On CEO appointment and compensation *

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Abstract

CEO compensation has received a lot of attention in the recent past, above all the widening gap between its level and that of the compensation of other employees. However, this increase in CEO pay was accompanied by changes in the structure of CEO pay (i.e., the increased use of stock options) and changes in CEO appointment (boards of directors choosing CEOs outside the firm rather than inside).

In this article, we propose a amended version of the standard principal-agent model that provides a rationale for the increases in *(i)* CEO pay, *(ii)* use of stock options in compensation schemes and *(iii)* hiring of CEOs externally.

Furthermore, we derive new testable implications regarding compensation packages proposed to internally promoted and externally chosen CEOs.

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1 Introduction

The dramatic and unprecedent increase in CEO pay in the 1980s and 1990s (see Frydman (2005)) led to questioning the efficiency of CEO compensation packages. Following Jensen and Murphy (1990)'s seminal paper, the debate concentrated first on the pay-performance sensitivity and then moved to the compensation level, given the observed widening gap between the pay level of executive officers and other employees.

However, another important change regarding CEOs took place over the same period: the way CEOs are appointed. Increasingly, board of directors have hired CEOs outside their firm, while in the 1960s and 1970s internal promotion was the standard way of reaching a CEO position. For example, in their long-run study of CEO turnover in the United States, Huson, Parrino and Starks (2001) provide evidence that over the period 1971-1976, only 15.3% of appointed CEOs were outsiders, while this proportion had reached 30% over the period 1989-1994.

Two types of explanations have been proposed for this evolution in CEO appointment. First, improvement in corporate governance led to the evolution of the composition of boards of directors, outside directors being increasingly represented (see, Huson, Parrino and Starks (2001), and Hermalin (2005)).[1] Second, the evolution of the economic environment influenced the type of skills required for the CEO job (Murphy and Zabojnik (2004, 2007), Frydman (2005)). In the words of Murphy and Zabojnik (2004), " *over the past three decades, general managerial skills (i.e., the skills transferable across companies, or even industries) became relatively more important for the CEO job, perhaps as a result of the steady progress in economics, management science, accounting, finance, and other disciplines which, if mastered by a CEO, can substantially improve his ability to manage any company."*

In this paper, we propose a model of CEO choice which provides a rationale for *(i)* the increase in CEO pay, *(ii)* the increased use of stock-options in compensation schemes, and *(iii)* the increase in hiring CEOs externally, as a result of the evolution of the type of skills required for a CEO job. Our model extends the current literature in the following way. Articles that have studied changes in CEO appointment also looked at the consequences on CEO pay *level* but ignored the *structure* of the compensation contracts. Conversely, articles that studied the pay level and the structure of compensation contracts (see, for example, Edmans, Gabaix and Landier (2009) for a

[1] Studying a sample of companies listed on The New York Stock Exchange, Hermalin and Weisbach (1988) find that that average percentage of outside directors on board increased from 37.6% in 1971 to 53.9% in 1983. Studying a sample of firms listed on the London Stock Exchange, Dahya, McConnell and Travlos (2002) find that the average percentage of outside directors in boards increased from 35% in 1989 to 69% in 1999.

recent contribution), did not address the issue of CEO appointment. This paper aims at filling the gap between these two sets of articles.

Formally, we study a standard principal-agent model in which shareholders of a firm need to appoint a new CEO. Managing a firm requires both firm-specific and general skills, and for each type, a manager is either high-skilled or low skilled. The firm runs projects and higher skills translate into a shift to the right of the probability distribution of project values if effort is exerted. Two types of candidates are considered for the CEO position. An internal candidate with perfectly known skills and an external candidate about whom there is uncertainty about his firm-specific skills.

We do not impose any cash constraint on the side of the principal. The only restriction set on the space of contracts is that, following Innes (1990) or Palomino and Prat (2003), contracts must be non-decreasing. Hence, we allow for cash incentives of any shape and any type of equity-based compensation as long as the total reward remains non-decreasing.

First, we analyze the contract proposed to an internal candidate. In such a case, the firm faces a pure moral-hazard problem. We derive conditions under which the optimal contract is *uniquely* a bonus contract. We also show that this bonus contract may be more or less sophisticated, i.e., may have one or more performance thresholds depending on the distribution of firm values.

Second, we analyze the contract proposed to an external candidate. Due to the asymmetric information about his skills, the firm faces both moral-hazard and adverse-selection problems. We derive (sufficient) conditions under which it is optimal for the principal to offer stock-options as part of the optimal contractual arrangement, even if optimal contracts are uniquely bonus contracts in the pure-moral-hazard case. Formally, the firm offers a menu of contracts, one of them including stock options, the other being a pure bonus contract. A high type agent selects the contract with stock options, while a low-type agent selects the pure bonus contract.

These results show that bonuses and stock-option are compensation tools used for different purposes, the former addressing moral-hazard issues while the latter may be used as a screening device. The presence of both cash bonuses and stock options in optimal compensation schemes is also consistent with empirical evidence provided by Murphy (1999) who shows that only a fraction of CEOs are awarded equity, and in studies released by consultancies that show that in many countries cash bonuses is the main source of variable pay (see Table 1).

Then turning to the optimal CEO choice, we show that as the importance of general skill increases relative to firm-specific skills, then the hiring of external candidates increases, and so do the use of stock options and the average CEO compensation.

The organization of this paper is as follows. Section 2 reviews the related literature. Section 3 presents the model. In Section 4, we derive the optimal contract for the internal candidate, hence in a pure moral-hazard environment. In Section 5, we then turn to the derivation of the optimal contract for an external candidate, hence considering a setting in which the principal faces both moral hazard and adverse selection problems. Section 6 studies the optimal CEO choice and how a change in the economic environment in which the firm operates may change the structure and level of CEO pay. Finally, Section 7 discusses some extensions of the model while Section 8 concludes. All proofs are in Appendix.

2 Related Literature

Our article is related to two aspects of CEO compensation that have often been studied separately. First, the optimal structure of CEO compensation, which deals with the pay-performance sensitivity, and second the level of CEO compensation. In a principal agent framework, the first issue is related to incentive compatibility constraints, while the second issue is related to the participation and limited liability constraints.

2.1 Optimal Structure for CEO compensation packages

A large body of literature has focused on the optimality of stock-option plans. The common feature of most of these articles is that they focus on the standard insurance-incentive trade-off, i.e., they study under what conditions stock options are optimal compensation tools in a pure moral-hazard setting (See, for example, Dittman and Maug (2007) and references therein). Furthermore, the contracting space is often restricted to equity-based incentive tools and, therefore, bonus contracts are ruled-out by assumption (Aseff and santos (2005), Dittman and Maug (2007), Choe (2006), Armstrong, Larcker, and Su (2007), Kadan and Swinkels (2007), and Stoughton and Wong (2008)). In contrast, some authors have used alternative frameworks to provide a rationale for the use of stock-options. O'Reilly, Crystal and Main (1988) and Bebchuk and Fried (2003) consider that agents have rent-seeking concerns. Hall and Liebman (1998) adopt a behavioral perspective by suggesting that stock-options are used because they are *"a less visible vehicle for paying CEO than salary and bonuses"*. De Meza and Webb (2007) and Dittmann, Maug and Spalt (2010) show that stock-options can be optimal if CEOs exhibit loss aversion. Finally, an explanation often offered by business practitioners themselves is that granting non-vested options is a way to retain employees.[2] Our article offers a different perspective by assuming that managers are heterogenous and that

[2] see Lazear (2005) for a discussion on the limits of such an argument.

firms suffer from lack of information regarding managers' ability. Hence, by allowing for *both* adverse selection and moral hazard, we show that several types of compensation packages, some of them mixing bonus and stock-options, may co-exist in equilibrium. The use of stock-option as a screening device is also studied by Cadenillas, Cvitanic and Zapatero (2005). However, they restrict their attention to equity-based compensation. Our perspective is also different from that of Oyer (2004) and Oyer and Schaefer (2005) who advocate that stock-option is a way to attract optimistic managers. We mainly differ from these last two articles on the ground that our agents are aware of their true ability.

Lazear (2000) also considers the impact of heterogenous agents on the structure of contracts. He shows that in a setting where contracting with low types entails continuing projects with negative net present value, equity can be used a selection device. We differ from Lazear's analysis in several aspects. First, Lazear (2000) considers a unique contract for both types of agents whereas we assume that the principal is allowed to offer a menu of contracts. We show that, in this case, heterogeneity of agents and asymmetric information regarding types cannot be a sufficient condition to optimally implement equity-based compensation schemes, only. Second, Lazear's (2000) result is that, in a setting with heterogenous agents, bonus plans will generate some inefficiencies. We extend this result by explicitly showing that mixing a bonus plans and stock-options in the contract offered to the high-skill agents can be an optimal strategy for a firm.

Our results are also related to those derived in the literature on non-linearities and flat wages. Several theories already address such a question. The first one is the *efficiency wage* theory initiated by Shapiro and Stiglitz (1984) and relies on the impossibility to contract on output. The *multi-tasks* theory developed by Holmström and Milgrom (1991) adds to such impossibility the fact that agents carry out multiple activities and choose the allocation of their effort based on offered contracts. We differ from these two theories on the ground that, following standard contract theory, we assume that 1) effort is non contractible and 2) the principal needs to rely on the realization of a single-task to evaluate the agent. In contrast, our restriction on the set of contracts stems from limited liability and monotonicity constraints.

The optimality of flat contracts when agents have limited liability has also been derived by Palomino and Prat (2003) but in a context of portfolio selection with an emphasis on risk-related moral hazard. Given that limited liability convexifies reward schemes in the low-performance region, risk-taking incentives are generated. They show that a bonus-contract, by capping the reward in case of good performances, reduces these risk-taking incentives.

Park (1995) and Kim (1997) show, in a pure moral hazard setting that a discrete bonus associated to a performance standard may lead to first-best agent effort. Such contract is one way, among others, for the firm of achieving the first-best solution. In a related contribution, Oyer (2000) extends the result of Park (1995) and Kim (1997) and shows that, when the participation constraints are non binding, a bonus scheme can be preferable to all other mechanism. Our article extends his result to a heterogeneous-agent framework with adverse selection on the side of the principal. We then show that, a bonus scheme remains uniquely optimal for low-type agents but that, in contrast, a combining a bonus plan and a stock-options can be part of an optimal arrangements for high-type agents.

2.2 On compensation levels

As evidence provided by Frydman and Saks (2005) shows, CEO compensation was almost flat between the end of World War II and the mid-1970s, and then rose dramatically in the 1980 and the 1990s. Much of the debate on the efficiency of CEO compensation was then fuelled by the observed pay raise in this latter period. Several explanations have been offered for this increase in CEO compensation.

Murphy and Zabojnik (2004, 2007) and Frydman (2005) suggest that the transformation of the environment in which firms operate increased the value of general skill relative to firm-specific skills. As a consequence, competition between firms to hire the most talented agents increased, leading to an increase in the external filling of CEO vacancies and of the compensation of agents with the highest general skills.

Our model borrows from these articles since our starting point is also that firm-specific and general skills are required to run a firm, and that a shift in the relative importance of those two types of skills occurred in the recent past, general skills getting more important. However, there are two main differences between our model and those of Murphy and Zabojnik (2004, 2007) and Frydman (2005). First, in our model, agents' bargaining power does not increase as the shift occurs. Still, we find that CEO compensation increases as the hiring of CEOs externally increases. Second, we also study the *structure* of the compensation contract, and show that the hiring of CEOs externally is accompanied by the use of stock-options in compensation contracts.

