monotone relationship between incentives and expected punishment. The intuition for this result is as follows. The larger is ε, the more important managerial effort is for the company's performance. Moreover, for low values of γ, incentives are relatively inefficient in affecting fraudulent behavior. Consequently, is optimal to provide strong incentives and thus to endure some amount of fraudulent behavior ($\alpha_{\max} = \widehat{\alpha}$ and $\lambda > 0$). Increasing γ increases the effectiveness of incentives in influencing fraudulent behavior. It also increases the marginal costs of incentives in (12) and thus larger values of γ are associated with lower values of $\widehat{\alpha}$ (see also Proposition 1). Further increases in γ reduce further the relative gains stemming from incentives and finally it is optimal to switch to the low-incentives-no-fraud equilibrium (with $\alpha_{\max} = \frac{\gamma}{\varepsilon\Delta}$). Further increases in γ lead now to an increase in incentives. Finally, for γ sufficiently large $\alpha_{\max} = \alpha^*$ and $\lambda = 0$. A similar argument applies if, instead of the rent reduction effect, we consider the business stealing effect. This result can be summarized as follows.

Proposition 5 *If effort is sufficiently important for the firm's performance (that is, rent reduction effect is sufficiently weak and/or business stealing effect is sufficiently strong), then optimal incentives ($\alpha_{\max}$) are V-shaped in the expected punishment γ with $\lambda > 0$ for low values of γ and $\lambda = 0$ for large values of γ.*

Proof. The result follows from the argument in the text above and the results stated in Proposition 1. ■

Let $\alpha_{\max}(\gamma)$ be the optimal incentive contract as a function of γ and $\lambda(\gamma)$ the corresponding equilibrium level of fraud. Thus, according to Proposition 5, if PMC is sufficiently weak, we may observe $\alpha(\gamma') < \alpha(\gamma'')$ and $\lambda(\gamma') > \lambda(\gamma'') = 0$, where $\gamma' < \gamma''$. That is, strong incentives do not lead to fraudulent behavior if these are associated with a large expected penalty while the same incentives or even weaker one may lead to fraudulent behavior if the expected penalty is sufficiently low.

6 Conclusion

We studied a model where shareholders face the problem of designing the optimal stock-based compensation package. We examined the role of PMC in influencing the shareholders trade-off between inducing effort and fraudulent behavior and found that optimal pay-performance sensitivity is non-monotone in the rent reduction effect of PMC and increasing in the business stealing effect. Combining the two effects we obtain, in general, that optimal incentives are non-monotone in the strength of PMC, while equilibrium fraudulent behavior is decreasing in the strength of PMC. As a consequence, there exists a non-monotone relationship between incentives and fraudulent behavior. Strong incentives, that is a high pay-performance sensitivity, together with strong PMC may not lead to fraudulent behavior while the same incentives or even weaker one together with a weaker PMC may lead to fraudulent behavior. We also investigated the role of the monitoring technology and found that if managerial effort is sufficiently important for the firm's performance (that is, the rent reduction effect is sufficiently weak and/or the business stealing effect is sufficiently strong), then optimal incentives are V-shaped in the manager's expected penalty where strong incentives and strong punishment do not lead to fraudulent behavior while the same incentives lead to fraudulent behavior if the expected punishment is too weak.

7 Appendix

Proof of Proposition 1. Note that, for each $\left(\varepsilon, \eta^2\right) < I^*$, $\alpha^* \leq \frac{\gamma}{\varepsilon \Delta}$. We rewrite (12) as $\frac{\partial}{\partial \alpha} E\left(S\right) = g\left(\alpha\right) - f\left(\alpha\right)$, where $g\left(\alpha\right) \equiv \varepsilon \eta^2 \left(1-\alpha\right)$ represents the marginal gains from an increase in α and $f\left(\alpha\right) \equiv \Delta \gamma \frac{\gamma + \varepsilon \Delta}{\left(\gamma + \alpha \varepsilon \Delta\right)^2}$ represents the marginal costs of incentives due to asymmetric information and fraudulent behavior. Note that both $g\left(\alpha\right)$ and $f\left(\alpha\right)$ are strictly decreasing in