Hermalin (2005) studies how CEO monitoring by boards of directors influences CEO appointment (i.e., internally or externally) and compensation levels. He shows that through greater board diligence, more external candidates become CEO, tenure duration shortens and compensation increases. The main differences between Hermalin's article and ours is that, when studying compensation scheme, we assume that the firm faces both morals hazard and adverse selection.[3] As a consequence, in our model, the optimal contract is performance-based. As a consequence, we can study the structure of the compensation contract and show that several types of compensation tools are used in equilibrium.

Gabaix and Landier (2008) consider a model in which CEOs have different levels of managerial talent and are matched to firms competitively. They show that CEO's equilibrium pay is increasing with both the size of his firm and the size of the average firm in the economy. Edmans *et al* (2009) extend Gabaix and Landier (2008) by considering the structure of the compensation contract. As in Gabaix and Landier's paper, the total pay level is determined by the agent's marginal productivity. Hence, pay levels are entirely determined by talent, not by incentives considerations. Incentive considerations only affect the division of total pay into cash and stock components. One of the main differences between these two models and ours is that they assume firms have perfect information about potential CEOs, while we assume there is asymmetric information about the quality of external CEO candidate. As a consequence, in the models of Gabaix and Landier (2008) and Edmans *et al* (2009), the choice between appointing an outsider or an insider as CEO is not an issue.

Finally, a last argument put forward for the increase in CEO pay is entrenchment: CEOs use captive boards of directors to deal themselves large increases in pay at the expense of companies' shareholders (see Bebchuck *et al*, 2003). As already mentioned, our model does not rely on CEO bargaining power. Still, we show that an evolution of the economic environment may lead to an increase in CEO pay. In our model, CEO extract rents only through asymmetric information (either about their action or skill levels).

2.3 Others

Our model is also related to models dealing with moral hazard and adverse selection in various contexts. Those deriving the possibility of separating equilibria can be put into two categories. In the first one, the effort of the agent modifies the support of output (e.g., Laffont and Tirole (1986), Picard (1987), Guesnerie, Picard and Rey (1988), Zou (1992, Section 3), Laffont (1995), Holmström (1999), Bernardo, Cai and Luo (2001), Theilen (2002), Sung (2005)). In the second one, effort only modifies the distribution of outputs. However, a key assumption of these models is that agents do not face limited liability constraints so that large type-dependent penalties can be imposed in case of bad realized performances (e.g., Heinkel and Stoughton (1993)). In contrast, we combine adverse selection and moral hazard in a different class of models, namely those in which effort only modifies

[3] In Hermalin (2005), the CEO receives a flat wage determined only by the participation constraint being binding.

the distribution of output but where agents have limited liability. Whinston's (1983) model is also developed in such a framework but, given that he restricts the analysis to two different levels of output, only pooling equilibria naturally emerge.

3 The Model

We consider a principal-agent model building upon the models of Murphy and Zabojnik (2004, 2007), Frydman (2005) and Hermalin (2005).

THE FIRM. Shareholders of a firm (the principal) delegate its management to a CEO (the agent).[4] This management requires two types of skills: general skills that are transferable across firms and firm-specific skills that are not transferable. In each type of skills, an agent is either high skilled (H) or low-skilled (L). An agent is then described by a pair $(i, j) \in \{H, L\} \times \{H, L\}$, i and j corresponding to general and firm-specific skills, respectively.

The firm has one ongoing project which value v is the realization of a random variable $\tilde{v}$ and belongs to an interval $[\underline{v}, \bar{v}]$, where $\underline{v} \geq 0$ and $\bar{v}$ could be $+\infty$.

The probability distribution of $\tilde{v}$ depends on the magnitude of the effort $e \in \{e_l, e_h\}$ exerted by the agent and his ability. Whenever the agent exerts a low effort ($e = e_l$), the probability distribution of $\tilde{v}$ is $Q(.)$, independently of the type of the agent. In contrast, when a high effort is exerted by the agent ($e = e_h$), the probability distribution of v is type dependent. For an agent of type (i, j) choosing $e = e_h$, the probability distribution of $\tilde{v}$ is $P_{ij}(.)$. Exerting a high effort e_h involves a non-pecuniary cost c whereas a low effort (e_l) is costless. We denote $p_{ij}(n)$ and $q(n)$ the probability densities associated to $P_{ij}(.)$ and $Q(.)$, respectively, i.e., $P_{ij}(w) = \int_{\underline{v}}^{w} p_{ij}(v)dv$ and $Q(w) = \int_{\underline{v}}^{w} q(v)dv$. We also denote $E_{ij}(v|e_h)$ the expected value generated by agent of type (i, j) when a effort is exerted and $E(v|e_l)$ the expected value generated by any type of agents when a low effort is exerted. The value of the firm is then defined as being the value of the project net of compensation expenses.

We make the following assumptions regarding the probability distributions.

Assumption 1 *The probability distributions when exerting a high effort (P_{ij}, $i, j = H, L$) dominate the probability distribution when exerting a low effort (Q) in the sense of First-Order Stochastic Dominance (FOSD).*

Assumption 2 *The probability distributions P_{Hj} and P_{iH} ($i, j = H, L$) dominate the probability distributions the probability distributions P_{Lj} and P_{iL}, in the sense of FOSD, respectively.*

[4] Shareholders are taken to be investors with funding but either no time nor skills to run the firm.

Finally, we define the function

$$CLR_{ij}(v) \equiv 1 - \frac{1 - Q(v)}{1 - P_{ij}(v)} \tag{1}$$

as the "cumulated" likelihood-ratio function. It defines the relative incremental probability that an agent of type (i, j) reaches at least a project value v when exerting a high level of effort rather than a low one. As discussed below, the cumulated likelihood-ratio function will play an important role in our analysis since we do not restrict our attention to families of probability distributions satisfying the monotone likelihood ratio property (MLRP hereafter).

CEO CANDIDATES. There are two types of candidates, insiders (or internal candidates) who are either current or former employees of the firm, and outsiders (or external candidates) who have never been employees of the firm.

The information of the shareholders about a candidate's skills depends on whether he is an insider or an outsider. If the candidate is an insider, shareholders have perfect knowledge of both his firm-specific and general skills. Conversely, if considering an outsider, shareholders have perfect knowledge of the general skills of the candidate, but not about his firm-specific skills. Shareholders believe that the candidate has high firm-specific skills with probability $\theta \in (0, 1)$, and low firm-specific skills with probability $1 - \theta$.

We additionally assume that there is a large pool of outsiders so that the firm can always find a candidate with a high level of general skills. Therefore, external candidates considered by the firm are of quality (H, H), with probability θ, and of quality (H, L), with probability $1 - \theta$. In a symmetric way, we assume that there is always an internal candidate with high firm-specific skills, so that the internal candidate is either of type (H, H) or (L, H).

On their side, candidates are assumed to have a perfect knowledge of their skills. This assumption may seem extreme, in particular that an external candidate perfectly knows his level of firm-specific skills. However, our results go through as long as outsiders are better informed than the shareholders of the firm about their skills.

THE CONTRACTS. Though the effort exerted by a CEO is not observable, the realized project value is observed. Therefore, the effort level chosen by the appointed CEO can be influenced by the compensation contract he is offered. Assuming that CEOs have limited liability normalized here at zero, a compensation contract is then defined as a mapping $t(.)$ from $[\underline{v}, \bar{v}]$ to $[0, +\infty)$ that specifies the transfer $t(v)$ the CEO receives if the project value v is realized.

We also make the technical assumption that a feasible contract has a finite number of discontinuities and, following Innes (1990) and Palomino and Prat (2003), impose that reward scheme be non-decreasing in outcome. The reason for this latter assumption is that whenever the contract is non-monotonic and the realized performance falls in a subset of performance levels for which the compensation scheme is decreasing, then the manager has incentives to sabotage performance.[5] Implicitly, it entails that the manager can manipulate the value of the project downward at no personal cost. Considering that the reward scheme must be non-decreasing eliminates such concerns for manipulation.

Before entering the core of the analysis, we define the following structures of contracts.

Definition 1

1. *A k-step bonus contract* $B(X_1, \ldots, X_k, t_1, \ldots, t_k)$ *is defined by* k *different value thresholds* $(v_1, v_2, ...v_k)$ *(with* $\underline{v} < v_1 < \ldots < v_k < \bar{v}$*) and* $k+1$ *different functions* $t_1(.), t_2(.), ..., t_{k+1}(.)$ *such that, for all* $i \in \{1, ...k+1\}$*, if a project value* v *is realized, then the agent receives*

$$\begin{cases} t_1(v) = a_1 & \text{if} \quad v_0 \leq v < v_1 \\ t_{i+1}(v) = t_i(v_i) + a_{i+1} + b_{i+1}v & \text{if} \quad v_i \leq v < v_{i+1} \\ t_{k+1}(v) = t_k(v_k) + a_{k+1} & \text{if} \quad v \geq v_k \end{cases}$$

   With $a_i \geq 0$ *and* $b_i \geq 0$.

2. *An option contract* $O(\hat{v}, \beta)$ *is defined by an exercise price* $\hat{v}$ *and a payoff* $\beta(v - \hat{v})$ *if the project value* $v \geq \hat{v}$ *is realized, and 0 otherwise.*

3. *A contract of stocks* $S(\alpha)$ *is defined by an attribution of a stake* α *of the project for the agent generating a payoff* αv *if the project value* v *is realized.*

The main differences between the three types of contract can be described as follows. Whenever based on stocks, the compensation increases linearly with the performance. Under an option contract, there exists a threshold (the exercise price) below which the agent receives no monetary reward and above which the compensation is linearly increasing in the firm value. Finally, bonus contracts are characterized by several thresholds. Below the lowest threshold and above the highest one, the compensation is flat.[6] In the interval between the lowest and the highest thresholds - usually called the incentive zone - the compensation is (weakly) increasing in performance. Hence, the main difference between an equity grant (either stock or stock-options) and a bonus contract is that the latter is characterized by a threshold beyond which the compensation is flat, which is never the case under equity grants.

[5] See Innes (1990) for more on this point.

[6] All thresholds coincide in the case of a 1-step bonus contract.

The objective of the shareholders. Shareholders aim at maximizing the value of the firm (i.e., the value of the project net of compensation expenses) under the constraint that the CEO chooses a high effort level.[7]

It has often been advocated that, in the case of top executives, the main concern is not to provide incentives for effort but rather for taking proper decisions. An alternative interpretation of the model described above is then to consider the CEO as someone who has some expertise regarding the proper decision to be taken. In such a case, the strategic decision of the shareholders is not to provide incentives for effort but rather to encourage the manager to take the right decision, which will affect positively the expected return of a project. In this setting, taking decision e_h is the decision in the interest of the firm, but the CEO derives some private benefits c from taking decision e_l. The problem faced by the shareholders is then identical to the one we describe below. As a consequence, the offered contract and the decision of the CEO would be identical in both settings.[8]

Finally, as in Hermalin (2005, section V), we assume that there are many CEO candidates and few firms so that firms have all the bargaining power in negotiating compensation contracts.

Timing. First, Shareholders observe the type of the internal candidate. Second, shareholders decide whether to make an offer to the internal or to an external candidate. Third, a take-it-or-leave-it offer is then made to the chosen candidate. Fourth, the selected candidate chooses his effort level. Fifth, the project value is realized and observed, and last transfers take place.

Given the nature of the problem, it is solved by backward induction. That is, first, the optimal contract for each type of CEO candidate (internal or external) is derived. Then, given the expected project value and compensation transfers associated to each type of candidate, shareholders select a candidate.

Before proceeding, it should be mentioned that, though we consider a one-period model (i.e., one realization of the project value), our analysis goes through if we consider a multi-period model and a multi-period contract offered at the time the CEO is appointed and valid for the entire tenure duration. Considering the negotiation of a new contract after the first one expires would require to take also into account the career concerns of the CEO. This is beyond the scope of this paper.

[7] Implicitly, we assume that, whatever the type of the agent, the effort cost is small with respect to the increase in the value of the firm's assets generated by exerting a high rather than low effort.

[8] A related issue is studied by Prendergast (2000, 2002). However, as the input (i.e., the decision of the agent) is not observable in our model, our issue is not about choosing between input based or output based compensation. Rather, we are focusing on the choice between different forms of output based compensation schemes.

4 Contract offered to an internal candidate

If a contract is offered to an internal candidate, shareholders have a perfect knowledge of the quality of the candidate. Therefore, the problem of the shareholders is to provide incentives to exert effort (i.e., choose $e = e_h$). In such a case, the maximization program of the shareholders can be defined as follows.

$$Max_{t_{ij}} \int_{\underline{v}}^{\bar{v}} (v - t_{ij}(v))p_{ij}(v)dv$$

subject to

(i) Incentive-compatibility constraints

$$\int_{\underline{v}}^{\bar{v}} (p_{ij}(v) - q(v))\, t_{ij}(v)dv \geq c \quad \forall i, j = H, L \tag{2}$$

(ii) Limited-liability constraint

$$t_{ij}(v) \geq 0, \quad \forall v \tag{3}$$

(iii) Non-decreasing-contract constraint

$$t_{ij}(v') \geq t_{ij}(v) \quad \forall v \text{ and } v' \geq v. \tag{4}$$

(iv) Participation constraint

$$\int_{\underline{v}}^{\bar{v}} t_{ij}(v)p_{ij}(v)dv - c \geq 0 \quad \forall i, j = H, L \tag{5}$$

We derive the following result.

Proposition 1

- *Suppose that $CLR_{ij}(.)$ reaches its global maximum at a single state $v^* < \bar{v}$, then the unique optimal contract is the one-step bonus contract $B(v^*, T_{ij}(v^*))$ with*

$$T_{ij}(v) = \frac{c}{Q(v) - P_{ij}(v)} \tag{6}$$

- *Suppose that $CLR_{ij}(.)$ reaches its global maximum at k (with $k \geq 1$) different states $\{v_1^*, \ldots, v_k^*\}$. If $v_k^* < \bar{v}$, then, all optimal contracts are i-step bonus contracts with $i \in \{1, \ldots, k\}$.*

Proposition 1 states that if the principal only faces a moral hazard problem, there are many cases in which all optimal contracts take the simple form of bonus contracts. The intuition for this result is the following. By constraining the wage scheme to be monotonic, the strategic decision of the principal is to choose for what project value and by which amount to *increase* the agent's pay. Adapting the standard intuition absent monotonicity constraints (based on likelihood ratios), we get the result that the agent receives an increase in salary when a project value v is realized, if reaching *at least* such a performance level is the best inference that a high level of effort has been realized. For such a threshold, the CLR function is then maximized.

If MLRP does not hold, CLR_{ij} can reach its global maximum for some project value $v < \bar{v}$. If this global maximum is unique, then Proposition 1 states that, in such a case, the unique optimal contract is a one-step bonus with threshold v^*_{ij}.[9]

Now, the second possibility when MLRP does not hold is that the CLR_{ij} reaches its global maximum in $k > 1$ states. Applying the same reasoning as in the case $k = 1$, we obtain that any contract that generates a salary increase in a state in which the CLR_{ij} reaches a global maximum is optimal. This implies that if the CLR_{ij} does not reach a global maximum in state $\bar{v}$, all optimal contracts are i-step bonus contracts with $i \in \{1, \ldots, k\}$. This result is consistent with the general shape of bonus contracts described in Murphy (1999) who explains that most bonus contracts are characterized by a first threshold (the lowest) below no bonus is paid and a last threshold (the highest) beyond which the bonus is flat. In the zone between these two thresholds (the incentive zone), the bonus is increasing in performance.

Before proceeding, it should be mentioned that the first part of Proposition 1 is related to the results of Oyer (2000) who establishes that, in the presence of limited liability, if 1) hazard rate functions are not monotonically increasing in outputs and 2) the distribution of outputs with a high effort dominates, the distribution of outputs with a low effort in the sense of hazard-rate dominance, then bonus contracts are optimal. Our condition that the CLR_{ij} reaches its global maximum at some $v^*_{ij} < \bar{v}$ is weaker than hazard-rate dominance since it is possible to have the CLR_{ij} reaching its global maximum at some $v^*_{ij} < \bar{v}$ without hazard-rate dominance.

An example

Finally, we wish to provide an example of a family of probability distributions such that the conditions of Proposition **??**, are satisfied, i.e., the cumulated likelihood ratio function has an interior global maximum.

[9] Note also that if the Likelihood ratio function $LR_{ij}(.)$ is single-peaked and reaches its maximum in some state $v^o_{ij} < \bar{v}$, then $v^*_{ij} < v^o_{ij}$. These proofs are available from the authors upon request.

Let $\underline{v} = 0$, $\bar{v} = 1$, and consider the following family of density functions

$$\begin{cases} p(\alpha, v) = \frac{1+\alpha}{\alpha} v & \text{if} \quad v \in [0, \alpha) \\ p(\alpha, v) = \frac{1-\alpha v}{1-\alpha} & \text{if} \quad v \in [\alpha, 1] \end{cases} \tag{7}$$

Where α is a parameter taken from $[0, 1)$. Furthermore, define $P(\alpha, v)$ the cumulative distribution function associated to $p(\alpha, v)$. This family of probability distributions is such that if $\alpha_1 > \alpha_2$ then $P(\alpha_1, .)$ dominates $P(\alpha_2, .)$ in the FOSD sense, and $P(0, .)$ is the uniform distribution function over the interval $[0, 1]$. Hence, this family of probability distribution is such that in the interval $\left[0, \frac{\alpha}{1+\alpha}\right]$, if $\alpha > 0$ then $p(\alpha, v) < p(0, v)$ while on the interval $\left[\frac{\alpha}{1+\alpha}, 1\right]$, $p(\alpha, v) > p(0, v)$.

In what follows, we then assume that $q(v) = p(0, v)$, $p_{ij}(v) = p(\alpha_{ij}, v)$, $(i, j = H, L)$, with $\alpha_{HH} > \alpha_{HL} > \alpha_{LL}$ and $\alpha_{HH} > \alpha_{LH} > \alpha_{LL}$. It implies that CLR_{ij} has a unique global maximum which is reached at $v^*_{ij} = 1 - \left(\frac{1-\alpha_{ij}}{1+\alpha_{ij}}\right)^{1/2}$. As a consequence, the conditions of Proposition 1 are satisfied. Therefore, the unique optimal contract for an internal candidate of type (i, j) is $B\left(v^*_{ij}, \frac{c}{P(0,v^*_{ij})-P(\alpha_{ij},v^*_{ij})}\right)$.

5 Optimal contract for an external candidate

We now turn to the case of an external candidate about whom there is asymmetric information about firm-specific skills. The problem of the shareholders is now

$$Max_{(t_{HL},t_{HH})}\theta \int_{\underline{v}}^{\bar{v}} (v - t_{HH}(v))p_{HH}(v)dv + (1-\theta) \int_{\underline{v}}^{\bar{v}} (v - t_{HL}(v))p_{HL}(v)dv$$

subject to

(i) Incentive-compatibility constraints

$$\int_{\underline{v}}^{\bar{v}} (p_{Hi}(v) - q(v))\, t_{Hi}(v)dv \geq c \quad \forall i = H, L \tag{8}$$

(ii) Adverse-selection constraints

$$\int_{\underline{v}}^{\bar{v}} (t_{Hi}(v) - t_{Hj}(v))\, p_{Hi}(v)dv \geq 0 \quad \forall i, j = H, L \text{ and } i \neq j \tag{9}$$

$$\int_{\underline{v}}^{\bar{v}} (t_{Hi}(v)p_{Hi}(v) - t_{Hj}(v)q(v))\, dv \geq c \quad \forall i, j = H, L \text{ and } i \neq j \tag{10}$$

(iii) Limited liability constraints

$$t_{Hi}(.) \geq 0 \quad \forall i = H, L. \tag{11}$$

(iv) Participation constraints

$$\int_{\underline{v}}^{\bar{v}} t_{Hi}(v)p_{Hi}(v)dv - c \geq 0 \quad \forall i = H, L \tag{12}$$

(v) Non-decreasing-contract constraints

$$t_{Hi}(v') \geq t_{Hi}(v) \quad \forall v' \geq v, \quad \forall i = H, L \tag{13}$$

We start by providing the following additional notations. First, let

$$F(v,\theta) \equiv T_{HL}(v)\left[(1-\theta)(1-P_{HL}(v)) + \theta(1-P_{HH}(v))\right].$$

$F(v,\theta)$ represents the cost of offering the one-step bonus contract $B(v, T_{HL}(v))$ to both types of external candidates. Second, denote $HR_{ij}(.)$ the hazard rate function associated to the probability distribution $P_{ij}(.)$, i.e., $HR_{ij}(v) = \frac{p_{ij}(v)}{1-P_{ij}(v)}$. We derive the following results.

Proposition 2 *Assume that $F(v,\theta)$ reaches its global minimum at a single state $v_\theta^{**} \in (\underline{v}, \bar{v})$.*

1. *The equilibrium contract for a candidate of type (H, L) is unique and corresponds to the bonus contract $B(v_\theta^{**}, T_{HL}(v_\theta^{**}))$.*

2. *Assume that CLR_{HH} reaches its global maximum at a single state $v_{HH}^{*} \in (\underline{v}, \bar{v})$, and there exists a unique state $v^o \in (\underline{v}, \bar{v})$ such that for any $v < v^o$, $HR_{HH}(v) < HR_{HL}(v)$ and for any $v > v^o$, $HR_{HH}(v) > HR_{HL}(v)$. Then, if $v_\theta^{**} < min(v_{HH}^{*}, v^o)$ or $v_\theta^{**} > max(v_{HH}^{*}, v^o)$ there exists an equilibrium contract for an agent of type (H, H) composed of a bonus contract and stock-options.*

The first part of the proposition states that the compensation contract for an agent of type (H, L) is unique and takes the form of a bonus contract. This optimality of bonus contracts is consistent with empirical evidence provided either in the academic literature (Holthausen *et al* (1995) and Murphy (1999)) or in studies released by consultancies (see, for example, Table 1, in Appendix) that illustrate that in many countries, cash bonuses are the most important or the unique component of variable pay.

The second part of the proposition then establishes that stock options is be part of an equilibrium contract for an agent of type (H, H). A sufficient condition for this result to be obtained is that there exists a state V that is less likely than the state v_θ^{**} to be outperformed by an agent of type (H, L), either exerting or not exerting effort, relative to an agent of type (H, H) exerting effort. Formally, it must be the case that *(i)* $\frac{1-Q(v_\theta^{**})}{1-P_{HH}(v_\theta^{**})} > \frac{1-Q(V)}{1-P_{HH}(V)}$ and *(ii)* $\frac{1-P_{HL}(v_\theta^{**})}{1-P_{HH}(v_\theta^{**})} > \frac{1-P_{HL}(V)}{1-P_{HH}(V)}$. This two conditions imply that, whatever the effort level, an agent of type (H, L) strictly prefers the bonus contract $B(v_\theta^{**}, T_{H,L}(v_\theta^{**}))$ to a bonus contract $B(V, T)$ that provides the agent of type (H, H) with the same expected transfer as the bonus contract $B(v_\theta^{**}, T_{H,L}(v_\theta^{**}))$. As consequence, there is room to design an optimal contract for the agent of type (H, H) that mixes a bonus contract $B(T', V)$ with $T' < T$ and some stock-options.