α, that $g(\alpha)$ is a linear function of α while $f(\alpha)$ is a strictly convex function of α and that $g(1) < f(1)$, i.e. $\frac{\partial}{\partial\alpha}E(S) < 0$ for $\alpha = 1$. Thus, condition $g(\alpha) = f(\alpha)$ may have either no solution, in which case $\frac{\partial}{\partial\alpha}E(S) < 0$ for each $\alpha \in \left[\frac{\gamma}{\varepsilon\Delta}, 1\right]$, one solution $\widehat{\alpha}$, in which case $\frac{\partial}{\partial\alpha}E(S) > 0$ for each $\alpha \in \left[\frac{\gamma}{\varepsilon\Delta}, \widehat{\alpha}\right)$ and $\frac{\partial}{\partial\alpha}E(S) < 0$ for each $\alpha \in (\widehat{\alpha}, 1]$ or two solutions in which case $E(S)$ is decreasing for low values of α, increasing for intermediate values of α and again decreasing for large values of α. Straightforward calculus shows that for $\alpha \geq \frac{\gamma}{\varepsilon\Delta}$, $\frac{\partial}{\partial\varepsilon}f(\alpha) < 0$, $\frac{\partial}{\partial\varepsilon}g(\alpha) > 0$, $\frac{\partial}{\partial\eta^2}g(\alpha) > 0$ and $\frac{\partial}{\partial\gamma}f(\alpha) > 0$.

Part (i). For $\left(\varepsilon, \eta^2\right) > \overline{I}$ we have that $g\left(\frac{\gamma}{\varepsilon\Delta}\right) > f\left(\frac{\gamma}{\varepsilon\Delta}\right)$. Since $g(1) < f(1)$ and because of the above mentioned properties of $g(\alpha)$ and $f(\alpha)$, there exists a unique $\widehat{\alpha}$ such that $g(\widehat{\alpha}) = f(\widehat{\alpha})$ where $\frac{\partial}{\partial\alpha}E(S) > 0$ for each $\alpha \in \left[\frac{\gamma}{\varepsilon\Delta}, \widehat{\alpha}\right)$ and $\frac{\partial}{\partial\alpha}E(S) < 0$ for each $\alpha \in (\widehat{\alpha}, 1]$.

Direct computation shows that $\overline{I} > I^*$. To prove that $\widehat{\alpha}$ is a unique maximum note that $\left(\varepsilon, \eta^2\right) > \overline{I} > I^*$. Consequently, for $\left(\varepsilon, \eta^2\right) > \overline{I}$, $\alpha^* > \frac{\gamma}{\varepsilon\Delta}$ and thus no maximum exists with $\alpha < \frac{\gamma}{\varepsilon\Delta}$.

To prove that $\frac{\partial}{\partial\varepsilon}\widehat{\alpha} > 0$ observe that, since $g(1) < f(1)$ and since a unique $\widehat{\alpha}$ solving $g(\widehat{\alpha}) = f(\widehat{\alpha})$ exists, it follows that $|g_\alpha(\widehat{\alpha})| > |f_\alpha(\widehat{\alpha})|$. Moreover, since $\alpha \geq \frac{\gamma}{\varepsilon\Delta}$, $f_\varepsilon(\alpha) < 0$, $g_\varepsilon(\alpha) > 0$ and using the implicit function theorem we have that $\frac{d\widehat{\alpha}}{d\varepsilon} = -\frac{f_\varepsilon(\widehat{\alpha}) - g_\varepsilon(\widehat{\alpha})}{|f_\alpha(\widehat{\alpha}) - g_\alpha(\widehat{\alpha})|} > 0$. Furthermore, since $f_\gamma(\alpha) > 0$ and $g_{\eta^2}(\alpha) > 0$ and using the implicit function theorem it follows that $\frac{d\widehat{\alpha}}{d\gamma} = -\frac{f_\gamma(\widehat{\alpha})}{|f_\alpha(\widehat{\alpha}) - g_\alpha(\widehat{\alpha})|} < 0$ and that $\frac{d\widehat{\alpha}}{d\eta^2} = -\frac{-g_{\eta^2}(\alpha)}{|f_\alpha(\widehat{\alpha}) - g_\alpha(\widehat{\alpha})|} > 0$.