The condition that CLR_{HH} is maximized at $v^*_{HH} \in (\underline{v}, \bar{v})$ ensures that there exists an interval such that condition *(i)* is verified, while the assumption that there exists a unique state $v^o \in (\underline{v}, \bar{v})$ such that for any $v < v^o$, $HR_{HH}(v) < HR_{HL}(v)$ and for any $v > v^o$ $HR_{HH}(v) > HR_{HL}(v)$ ensures that there exists an interval such that condition *(ii)* is satisfied. Finally, if $v^{**}_\theta < \min(v^*_{HH}, v^o)$ or $v^{**}_\theta > \max(v^*_{HH}, v^o)$, then the intersection of these two intervals is non-empty.

The comparison of the results derived in Propositions 1 and 2 shows that bonus plans and stock-options are compensation tools addressing different issues, where bonus plans are used as a device aiming at reducing agency conflict whereas stock-options are used as a screening device, hence providing a rationale for their joint use in compensation contract.

Furthermore, these results are consistent with empirical evidence. First, according to Murphy (1999), the typical executive compensation package contains three components: a base salary, an annual cash bonus and equity (stock options and/or restricted stocks), this compensation structure being observed worldwide. Second, according to Towers Perrin's *Worlwide Total Remuneration Report 2005-2006*, in many countries such as Argentina, Australia, Belgium, Germany, India, Mexico, The Netherlands, Poland, Taïwan, Spain and Venezuela, CEOs receive both cash bonuses and equity and cash bonuses represent a larger share of the total remuneration than equity. Finally, the result obtained from the comparison of Propositions 1 and 2 that stock-option are only offered to an external candidate is consistent with the results of Hartzell and Parrino (2009, Table 3.B) who study CEO employment agreements and find that, with respect to the median CEO with an implicit employment agreement, the median CEOs with an explicit employment agreement *(i)* has a higher fraction of his total remuneration which is stock-based and *(ii)* is more likely to have been appointed from outside the firm.

Our results have also implications regarding the empirical testing of the efficiency of executive compensation contracts, suggesting that using the equity component of compensation contracts to test this efficiency may not be appropriate.[10] The reasons are, first, that in a pure moral hazard environment, equity may be a second best compensation tool used only if firms are cash constrained. Second, if firms face both moral hazard and adverse selection problems, the use of equity aims at screening agents and not primarily at improving performances. Therefore, our results suggest to take

[10] See, for example, Garen (1994), Yermack (1995), Core and Guay (1999), Dittman and Maug (2006), Armstrong, Larcker and Su (2007) for empirical studies on the efficiency of compensation contract focusing on the equity component of the compensation.

into account the cash-bonus component of the compensation contract when testing the efficiency of these contract, above all when considering non-US firms, for which cash bonuses represent often the largest share of variable compensation.

An example

We consider the same family of density function as in the example of the previous section, i.e.,

$$\begin{cases} p(\alpha, v) = \frac{1+\alpha}{\alpha} v & \text{if} \quad v \in [0, \alpha] \\ p(\alpha, v) = \frac{1-\alpha v}{1-\alpha} & \text{if} \quad v \in [\alpha, 1] \end{cases} \tag{14}$$

For this family of density functions, it can be shown that the associated function $F(\theta, v)$ reaches its global minimum at

$$v_\theta^{**} = \frac{(1+\alpha_{HL})\alpha_{HH} + \left[2\theta\alpha_{HH}\alpha_{HL}(\alpha_{HH} - \alpha_{HL}) + \alpha_{HH}^2(1-\alpha_{HL}^2)\right]^{1/2}}{\alpha_{HH}(1+\alpha_{HL}) - \theta(\alpha_{HH} - \alpha_{HL})}$$

while

$$v^o = \frac{2(1+\alpha_{HH}) - \alpha_{HL}(1-\alpha_{HH}) - \left[(2(1+\alpha_{HH}) - \alpha_{HL}(1-\alpha_{HH}))^2 - 8\alpha_{HH}(1+\alpha_{HH})\right]^{1/2}}{2(1+\alpha_{HH})}$$

Hence, for any $\theta \geq 0$, and $\alpha_{HL} \in (0, \alpha_{HH})$, we have $v_\theta^{**} < v_{HH}^* < v^o$. As a consequence, the conditions of Proposition 2 for a separating equilibrium are satisfied.
As an illustration, assume that $c = 0.01$, $\theta = 0.5$, $\alpha_{HL} = 0.5$, and $\alpha_{HH} = 0.75$. For such parameter values, we obtain that $v_{0.5}^{**} = 0.407$, $v_{HH}^* = 0.622$ and $v^o = 0.695$, and the unique optimal contract for an agent of type (H, L) is $B(v_{0.5}^{**}, T^{**})$ with $T^{**} = 0.0631$. For an agent of type (H, H), there exists an equilibrium contract composed of a stock option contract $O(\alpha_{HH}, 0.01)$, i.e., the CEO is offered 1% of the project value if the value exceeds α_{HH}, and a bonus contract $B(\alpha_{HH}, T^o)$ with

$$T^o = \frac{T^{**}[1 - P(\alpha_{HH}, v_{0.5}^{**})] - 0.01\int_{\alpha_{HH}}^1 (v - \alpha_{HH})p(\alpha_{HH}, v)dv}{1 - P(\alpha_{HH}, \alpha_{HH})} = 0.1394$$

6 Optimal CEO choice

Having derived the optimal (menu of) contracts proposed to an internal or an external CEO candidate, we can now turn to the optimal CEO choice.
Additionally, we want to study how the choice and the compensation of a CEO are affected by a shift from the predominance of firm-specific skills to the predominance of general skills. In this respect, we follow Murphy and Zabojnik (2004, 2007).

In order to capture the increasing importance of general skills relative to firm-specific skill, we distinguish two regimes. In the first one, firms-specific skills are the predominant type of skills, hence we assume that P_{LH} dominates P_{HL} in the FOSD sense (FS-regime hereafter). Conversely, in the second regime, general skills are the predominant type of skills, hence P_{HL} dominates P_{LH} in the FOSD sense (G-regime hereafter). Formally, we make the following assumption.

Assumption 3 *Consider any two probability distributions P_1 and P_2 such that*

$$P_{HH} >_{fosd} P_1 >_{fosd} P_2 >_{fosd} P_{LL}.$$

(where $P_1 >_{fosd} P_2$ means that P_1 dominates P_2 the FOSD sense.)
Under the FS-regime, $P_{LH} = P_1$ and $P_{HL} = P_2$, while under the G-regime, $P_{HL} = P_1$ and $P_{LH} = P_2$.

In our model, a CEO impacts the value of the firm in two ways. First, through the expected value of the project, and second through the expected compensation cost since all compensation costs are expensed in our model.
We then derive the following results regarding the optimal CEO choice.

Proposition 3
(i) Assume that the internal candidate is of type (H, H). Then, he is always the hired candidate.
(ii) Assume that the internal candidate is of type (L, H). Then, switching from the FS-regime to the G-regime, the hiring of external candidates increases. (Formally, for any set of parameters such that an external candidate is hired under the FS-regime, an external candidate is hired under the G-regime, and there exist sets of parameters such that the internal candidate is hired under the FS-regime while an external candidate is hired under the G-regime.)

If the internal candidate is of type (H, H) then, for any θ, an external candidate generates a lower expected project value and a higher expected compensation. As a consequence, the internal candidate is always preferred to an external one. If the internal candidate is of type (L, H), then the benefits of hiring an external depends on whether $E_{HL}(V|e_h) > E_{LH}(V|e_h)$ or $E_{HL}(V|e_h) < E_{LH}(V|e_h)$. The first inequality holds under the G-regime while the second holds under the FS-regime. Moreover, shifting from the FS-regime to the G-regime, the expected compensation of an internal candidate of type (L, H) increases while that of an external candidate decreases due to the fact that $P_1(.)$ dominates $P_2(.)$ in the FOSD sense. As a consequence, hiring an external candidate is more profitable under the G-regime than under the FS-regime.

Finally, regarding the evolution of compensation expenses as a shift from the FS-regime to the G-regime occurs, we derive the following result.

Proposition 4 *Assume that the internal candidate is hired in the FS-regime. Then,*
(i) CEO compensation increases in case of shift from the FS-regime to the G-regime.
(ii) Under the G-regime, the compensation of externally hired CEOs is larger than the compensation of internally promoted CEOs.

If internal candidates are hired under the FS-regime and a shift of regime occurs, then three cases have to be considered. First, the internal candidate is of type (H, H). In such a case, he is hired under both regimes, and his compensation is unaffected change shift of regime. Second, the internal candidate is of type (L, H) and he is still the hired candidate under the G-regime. In such a case, external candidates are never hired, and the compensation of the selected CEO increases when the regime shift occurs since P_1 dominates P_2 in the FOSD sense. Third, the internal candidate is of type (L, H) and the external candidate is selected under the G-regime. In such a case, the expected CEO compensation increases through a regime shift due to the adverse selection concerns faced by the firm when hiring an external candidate. Hence, considering the three cases, we obtain the result that CEO compensation increases if a regime shift occurs (part *(i)* of the proposition). This result is consistent with empirical evidence about the increase in CEO pay over the last three decade, and the increased proportion of outsiders appointed as CEO.
Furthermore, since P_{HH} dominates P_{HL} in the FOSD-sense, then, under the G-regime, the compensation of an internally selected CEO of type (H, H) is lower than that of an externally selected candidate. It implies that if the external candidate is selected under the G-regime (this happens when the internal candidate is of type (L, H)), his compensation is larger than that of an internally selected candidate (who is of type (H, H)) under the G-regime (part *(ii)* of the proposition). This result is consistent with empirical evidence provided by Murphy and Zabojnik (2007) who document that the premium for external hires is about 15.3 percent.

7 Extension

7.1 Initial endowment

So far, we have assumed that CEO candidates have a zero stake in the firm. While this assumption is reasonable when considering an external candidate, this is not the case when considering the internal one. An internal CEO candidate may have been granted equity before being considered a CEO candidate.

Our model can be extended to take this equity ownership into account. Assume that the internal candidate owns a stake $\alpha_0 \geq 0$ in the firm which comes from equity he has been granted previously. As exerting effort shifts the probability distribution of the project value, it generates some positive payoffs through the initial endowment in equity. Let

$$c'_{ij} \equiv \frac{c - \alpha_0 \int_{\underline{v}}^{\bar{v}} (p_{ij}(v) - q(v))vdv}{1 - \alpha}$$

represent a normalized cost of exerting effort net of the gain generated by equity holding. Given that $c'_{iL} > c'_{iH}$ and $c'_{Lj} > c'_{Hj}$, $(i, j = H, L)$, we assume that $\alpha_0 < \frac{c}{\int_{\underline{v}}^{\bar{v}} (p_{HH}(v) - q(v))vdv}$, so that $c'_{HH} > 0$. This ensures that, in the absence of an incentive contract, the stake held by an internal candidate of type (H, H) is not sufficient to provide incentives to exert effort.

The problem of the shareholders is identical to that of Section 4 with c'_{ij} substituting c. Given that c'_{ij} is decreasing in α_0, we directly get the following result.

Proposition 5 *The larger the stake held by the internal candidate, the lower the transfer he receives.*

The value of the firm being the project value net of compensation expenses, a direct consequence of this result is that the value of the firm is positively correlated to the stake held by managers. This is is consistent with empirical evidence provided by Mehran (1995).

Another implication of the proposition is that for some parameter specifications there exists $\bar{\alpha} > 0$ such that if $\alpha_0 < \bar{\alpha}$ then an external candidate is hired while if $\alpha_0 > \bar{\alpha}$ then an internal candidate is hired. We can then derive the following testable implication regarding CEO appointment: the larger the stake held by top executives outside the CEO, the larger the probability that an outgoing CEO will be replaced by an insider.

7.2 Stock-option *vs* restricted-stocks

Though we have focused on stock-options so far, they are not the unique type of equity grant that managers may receive. As shown for example by Murphy (1999), restricted-stock grants are also frequently used in compensation packages. The following proposition establishes that restricted-stocks can also be used in compensation contracts designed for an external candidate of type (H, H).

Proposition 6 *Assume that the conditions of Proposition 2.2 are satisfied. Then, there also exists an equilibrium contract including restricted stocks for an external candidate of type (H, H).*

However, the proposition does not imply that for any set of parameters such that there exists an optimal contract including stock options, there also exists an optimal contract including restricted-stocks. As a matter of fact this is not the case, the reason being that with respect to stocks, options offer one more degree of freedom in the design of compensation contract: to some extent, stock-option contracts allow to play with the convexity of the compensation as a function of the performance. As a consequence, they are easier to implement as a screening device.

Turning to the comparison of the equilibrium contracts for agents of type (H, H) derived in Propositions 2 and 6, we get the result that the only difference lies in the structure of the incentive scheme but the expected cost to the principal is the same, i.e., partially contracting with options or partially contracting with stocks are two payoff equivalent reward schemes for an agent of type (H, H). This result is consistent with those of Carter, Lynch and Tuna (2007) who show that the allocation of stocks or options in the compensation package can vary from one agent to the other but that it has no impact on the total compensation CEOs receive. Choe (2006) provides a related theoretical result, namely, that restricted stocks and options can be equivalent optimal compensation tools. However, Choe (2006) derives this result under the condition that contracts rely only on stock market instruments which rules out bonus contracts.[11] In contrast, we have only restricted the space of contracts by considering non-decreasing reward schemes and, by doing so, we have shown that contracts mixing bonus schemes and restricted stocks, and contracts mixing options and bonus schemes can be equivalent optimal compensation contracts in the presence of moral hazard and adverse selection.

There are two underlying reasons for which the shareholders are indifferent between offering options or restricted stocks in our model. First, there is no difference in tax treatment between transfers in options or stocks, and second, all types of equity are expensed since the value of the firm is the project value net of compensation costs. If we introduce a favorable tax treatment for options in our model, then options will become the only type of equity used in the compensation package for an agent of type (H, H). However, the total compensation received by this agent will be unchanged. Therefore, removing a tax-advantage for options in our model may reduce their use (the firm is now indifferent between options and restricted stocks), which, again, is consistent with Carter, Lynch and Tuna (2007) who provide evidence that firms that start expensing options reduce the portion of options and, in contrast, increase the fraction of restricted-stock in the compensation package.

[11] As already mentioned, even if the market value of the firm is the only verifiable variable, nothing prevents a principal from writing a bonus contract with market-value thresholds.

8 Concluding Remarks

Over the last three decades, an unprecedent rise in CEO pay and an increase in the use of equity in the variable part of compensation packages have been observed, at least in the United States. However, another important change regarding CEOs took place over the same period: the way they are appointed. Increasingly, boards of directors choose a CEO outside the firm rather than by promoting an insider.

In this article, we have shown that *(i)* an increase in CEO pay level, *(ii)* an increased use of equity in compensation packages of CEOs and *(iii)* an increase in the choice of outsiders as CEOs may be the consequences of the same phenomenon: an evolution of the economic environment influencing the type of skills for the CEO job, general skills rather than firm-specific skill becoming the predominantly required type of skills.

One issue we have not addressed is how the tenure duration interacts with compensation structure and the choice between insiders and outsider for a CEO position. This is the objective of our future work.

Appendix

Proof of Proposition 1:

We proceed as in Palomino and Prat (2003), that is through a discretization of the original continuous problem.

Suppose that the principal is restricted to use contracts that have no more than n steps, where n is a positive integer. Having a finite number of discontinuities, $t_{ij}(.)$ is Riemann-integrable. Hence, as n tends to infinity, any contract $t_{ij}(.)$ is approximated by a n-step contracts.

Formally, for any n, we consider the following discretization. Let $v_0 = \underline{v}$, $v_m = \underline{v} + m(\bar{v} - \underline{v})/(n+1)$ and $v_{n+1} = \bar{v}$. A n-step contract is defined by thresholds v_m $(m = 1, \ldots, n)$ and $n+1$ compensation levels t_{ij}^m $(m = 1, \ldots, n+1)$, with t_{ij}^m non decreasing in m.

If n is held fixed and the principal is restricted to using n-step contracts, then the principal's problem becomes

$$\max_{t_{ij}^m} E_{ij}[v|e = 1] - \sum_{m=1}^{n+1} t_{ij}^m (P_{ij}(v_m) - P_{ij}(v_{m-1}))$$

Subject to

$$\sum_{m=1}^{n+1} t_{ij}^m (P_{ij}(v_m) - P_{ij}(v_{m-1})) - \sum_{m=1}^{n+1} t_{ij}^m (Q(v_m) - Qij(v_{m-1})) \geq c$$

$$t_{ij}^1 \geq 0 \text{ and } t_{ij}^{m+1} \geq t_{ij}^m \ (m = 1, \ldots, n)$$

Given the limited liability constraints, it is a routine matter to show that agents' participation constraints are always slack.

For the rest of the analysis, it will be convenient to make a change of variable and consider the following equivalent optimization program. For all $m = 1, \ldots, n$, we denote τ_{ij}^m the differential in transfers between two successive states, i.e., $\tau_{ij}^m \equiv t_{ij}^{m+1} - t_{ij}^m$. We can then rewrite the optimization problem of the principal as

$$Max_{(t_{ij}^1, \tau_{ij}^m)} E_{ij}[V|e_h] - t_{ij}^1 - \sum_{m=1}^{n} \tau_{ij}^m (1 - P_{ij}(v_m))$$

Subject to

$$t_{ij}^1 + \sum_{m=1}^{n} \tau_{ij}^m (1 - P_{ij}(v_m)) - c \geq t_{ij}^1 + \sum_{m=1}^{n} \tau_{ij}^m (1 - Q(v_m)) \tag{15}$$

$$\tau_{ij}^m \geq 0 \quad \forall m \geq 1 \text{ and } i, j = H, L. \tag{16}$$

$$t_{ij}^1 \geq 0 \quad \forall i, j = H, L. \tag{17}$$

It is obviously optimal to set $t_{ij}^1 = 0$ since the principal's objective is decreasing in t_{ij}^1 and this transfer provides no incentives to exert effort.

The Lagrangian is then

$$\mathcal{L} = E_{ij}[V|e_h] - \sum_{m=1}^{n} \tau_{ij}^m (1 - P_{ij}(v_m)) + \lambda \sum_{m=1}^{n} \tau_{ij}^m (Q(v_m) - P_{ij}(v_m)) + \sum_{m=1}^{n} \mu_m \tau_{ij}^m$$

The first-order conditions (FOCs) of the maximization problem are then given by

$$\frac{\partial \mathcal{L}}{\partial \tau_{ij}^m} = -[1 - P_{ij}(v_m)] + \lambda[Q(v_m) - P_{ij}(v_m)] + \mu_m = 0 \quad \forall m \geq 1 \tag{18}$$

These FOCs can be rewritten as

$$-\frac{1}{CLR_{ij}(v_m)} + \lambda + \frac{\mu_n}{Q(v_m) - P_{ij}(v_m)} = 0 \tag{19}$$

Let

$$\mathcal{M}_{ij}^n = \{m \in \{1, \ldots, n\} | \quad CLR_{ij}(v_m) \geq CLR_{ij}(v_{m'}) \quad \forall m' \in \{1, \ldots, n\}\}$$

and denote K_{ij}^n the number of elements of $\mathcal{M}_{ij}^n$.

First, assume that K_{ij}^n, and denote $\hat{m}_{ij}^n$, the unique element of $\mathcal{M}_{ij}^n$. Then, the unique solution of the system of first-order conditions is $\lambda = \frac{1}{CLR_{ij}(v_{\hat{m}_{ij}^n})}$, $\mu_{\hat{m}_{ij}^n} = 0$, and for all $m \neq \hat{m}_{ij}^n$, $\mu_m > 0$. Indeed, obviously λ cannot be strictly larger than $\frac{1}{CLR_{ij}(v_{\hat{m}_{ij}^n})}$. Now, suppose that $\lambda < \frac{1}{CLR_{ij}(v_{\hat{m}_{ij}^n})}$. Then, $\frac{-1}{CLR_{ij}(v_m)} + \lambda$ is negative and largest at $m = \hat{m}_{ij}^n$. This entails that all μ_m must be positive. If this were the case, then the IC constraint would not be satisfied. This implies that the unique solution is that for all $m \neq \hat{m}_{ij}^n$, $\tau_{ij}^m = 0$ and the IC constraint is binding, in turn implying that $\tau_{ij}^{\hat{m}_{ij}^n} = \frac{c}{Q(v_{\hat{m}_{ij}^n}) - P_{ij}(v_{\hat{m}_{ij}^n})}$. The expected compensation cost for the principal is then $c/CLR_{ij}(v_{\hat{m}_{ij}^n})$.

Second, assume that $K_n > 1$. The system of first-order conditions remains as in the case $K_n = 1$. However, the solution of this system is not unique anymore. For any $\hat{m}_{ij}^n \in \mathcal{M}_{ij}^n$ it is always optimal to set $\lambda = \frac{1}{CLR_{ij}(v_{\hat{m}_{ij}^n})}$, $\mu_{\hat{m}_{ij}^n} = 0$, and for all $m \neq \hat{m}_{ij}^n$, $\mu_m > 0$. Hence, for any $\hat{m}_{ij}^n \in \mathcal{M}_{ij}^n$, the n-step contract with $\tau_{ij}^{\hat{m}_{ij}^n} = \frac{c}{Q(v_{\hat{m}_{ij}^n}) - P_{ij}(v_{\hat{m}_{ij}^n})}$ and for all $m \neq \hat{m}_{ij}^n$, $\tau_{ij}^m = 0$ is optimal.

However, since the expected implementation cost is identical (and minimized) for all $\hat{m}_{ij}^n \in \mathcal{M}_{ij}^n$, it directly follows that any linear combination of these K_n contracts is also optimal.

Now, assume that $CLR_{ij}(.)$ reaches its global maximum at a unique point v^*. Since that P_{ij} and Q are continuous, then, as n tends to infinity, for any element $\hat{m}_{ij}^n \in \mathcal{M}_{ij}^n$, $|v^* - v_{\hat{m}_{ij}^n}|$ tends to zero. Hence $B(v^*, T_{ij}(v^*))$ is the unique optimal contract of the original continuous problem.