Part (ii). Case $I^* < \left(\varepsilon, \eta^2\right) < \overline{I}$. For $\left(\varepsilon, \eta^2\right) < \overline{I}$ we have that $g\left(\frac{\gamma}{\varepsilon\Delta}\right) < f\left(\frac{\gamma}{\varepsilon\Delta}\right)$ and hence, given the above mentioned properties of $g(\alpha)$ and $f(\alpha)$, there may either exist 0 or 2 solutions. We exploit the fact that $g(\alpha)$ is a linear function and $f(\alpha)$ a convex function to find values for $\left(\varepsilon, \eta^2\right)$ such that $f(\alpha) > g(\alpha)$. This happens if (a) $\left|f'\left(\frac{\gamma}{\varepsilon\Delta}\right)\right| < \left|g'\left(\frac{\gamma}{\varepsilon\Delta}\right)\right|$, or if (b) $\left|f'\left(\frac{\gamma}{\varepsilon\Delta}\right)\right| > \left|g'\left(\frac{\gamma}{\varepsilon\Delta}\right)\right|$ and $f(\alpha^+) > g(\alpha^+)$ where α^+ is such that $f'(\alpha^+) = g'(\alpha^+)$. Finally, in case (c) we show that if $\left|f'\left(\frac{\gamma}{\varepsilon\Delta}\right)\right| > \left|g'\left(\frac{\gamma}{\varepsilon\Delta}\right)\right|$ and $f(\alpha^+) < g(\alpha^+)$ two solutions to $g(\alpha) = f(\alpha)$ exist.

Consider first case (a). If $\left(\varepsilon, \eta^2\right) < \widetilde{I} \equiv \left\{\left(\varepsilon, \eta^2\right) \in \Re^2_+ : \varepsilon = \frac{\gamma}{\Delta}\left(\eta^2 k - 1\right)\right\}$, then $\left|f'\left(\frac{\gamma}{\varepsilon\Delta}\right)\right| <$

$\left|g'\left(\frac{\gamma}{\varepsilon\Delta}\right)\right|$ and, since $f(\alpha)$ is a convex function, no solution to the equality $g(\alpha) = f(\alpha)$ exists. As a consequence, $\frac{\partial}{\partial\alpha}E(S) < 0$ for each $\alpha \in \left[\frac{\gamma}{\varepsilon\Delta}, 1\right]$.

Consider next case (b), where $\left(\varepsilon, \eta^2\right) > \widetilde{I}$. For $\max\left\{\widetilde{I}, I^+\right\} < \left(\varepsilon, \eta^2\right) < \underline{I}^0$, where

$$I^+ \equiv \left\{\left(\varepsilon, \eta^2\right) \in \Re^2_+ : \varepsilon = \frac{\gamma}{\Delta}\left(\sqrt{\frac{8}{\eta^2 k}} - 1\right)\right\}$$

and

$$\underline{I}^0 \equiv \left\{\left(\varepsilon, \eta^2\right) \in \Re^2_+ : \varepsilon = \frac{\gamma}{\Delta}\left(\sqrt{\frac{27}{\eta^2 k}} - 1\right)\right\}$$

we have that $f(\alpha^+) > g(\alpha^+)$, where $\alpha^+ \equiv \frac{1}{\varepsilon\Delta}\left[2\frac{\Delta^2\gamma}{\eta^2}(\gamma + \varepsilon\Delta)\right]^{\frac{1}{3}} - \frac{\gamma}{\varepsilon\Delta} \in (0, 1)$ is such that $g'(\alpha^+) = f'(\alpha^+)$. As a consequence, no solution to equality $g(\alpha) = f(\alpha)$ exists and hence $\frac{\partial}{\partial\alpha}E(S) < 0$ for each $\alpha \in \left[\frac{\gamma}{\varepsilon\Delta}, 1\right]$. Note that at $\left(\varepsilon, \eta^2\right) = I^+$, $\alpha^+ = 1$ with $f(\alpha^+) > g(\alpha^+)$. As a consequence, if $\widetilde{I} < I^+$, then also for $\widetilde{I} < \left(\varepsilon, \eta^2\right) < I^+$, $\frac{\partial}{\partial\alpha}E(S) < 0$ for each $\alpha \in \left[\frac{\gamma}{\varepsilon\Delta}, 1\right]$ since as ε decreases, $g(\alpha)$ decreases while $f(\alpha)$ increases, and a reduction in η^2 reduces $g(\alpha)$. Consequently, no solution to $f(\alpha) = g(\alpha)$ exists.