Now, assume that $CLR_{ij}(.)$ reaches its global maximum at K points $v_1^* \ldots, v_K^*$. Then, for any v_k^* $(k = 1, \ldots, K)$ and for any $\varepsilon > 0$, there exists $\bar{n}$ such that if $n > \bar{n}$ there exists $\hat{m}_{ij}^n \in \mathcal{M}_{ij}^n$

such that $|v^*_k - v_{m^*_n}| < \varepsilon$. Then, any element $\hat{m}^n_{ij} \in \mathcal{M}^n_{ij}$, there exists $v^* \in \{v^*_1 \ldots, v^*_K\}$ such that $|v^* - v_{\hat{m}^n_{ij}}|$. Therefore, any contract $B(v^*_k, Tij(v^*_k))$ is a solution of the original continuous problem. As a consequence, any linear combination of these solutions is a solution of the original continuous problem. □

Proof of Proposition 2:

As for Proposition 1, the proof proceeds through a discretization of the original of continuous problem, and the same discretization is used, i.e., $v_0 = \underline{v}$, $v_m = \underline{v} + m(\bar{v} - \underline{v})/(n+1)$ and $v_{n+1} = \bar{v}$. A n-step contract is defined by thresholds v_m $(m = 1, \ldots, n)$ and $n+1$ compensation levels t^m $(m = 1, \ldots, n+1)$, with t^m non decreasing in m.

For all $m = 1, \ldots, n$, we denote τ^m_{Hi} the differential in transfers between two successive states, i.e., $\tau^m_{Hi} \equiv t^{m+1}_{Hi} - t^m_{Hi}$.

If n is held fixed and the principal is restricted to using n-step contracts, then the principal's problem becomes

$$\begin{aligned} Max_{(t^1_{Hi}, \tau^m_{Hi})} \quad & \theta \left[E_{HH}(V|e_h) - t^1_{HH} - \textstyle\sum_{m=1}^n \tau^m_{HH}(1 - P_{HH}(v_m))\right] \\ & +(1-\theta)\left[E_{HL}(V|e_h) - t^1_{HL} - \textstyle\sum_{n=1}^n \tau^m_{HL}(1 - P_{HL}(v_m))\right] \end{aligned}$$

Subject to

$$t^1_{HH} + \sum_{m=1}^n \tau^m_{HH}(1 - P_{HH}(v_m)) - c \geq t^1_{HH} + \sum_{m=1}^n \tau^m_{HH}(1 - Q(v_m)) \tag{20}$$

$$t^1_{HH} + \sum_{m=1}^n \tau^m_{HH}(1 - P_{HH}(v_m)) - c \geq t^1_{HL} + \sum_{m=1}^n \tau^m_{HL}(1 - P_{HH}(v_m)) - c \tag{21}$$

$$t^1_{HH} + \sum_{m=1}^n \tau^m_{HH}(1 - P_{HH}(v_m)) - c \geq t^1_{HL} + \sum_{m=1}^n \tau^m_{HL}(1 - Q(v_m)) \tag{22}$$

$$t^1_{HL} + \sum_{m=1}^n \tau^m_{HL}(1 - P_{HL}(v_m)) - c \geq t^1_{HL} + \sum_{m=1}^n \tau^m_{HL}(1 - Q(v_m)) \tag{23}$$

$$t^1_{HL} + \sum_{m=1}^n \tau^m_{HL}(1 - P_{HL}(v_m)) - c \geq t^1_{HH} + \sum_{m=1}^n \tau^m_{HH}(1 - P_{HL}(v_m)) - c \tag{24}$$

$$t^1_{HL} + \sum_{m=1}^n \tau^m_{HL}(1 - P_{HL}(v_m)) - c \geq t^1_{HH} + \sum_{m=1}^n \tau^m_{HH}(1 - Q(v_m)) \tag{25}$$

$$t^1_{ij} \geq 0 \text{ and } t^{m+1}_{ij} \geq t^m_{ij} \ (m = 1, \ldots, n)$$

The Lagrangian is then

$$\begin{aligned}\mathcal{L} = \quad & \theta\left[E_{HH}(V|e_h) - t^1_{HH} - \textstyle\sum_{m=1}^n \tau^m_{HH}(1-P_{HH}(v_m))\right] \\ & +(1-\theta)\left[E_{HL}(V|e_h) - t^1_{HL} - \textstyle\sum_{n=1}^n \tau^m_{HL}(1-P_{HL}(v_m))\right] \\ & +\lambda_1\left[\textstyle\sum_{m=1}^n \tau^m_{HH}(Q(v_m)-P_{HH}(v_m))\right] \\ & +\lambda_2\left[t^1_{HH} - t^1_{HL} + \textstyle\sum_{m=1}^n (\tau^m_{HH}-\tau^m_{HL})(1-P_{HH}(v_m))\right] \\ & +\lambda_3\left[t^1_{HH} - t^1_{HL} + \textstyle\sum_{m=1}^n (\tau^m_{HH}(1-P_{HH}(v_m)) - \tau^m_{HL}(1-Q(v_m))\right] \\ & +\lambda_4\left[\textstyle\sum_{m=1}^n \tau^m_{HL}(Q(v_m)-P_{HL}(v_m))\right] \\ & +\lambda_5\left[t^1_{HL} - t^1_{HH} + \textstyle\sum_{m=1}^n (\tau^m_{HL}-\tau^m_{HH})(1-P_{HL}(v_m))\right] \\ & +\lambda_6\left[t^1_{HH} - t^1_{HL} + \textstyle\sum_{m=1}^n (\tau^m_{HL}(1-P_{HL}(v_m)) - \tau^m_{HH}(1-Q(v_m))\right]\end{aligned}$$

The first-order conditions of the maximization program are:

$$\frac{\partial L}{\partial \tau^m_{HH}} = (-\theta+\lambda_2+\lambda_3)(1-P_{HH}(v_m)) + \lambda_1(Q(v_m)-P_{HH}(v_m)) - \lambda_5(1-P_{HL}(v_m)) - \lambda_6(1-Q(v_m)) + \mu^m_{HH} = 0 \quad (26)$$

$$\frac{\partial L}{\partial \tau^m_{HL}} = (-(1-\theta)+\lambda_5+\lambda_6)(1-P_{HL}(v_m)) - \lambda_2(1-P_{HH}(v_m)) - \lambda_3(1-Q(v_m)) + \lambda_4(Q(v_m)-P_{HL}(v_m)) + \mu^m_{HL} = 0 \quad (27)$$

$$\frac{\partial L}{\partial t^1_{HH}} = -\theta + \lambda_2 + \lambda_3 - \lambda_5 - \lambda_6 + \mu^0_{HH} = 0 \quad (28)$$

$$\frac{\partial L}{\partial t^1_{HL}} = -(1-\theta) - \lambda_2 - \lambda_3 + \lambda_5 + \lambda_6 + \mu^0_{HL} = 0 \quad (29)$$

Given that Condition (26) must hold for all m, it implies that we cannot have $\lambda_1 = \lambda_2 = \lambda_3 = 0$. Similarly, it follows from equation (27) that we cannot have $\lambda_4 = \lambda_5 = \lambda_6 = 0$. From conditions (28) and (29) we get that $\mu^0_{HH} + \mu^0_{HL} = 1$. Therefore, we cannot have both $t^1_{HH} > 0$ and $t^1_{HL} > 0$. We know from FOSD (assumption 1) and the fact that the reward scheme is non decreasing that

$$t^1_{HL} + \sum_{m=1}^n \tau^m_{HL}[1-P_{HH}(v_m)] - c > t^1_{HL} + \sum_{m=1}^n \tau^m_{HL}[1-P_{HL}(v_m)] - c \quad (30)$$

Now suppose that $t^1_{HL} + \sum_{m=1}^n \tau^m_{HL}[1-P_{HH}(v_m)] - c \leq t^1_{HL} + \sum_{m=1}^n \tau^m_{HL}[1-Q(v_m)]$. Inequality (30) implies that the IC constraint of the agent of type (H, L), given by condition (23) cannot be satisfied! So if the agent of type (H, H) ever chooses the contract designed for an agent of type (H, L), he should strictly exert effort. It implies also that the RHS of condition (21) must be larger than the RHS of condition (22). It follows then that $\lambda_3 = 0$.

Consider again inequality (30). Using condition (25) it implies that

$$t^1_{HL} + \sum_{m=1}^n \tau^m_{HL}(1-P_{HH}(v_m)) - c > t^1_{HH} + \sum_{m=1}^n \tau^m_{HH}(1-Q(v_m)). \quad (31)$$

From condition (21), we know that

$$t_{HH}^1 + \sum_{m=1}^{n} \tau_{HH}^m (1 - P_{HH}(v_m)) - c \geq t_{HL}^1 + \sum_{m=1}^{n} \tau_{HL}^m (1 - P_{HH}(v_m)) - c.$$

We then get

$$t_{HH}^1 + \sum_{m=1}^{n} \tau_{HH}^m (1 - P_{HH}(v_m)) - c > t_{HH}^1 + \sum_{m=1}^{n} \tau_{HH}^m (1 - Q(v_m)).$$

Namely, the IC constraint of the agent of type (H, H) has to be slack. We then deduce that $\lambda_1 = 0$. Since, as stated above, λ_1, λ_2 and λ_3 cannot be simultaneously equal to 0, we conclude that $\lambda_2 > 0$.

Proof of 1) We show now that the equilibrium with the above described characteristics is the unique equilibrium contract for an agent of type (H, L) in the maximization problem of the principal. Given that $\lambda_2 > 0$, the high type is indifferent, conditionally on exerting effort, between choosing the contract designed for him or the one designed for the low type. This entails that the expected cost for the principal of offering, to both agents, the contract initially designed for an agent of type (H, L) must only be equal to the cost of offering two separated contracts.

It directly implies that the contract offered to an agent of type (H, L) corresponds exactly to the optimal pooling contract. Let us proceed by contradiction and let us suppose that there exists another equilibrium contract for an agent of type (H, L). That is, there would exist a separating equilibrium in which the implementation cost of the principal would be lower than the one associated to the optimal pooling contract. But since $\lambda_2 > 0$, the expected cost for the principal of such contract is equivalent to a pooling one where both agent would choose the contract designed for an agent of type (H, L). But this cannot be since, as we show below, the pooling contract is unique.

Let us indeed derive the optimal pooling equilibrium. It is the solution of the following maximization program.

$$Max_{t^1,\tau^m} \theta \left[E_{HH}(V|e_h) - t^1 - \sum_{m=1}^{n} \tau^m (1 - P_{HH}(v_m)) \right] + (1-\theta) \left[E_{HL}(v|e_h) - t^1 - \sum_{m=1}^{n} \tau^m (1 - P_{HL}(v_m)) \right]$$

Subject to (20),(23), the limited liability and the non-decreasing contract constraints.

As in the case of Proposition 1, setting $t^1 = 0$ is optimal since the objective function of the principal is decreasing in t^1, and t^1 provides no incentives to exert effort.