Case (c). Reversing the argument of case (b) it follows that if $\left(\varepsilon, \eta^2\right) > \widetilde{I}$ and $\left(\varepsilon, \eta^2\right) > \underline{I}^0$, then $f(\alpha^+) < g(\alpha^+)$ and thus, because of the above mentioned properties of $g(\alpha)$ and $f(\alpha)$, two solutions to the equality $f(\alpha) = g(\alpha)$ exist.

Direct computation shows that for each $\eta^2 k > 1$, $\overline{I} \geq \underline{I}^0$, that for $\eta^2 k = 3$, $\overline{I} = \underline{I}^0 = \widetilde{I}$, that for each $\eta^2 k < 3$, $\underline{I}^0 > \widetilde{I}$, that for each $\eta^2 k > 3$, $\overline{I} < \widetilde{I}$ and that for each $\eta^2 k < 3$, $I^* < \underline{I}^0$.

Consider first the case where $\eta^2 k > 3$, where $\widetilde{I} > \overline{I} > \underline{I}^0$. For $I^* < \left(\varepsilon, \eta^2\right) < \overline{I}$ we are in case (a) and thus we know that $\frac{\partial}{\partial\alpha}E(S) < 0$ for each $\alpha \in \left[\frac{\gamma}{\varepsilon\Delta}, 1\right]$ and consequently that no solution to $f(\alpha) = g(\alpha)$ exists. Hence, $\alpha_{\max} = \frac{\gamma}{\varepsilon\Delta}$.

Consider next the case where $\eta^2 k < 3$, where $\overline{I} > \underline{I}^0 > \widetilde{I}$. For $\overline{I} > \left(\varepsilon, \eta^2\right) > \underline{I}^0$ we are in case (c) where two local maxima exist: $\widehat{\alpha}$ and $\frac{\gamma}{\varepsilon\Delta}$. For $\underline{I}^0 > \left(\varepsilon, \eta^2\right) > I^*$, we are either in case (a) or in case (b). In both cases $\frac{\partial}{\partial\alpha}E(S) < 0$ for each $\alpha \in \left[\frac{\gamma}{\varepsilon\Delta}, 1\right]$ and consequently no solution to $f(\alpha) = g(\alpha)$ exists. Hence, $\alpha_{\max} = \frac{\gamma}{\varepsilon\Delta}$.

Part (iii) Case $(\varepsilon, \eta^2) < I^*$, where $\alpha^* < \frac{\gamma}{\varepsilon\Delta}$. In order to prove that $\alpha_{\max} = \alpha^*$ it is sufficient to show that $\frac{\partial}{\partial\alpha}E(S) < 0$ for each $\alpha \in \left[\frac{\gamma}{\varepsilon\Delta}, 1\right]$. Consider first the case where $\eta^2 k < 3$. Since $I^* < \underline{I}^0 < \overline{I}$, it follows that either case (a) or case (b) of Part (ii) applies and thus $\frac{\partial}{\partial\alpha}E(S) < 0$ for each $\alpha \in \left[\frac{\gamma}{\varepsilon\Delta}, 1\right]$. Consider next the case where $\eta^2 k > 3$, where $\widetilde{I} > \overline{I} > \underline{I}^0$. Since $I^* < \overline{I}$, case (a) of Part (ii) applies and thus $\frac{\partial}{\partial\alpha}E(S) < 0$ for each $\alpha \in \left[\frac{\gamma}{\varepsilon\Delta}, 1\right]$.

Finally, note that for $\eta^2 k > 3$, threshold $\underline{I}^0$ is never relevant and thus, in order to simplify the exposition, in the main part of the paper this threshold has been replaced with threshold $\underline{I}$. ■

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