The Lagrangian is then

$$\begin{aligned}\mathcal{L} = \quad & \theta \left[E_{HH}(V|e_h) - \textstyle\sum_{m=1}^{n} \tau^m (1 - P_{HH}(v_m)) \right] (1-\theta) \left[E_{HL}(V|e_h) - \textstyle\sum_{m=1}^{n} \tau^m (1 - P_{HL}(v_m)) \right] \\ & + \eta_1 \left[\textstyle\sum_{m=1}^{n} \tau^m (Q(v_m) - P_{HH}(v_m)) \right] + \eta_2 \left[\textstyle\sum_{m=1}^{n} \tau^m (Q(v_m) - P_{HL}(v_m)) \right] + \textstyle\sum_{m=1}^{n} \mu_m \tau^m\end{aligned}$$

The FOCs of this maximization program are

$$\frac{\partial L}{\partial \tau^m} = -\theta(1-P_{HH}(v_m))-(1-\theta)(1-P_{HL}(v_m))+\eta_1(Q(v_m)-P_{HH}(v_m))+\eta_2(Q(v_m)-P_{HL}(v_m))+\mu^m = 0 \tag{32}$$

First order stochastic dominance implies that

$$\sum_{m=1}^{n} \tau^m(Q(v_m) - P_{HH}(v_m)) > \sum_{m=1}^{n} \tau^m(Q(v_m) - P_{HL}(v_m))$$

so (20) cannot be binding. Therefore $\eta_1 = 0$. Equation (32) can then be rewritten as

$$-\frac{1}{CLR_{HL}(v_m)}\left[1-\theta+\theta\frac{1-P_{HH}(v_m)}{1-P_{HL}(v_m)}\right]+\eta_2+\frac{\mu^m}{Q(v_m)-P_{HL}(v_m)} = 0.$$

Which is equivalent to

$$-F(v_m,\theta)+\eta_2+\frac{\mu^m}{Q(v_m)-P_{HL}(v_m)} = 0.$$

The rest of the proof is similar to that of Proposition 1. That is, let

$$\mathcal{M}'_n(\theta) = \{m| \quad F(v_m,\theta) \geq F(v_{m'},\theta) \quad \forall m' \in \{1,\ldots,n\}\}$$

and denote $K'_n(\theta)$ the number of elements of $\mathcal{M}'_n(\theta)$.
First, assume that $K'_n(\theta) = 1$, and denote m_n^θ, the unique element of $\mathcal{M}'_n(\theta)$. Using the same reasoning as in the proof of Proposition 1, we obtain that the unique solution of the system of FOCs is $\eta_2 = \frac{1}{F(v_{m_n^\theta},\theta)}$, $\mu_{m_n^\theta} = 0$, and for all $m \neq m_n^\theta$, $\mu_m > 0$, implying that for all $m \neq m_n^\theta$, $\tau^m = 0$ and $\tau_{m_n^\theta} = \frac{c}{Q(v_{m_n^\theta})-P_{HL}(v_{m_n^\theta})}$.
Second, assume that $K'_n > 1$. Proceeding again as in the proof of proposition 1, we obtain that for any $m_n^\theta \in \mathcal{M}'_n(\theta)$, there is a solution such that $m \neq m_n^\theta$, $\tau^m = 0$ and $\tau_{m_n^\theta} = \frac{c}{Q(v_{m_n^\theta})-P_{HL}(v_{m_n^\theta})}$.
By assumption, $F(.,\theta)$ reaches its global maximum at a unique point v_θ^{**}. Since that P_{HH}, P_{HL} and Q are continuous, so is $F(.,\theta)$. Hence, as n tends to infinity, for any element $m_n^\theta \in \mathcal{M}'_n(\theta)$, $|v_\theta^{**} - v_{m_n^\theta}|$ tends to zero. Hence $B(v_\theta^{**}, T_{HL}(v_\theta^{**}))$ is the unique pooling contract of the original continuous problem. Consequently, the equilibrium contract for an agent of type (H,L) is also unique and is given by $B(v_\theta^{**}, T_{HL}(v_\theta^{**}))$.

Proof of 2: First, we already know that the adverse selection IC constraint of an agent of type (H,H) (constraint (21)) is binding. Therefore, an equilibrium contract made of a bonus contact $B(T,V)$ and a stock-option contract $O(\beta,\hat{v})$ and designed for an agent of type (H,H) must satisfy the following conditions. First, the expected compensation is equal to that of the pooling equilibrium, i.e.,

$$T[1-P_{HH}(V)]+\beta\int_{\hat{v}}^{\bar{v}}(v-\hat{v})p_{HH}(v)dv = \frac{1-P_{HH}(v_\theta^{**})}{Q(v_\theta^{**})-P_{HL}(v_\theta^{**})}c \tag{33}$$

Second, the agent of type (H,H) exerts effort, i.e.,

$$T[Q(V) - P_{HH}(V)] + \beta \int_{\hat{v}}^{\bar{v}} (v - \hat{v})[p_{HH}(v) - q(v)]dv \geq c \tag{34}$$

Third, adverse selection constraints (24) and (25) are satisfied, i.e.,

$$\frac{1 - P_{HL}(v_\theta^{**})}{Q(v_\theta^{**}) - P_{HL}(v_\theta^{**})}c - c \geq T[1 - P_{HL}(V)] + \beta \int_{\hat{v}}^{\bar{v}} (v - \hat{v})p_{HL}(v)dv - c \tag{35}$$

$$\frac{1 - Q(v_\theta^{**})}{Q(v_\theta^{**}) - P_{HL}(v_\theta^{**})}c \geq T[1 - Q(V)] + \beta \int_{\hat{v}}^{\bar{v}} (v - \hat{v})q(v)dv \tag{36}$$

Using equality (33), then inequalities (35) and (36) can be rewritten as

$$T\left[\frac{1 - P_{HL}(v_\theta^{**})}{1 - P_{HH}(v_\theta^{**})}[1 - P_{HH}(V)] - [1 - P_{HL}(V)]\right] + \beta \int_{\hat{v}}^{\bar{v}} \left[\frac{1 - P_{HL}(v_\theta^{**})}{1 - P_{HH}(v_\theta^{**})}p_{HH}(v) - p_{HL}(v)\right](v - \hat{v})dv \geq 0 \tag{37}$$

and

$$T\left[\frac{1 - Q(v_\theta^{**})}{1 - P_{HH}(v_\theta^{**})}[1 - P_{HH}(V)] - [1 - Q(V)]\right] + \beta \int_{\hat{v}}^{\bar{v}} \left[\frac{1 - Q(v_\theta^{**})}{1 - P_{HH}(v_\theta^{**})}p_{HH}(v) - q(v)\right](v - \hat{v})dv \geq 0, \tag{38}$$

respectively. Let

$$A_{HL}(v) = \frac{1 - P_{HL}(v_\theta^{**})}{1 - P_{HH}(v_\theta^{**})}[1 - P_{HH}(v)] - [1 - P_{HL}(v)]$$

and

$$A_Q(v) = \frac{1 - Q(v_\theta^{**})}{1 - P_{HH}(v_\theta^{**})}[1 - P_{HH}(v)] - [1 - Q(v)]$$

A sufficient condition for the two adverse selection constraints to be satisfied simultaneously is that there exists an interval I such that for any bonus threshold $V \in I$, $A_Q(V) > 0$ and $A_{HL}(V) > 0$. In such a case, for any $\hat{v} \in (\underline{v}, \bar{v})$, there exists $\bar{\beta}_1(\hat{v}) > 0$ such that for any $\beta \in (0, \bar{\beta}_1(\hat{v}))$, inequalities (37) and (38) are satisfied.

We now show that the conditions stated in the proposition are sufficient for the interval I to be non-empty. First, note that $A_Q(v) > 0$ is equivalent to $CLR_{HH}(v) > CLR_{HH}(v_\theta^{**})$. Second, given that CLR_{HH} is positive and reaches its global maximum at $v_{HH}^* \in (\underline{v}, \bar{v})$, it implies that there exists an interval I_Q containing v_{HH}^* such that for any $v \in I_Q$, $A_Q(v) > 0$. Third, note that $HR_{HH}(v) > (<) HR_{HL}(v)$ on some interval is equivalent to having the function $\frac{1-P_{HL}(.)}{1-P_{HH}(.)}$ decreasing (increasing) in v in that interval. Given the assumption that there exists a unique state $v^o \in (\underline{v}, \bar{v})$ such that for any $v < v^o$, $HR_{HH}(v) < HR_{HL}(v)$ and for any $v > v^o$, $HR_{HH}(v) > HR_{HL}(v)$, it follows that the function $\frac{1-P_{HL}(.)}{1-P_{HH}(.)}$ is decreasing on $[0, v^o]$ and increasing on $[v^o, \bar{v}]$. As a consequence, there exists an interval I_{HL} containing v^o such that for any bonus threshold $V \in I_{HL}$, $A_{HL}(V) > 0$. The interval I is then the intersection of I_Q and I_{HL}.

The next task is then to derive conditions under which this intersection is non empty. First, note that $A_Q(v_\theta^{**}) = A_{HL}(v_\theta^{**}) = 0$. By continuity, it implies that if $v_\theta^{**} < \min(v_{HH}^*, v^o)$ there exists $\varepsilon > 0$ such that for any $v \in (v_\theta^{**}, v_\theta^{**} + \varepsilon)$, $A_Q(v) > 0$ and $A_{HL}(v) > 0$. Hence, $v \in I$, implying that I is non empty. Similarly, if $v_\theta^{**} > \max(v_{HH}^*, v^o)$ there exists $\varepsilon' > 0$ such that for any $v' \in (v_\theta^{**} - \varepsilon', v_\theta^{**})$, $A_Q(v') > 0$ and $A_{HL}(v') > 0$. Hence, $v' \in I$, implying that I is non empty.

Finally, we need to check that the incentive compatibility constraint for the agent of type (H,H) is satisfied with the new contract. Using Equation (33), then Inequality (34) can be rewritten as

$$\left(\frac{1 - P_{HH}(v_\theta^{**})}{Q(v_\theta^{**}) - P_{HL}(v_\theta^{**})} \frac{[Q(V) - P_{HH}(V)]}{[1 - P_{HH}(V)]} - 1\right) c + \beta \int_{\hat{v}}^{\bar{v}} \left(\frac{1 - Q(V)}{1 - P_{HH}(V)} p_{HH}(v) - q(v)\right) (v - \hat{v}) dv \geq 0, \tag{39}$$

In turn, this can be rewritten as

$$\left(\frac{Q(v_\theta^{**}) - P_{HH}(v_\theta^{**})}{Q(v_\theta^{**}) - P_{HL}(v_\theta^{**})} \frac{CLR_{HH}(V)}{CLR_{HH}(v_\theta^{**})} - 1\right) c + \beta \int_{\hat{v}}^{\bar{v}} \left(\frac{1 - Q(V)}{1 - P_{HH}(V)} p_{HH}(v) - q(v)\right) (v - \hat{v}) dv \geq 0, \tag{40}$$

First, we know that that for any $V \in I_Q$, $CLR_{HH}(V) > CLR_{HH}(v_\theta^{**})$. Second, since $P_{HH}(.)$ dominates $P_{HL}(.)$ in the FOSD sense, then for any v, $\frac{Q(v) - P_{HH}(v)}{Q(v) - P_{HL}(v)} \geq 1$. Therefore, by continuity, for any $\hat{v}$, there exists $\bar{\beta}_2(\hat{v}) > 0$ such that if $\beta < \bar{\beta}_2(\hat{v})$, then Inequality (40) is satisfied and so is the incentive compatibility constraint.

As a consequence, a compensation contract composed of a bonus plan $B(T, V)$ and a stock –option plan $O(\beta, \hat{v})$ such that $V \in I$, $\beta \in \big(0, min(\bar{\beta}_1(\hat{v}), \bar{\beta}_2(\hat{v}))\big)$ and equality (33) is satisfied is an equilibrium contract for an agent of type (H, H). This completes the proof. □

Proof of Proposition 3:

For any type of internal candidate, the first task is to compare the firm value generated by this internal candidate with the firm value generated by an external candidate. The expected firm value generated by this latter candidate is

$$\mathcal{V}_{ext} = \theta E_{HH}(V|e_h) + (1 - \theta) E_{HL}(V|e_h) - F(v_\theta^{**}, \theta) \tag{41}$$

While the expected firm value generated by an internal candidate of type (i,j) is

$$\mathcal{V}_{ij} = E_{ij}(V|e_h) - [1 - P_{ij}(v_{ij}^*)] T_{ij}(v_{ij}^*) \tag{42}$$

Where $v_{ij}^* \in argmax_v \frac{1}{CLR_{ij}(v)}$.

The difference $\mathcal{V}_{ij} - \mathcal{V}_{ext}$ can then be written as

$$\begin{aligned} \mathcal{V}_{ij} - \mathcal{V}_{ext} &= \theta[E_{ij}(V|e_h) - E_{HH}(V|e_h)] + (1-\theta)[E_{ij}(V|e_h) - E_{HL}(V|e_h)] \\ & -\tfrac{c}{CLR_{ij}(v^*_{ij})} + \tfrac{c}{CLR_{HL}(v^{**}_\theta)}\left[(1-\theta) + \theta\tfrac{1-P_{HH}(v^{**}_\theta)}{1-P_{HL}(v^{**}_\theta)}\right] \end{aligned} \tag{43}$$

First note that if P_{ij} dominates P_{HL} in the FOSD sense then for any v $CLR_{ij}(v) \geq CLR_{HL}(v)$. It is then straightforward that if the internal candidate is of type (H, H), then $\mathcal{V}_{HH} - \mathcal{V}_{ext} > 0$. As a consequence, an internal candidate is always hired.

Now, assume that the internal candidate is of type (L, H) and consider, first, the FS-regime. The expected compensation of the external candidate is always larger than that of the internal candidate since, by definition

$$\frac{c}{CLR_{LH}(v^*_{LH})} < \frac{c}{CLR_{LH}(v^{**}_\theta)} < \frac{c}{CLR_{HL}(v^{**}_\theta)},$$

and

$$\frac{c}{CLR_{HL}(v^{**}_\theta)} \leq \frac{c}{CLR_{HL}(v^{**}_\theta)}\left[(1-\theta) + \theta\frac{1-P_{HH}(v^{**}_\theta)}{1-P_{HL}(v^{**}_\theta)}\right],$$

since for all v, $\frac{1-P_{HH}(v)}{1-P_{HL}(v)} \geq 1$.

Let p_i and CLR_i $(i = 1, 2)$ be the probability distribution and the cumulated likelihood ratio function associated to the cumulative distribution function P_i, and $E_i(V) = \int_{\underline{v}}^{\bar{v}} vp_i(v)dv$. Under the FS-regime,

$$\begin{aligned} \mathcal{V}_{LH} - \mathcal{V}_{ext} = \Delta_{FS}\mathcal{V} = &\ \theta[E_1(v) - E_{HH}(v|e_h)] + (1-\theta)[E_1(v) - E_2(v)] \\ & -\tfrac{c}{CLR_1(v^*_1)} + \tfrac{c}{CLR_2(v^{**}_{\theta,2})}\left[(1-\theta) + \theta\tfrac{1-P_{HH}(v^{**}_{\theta,2})}{1-P_2(v^{**}_{\theta,2})}\right] \end{aligned}$$

While under the G-regime

$$\begin{aligned} \mathcal{V}_{LH} - \mathcal{V}_{ext} = \Delta_{G}\mathcal{V} = &\ \theta[E_2(V) - E_{HH}(V|e_h)] + (1-\theta)[E_2(V) - E_1(V)] \\ & -\tfrac{c}{CLR_2(v^*_2)} + \tfrac{c}{CLR_1(v^{**}_{\theta,1})}\left[(1-\theta) + \theta\tfrac{1-P_{HH}(v^{**}_{\theta,1})}{1-P_1(v^{**}_{\theta,1})}\right] \end{aligned}$$

To get the desired result it is sufficient to show that $\Delta_G\mathcal{V} - \Delta_{FS}\mathcal{V} < 0$. Let

$$F_i(v,\theta) = \frac{c}{CLR_i(v)}\left[(1-\theta) + \theta\frac{1-P_{HH}(v)}{1-P_i(v)}\right] \quad i = 1, 2$$

and $v^{**}_{\theta,i}$ the unique state at which $F_i(v,\theta)$ reaches its global minimum.

Then,

$$\Delta_G\mathcal{V} - \Delta_{FS}\mathcal{V} = -(2-\theta)(E_1(V) - E_2(V)) + F_1(v^{**}_{\theta,1},\theta) - F_2(v^{**}_{\theta,2},\theta) + \frac{c}{CLR_1(v^*_1)} - \frac{c}{CLR_2(v^*_2)}$$

Given that P_1 dominates P_2 in the FOSD sense, $F_1(v^{**}_{\theta,1},\theta) < F_2(v^{**}_{\theta,2},\theta)$ and $\frac{c}{CLR_1(v^*_1)} < \frac{c}{CLR_2(v^*_2)}$. Hence, we have the desired result. □

Proof of Proposition 4:

First, assume that the internal candidate hired under the FS-regime is of type (H, H). As established by Proposition 3, this candidate is also chosen under the G-regime, and his expected compensation is not affected by a change of regime.

Second, assume that the internal candidate is of type (L, H) and is hired under both regimes. His expected compensation is $\frac{c}{CLR_1(v_1^*)}$ under the FS-regime while it is $\frac{c}{CLR_2(v_2^*)}$ under the G-regime. Given that P_1 dominates P_2 in the FOSD sense, then for any v, $CLR_1(v) \geq CLR_2(v)$, then the compensation increases when a shift from the FS-regime to the G-regime occurs.

Third, assume that the internal candidate of type (L, H) is hired the FS-regime but an external candidate is hired under the G-regime. The expected CEO compensation under the FS-regime is $\frac{c}{CLR_1(v_1^*)}$ while under the G-regime it is

$$\frac{c}{CLR_1(v_{\theta,1}^{**})}\left[(1-\theta)+\theta\frac{1-P_{HH}(v_{\theta,1}^{**})}{1-P_1(v_{\theta,1}^{**})}\right]$$

Given that P_{HH} dominates P_1 in the FOSD sense, then $\frac{1-P_{HH}(v_{\theta,1}^{**})}{1-P_1(v_{\theta,1}^{**})} > 1$. Furthermore, given the definitions of $v_{\theta,1}^{**}$ and v_1^*, $\frac{c}{CLR_1(v_1^*)} < \frac{c}{CLR_1(v_{\theta,1}^{**})}$. Hence, the expected compensation of the hired candidate is larger under the G-regime than under the FS-regime. This proves part *(i)* of the proposition.

Now, given that P_{HH} dominates P_1 in the FOSD sense, it implies that

$$\frac{c}{CLR_{HH}(v_{HH}^*)} < \frac{c}{CLR_1(v_{\theta,1}^{**})}\left[(1-\theta)+\theta\frac{1-P_{HH}(v_{\theta,1}^{**})}{1-P_1(v_{\theta,1}^{**})}\right]$$

As a consequence, if external candidates are selected under the G-regime, their compensation is larger than that of internally selected candidates under the G-regime, since only internal candidates of type (H, H) are promoted as CEO in the G-regime in this case (part *(ii)* of the proposition).

This completes the proof. □

Proof of Proposition 6:

We proceed as in the Proof of Proposition 2.2. First, we already know that constraint (21) is binding. Therefore, an equilibrium contract made of a bonus contact $B(T, V)$ and a stock contract $S(\beta)$ and designed for an agent of type (H, H) must satisfy the following conditions. First, the expected compensation is equal to that of the pooling equilibrium, i.e.,

$$T[1-P_{HH}(V)] + \beta\int_{\underline{v}}^{\bar{v}} vp_{HH}(v)dv = \frac{1-P_{HH}(v_\theta^{**})}{Q(v_\theta^{**})-P_{HL}(v_\theta^{**})}c \tag{44}$$

Second, the agent of type (H, H) exerts effort, i.e.,

$$T[Q(V) - P_{HH}(V)] + \beta \int_{\underline{v}}^{\bar{v}} v[p_{HH}(v) - q(v)]dv \geq c \tag{45}$$

Third, adverse selection constraints (24) and (25) are satisfied, i.e.,

$$\frac{1 - P_{HL}(v_\theta^{**})}{Q(v_\theta^{**}) - P_{HL}(v_\theta^{**})}c - c \geq T[1 - P_{HL}(V)] + \beta \int_{\underline{v}}^{\bar{v}} vp_{HL}(v)dv - c \tag{46}$$

$$\frac{1 - Q(v_\theta^{**})}{Q(v_\theta^{**}) - P_{HL}(v_\theta^{**})}c \geq T[1 - Q(V)] + \beta \int_{\underline{v}}^{\bar{v}} vq(v)dv \tag{47}$$

Using equality (44), then inequalities (46) and (47) can be rewritten as

$$TA_{HL}(v) + \beta \int_{\underline{v}}^{\bar{v}} \left[\frac{1 - P_{HL}(v_\theta^{**})}{1 - P_{HH}(v_\theta^{**})}p_{HH}(v) - p_{HL}(v)\right] vdv \geq 0 \tag{48}$$

and

$$TA_Q(v) + \beta \int_{\underline{v}}^{\bar{v}} \left[\frac{1 - Q(v_\theta^{**})}{1 - P_{HH}(v_\theta^{**})}p_{HH}(v) - q(v)\right] vdv \geq 0, \tag{49}$$

Respectively, where A_{HL} and A_Q are as in the proof of Proposition 2.2. From this proof, we know that there exists an interval I (non-empty) such that if $v \in I$ then $A_Q(v) > 0$ and $A_{HL}(v) > 0$. As a consequence, there exists $\bar{\beta}_1 > 0$ such that for any $\beta \in (0, \bar{\beta}_1)$, inequalities (48) and (49) are satisfied.

Finally, we need to check that the incentive compatibility constraint for the agent of type (H, H) is satisfied with the new contract. Proceeding again as in the proof of Proposition 2.2, we deduce that the incentive compatibility constraint can be rewritten as

$$\left(\frac{Q(v_\theta^{**}) - P_{HH}(v_\theta^{**})}{Q(v_\theta^{**}) - P_{HL}(v_\theta^{**})}\frac{CLR_{HH}(V)}{CLR_{HH}(v_\theta^{**})} - 1\right) c + \beta \int_{\underline{v}}^{\bar{v}} \left(\frac{1 - Q(V)}{1 - P_{HH}(V)}p_{HH}(v) - q(v)\right) vdv \geq 0, \tag{50}$$

and there exists $\bar{\beta}_2 > 0$ such that if $\beta < \bar{\beta}_2$, then Inequality (50) is satisfied and so is the incentive compatibility constraint.

As a consequence, a compensation contract composed of a bonus plan $B(T, V)$ and a stock contract $S(\beta)$ such that $V \in I$, $\beta \in \big(0, min(\bar{\beta}_1, \bar{\beta}_2)\big)$ and equality (44) is satisfied is an equilibrium contract for an agent of type (H, H). This completes the proof. □

Table 1: Variable Pay as a percentage of annual basic Compensation for CEO worldwide

	1998		**2005**	
Country	**Bonus**	**Equity**	**Bonus**	**Equity**
Argentina	32	16	39	32
Australia	30	4	32	16
Belgium	27	8	40	30
Brazil	27	27	49	54
Canada	35	28	50	85
China (Hong-Kong)	29	24	37	14
China (Shanghai)	NA	NA	18	136
France	19	30	36	66
Germany	27	0	90	50
India	NA	NA	32	0
Italy	30	11	35	50
Japan	16	0	14	25
Malaysia	31	28	32	80
Mexico	26	2	42	39
Netherlands	24	17	55	40
Poland	NA	NA	45	20
Singapore	36	22	32	123
South Africa	20	18	100	122
South Korea	27	0	40	40
Spain	28	0	44	40
Sweden	20	0	25	20
Switzerland	28	6	50	65
Taiwan	NA	NA	18	18
United Kingdom	22	38	30	50
United States	39	97	51	171
Venezuela	78	0	69	28

Source: Towers Perrin's Worlwide Total Remuneration Report 2005-2006

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