The CEO Arms Race

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This article constructs a game-theoretic model in which high chief executive officer (CEO) pay emerges as the outcome of an arms race, with each firm hiring a highly paid CEO to protect its competitive position against rivals who also hire highly paid CEOs. For an arms race to emerge, highly paid CEOs must generate idiosyncratic, privately known internal effects on profit, and CEO pay disparities must also generate asymmetric profit differences from external effects beyond the simple differences in pay. If the distribution of internal effects satisfies a key uniformity condition, an arms race emerges as the only equilibrium of the game.

JEL Classification: C72, J33, D82

1. Introduction

Over the past decade both journalists and academics have written about the level of chief executive officer (CEO) pay both in the United States and in Europe. In 1989, the average CEO total compensation in the United States was $2.3 million; this increased to $8.4 million in 1999 and reached $11.4 million in 2009.1 At the same time, average annual worker income in the United States rose from only $32,438 to $38,376.2 Recently, this type of earnings discrepancy has attracted the interest of politicians, the media, and the general public, and it is the driving force behind movements such as “Occupy Wall Street.”3 Because of the large increase in CEO pay, and because it is so high relative to the pay of ordinary workers, much of the recent academic literature on executive compensation has sought to rationalize these trends.

The conventional approach to this issue entails investigating whether increased CEO pay is matched by increased value to the firm. To this end, Finkelstein and Boyd (1998) find that pay is positively correlated with managerial discretion, and Murphy and Zábojník (2004, 2007) argue that increased CEO pay follows from increases in the general (as opposed to specific)

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1 Source: Forbes Annual Executive Compensation Reports. Data are in 2008 dollars.
2 Source: U.S. Census Bureau. Data are in 2008 dollars.
3 Occupy Wall Street is a movement that began on September 17, 2011, in Liberty Square in Manhattan’s Financial District, and it has spread to over 100 cities in the United States. Their goal is “to expose how the richest 1% of people are writing the rules of an unfair global economy.” Source: http://occupywallst.org/about/ (accessed on November 07, 2011).
human capital required for the job. Rajgopal, Shelvin, and Zamora (2006) find that increased
demand for talented CEOs, caused by market-wide shocks, forces firms to set CEO pay high in
order to retain their more talented CEOs. Geletkanycz, Boyd, and Finkelstein (2001) go on to
demonstrate that CEOs receive premiums for strategically valuable external networks, and
Westphal, Boivie, and Ming Chng (2006) document that these networks include informal
(friendship) networks with top executives of both suppliers and financial institutions. Kroll et
al. (1997), Schaefer (1998), and Gabaix and Landier (2008) show that CEO compensation
increases with the size of the average firm in the economy. Most recently, Chang, Dasgupta,
and Hilary (2010) tested whether firm performance and high pay reflect CEO ability or
something else, such as other firm assets, either physical or human, or simply luck. They
rejected their other explanations in favor of high CEO pay reflecting high CEO ability.

An alternative approach looks for reasons why CEO pay might be higher than would be
consistent with the usual labor-market approach. Bebchuk, Fried, and Walker (2002) consider
the fact that CEOs have some ability to set their own pay, allowing them to extract rents. Dow
and Raposo (2005) explore the implications of CEO contracts being different from typical
principal-agent contracts because the former change over time in accordance with firm’s
performance and strategic direction. Aggarwal and Samwick (1999) argue that CEO
compensation is positively sensitive to rival firms’ performance. More recently, Malmendier
and Tate (2009) found that firms pay award-winning CEOs more, even though they do not
perform better than their non-award-winning matches, suggesting alternative benefits of having
a highly paid “superstar” CEO. Hayes and Schaefer (2009) showed a “Lake Wobegon effect,”
in which firms pay their CEOs highly to signal that their chief executives are above average.4

We add to this second stream of literature by providing an additional reason for high CEO
pay—an arms race. Firms desire highly paid CEOs because their rivals have highly paid CEOs.
In fact, in our model, the only reason most firms hire highly paid CEOs is because they believe
their rivals will, and only a small fraction of firms would choose to hire highly paid CEOs if
they thought their rivals would hire low-paid CEOs. Even so, this small fraction willing to hire
highly paid CEOs causes a ripple effect that courses through the entire set of firms, with all
firms choosing to hire highly paid CEOs in equilibrium.5

The arms race literature began during the 1960s motivated by the Cold War. The first
mathematical model of an arms race was formulated by Richardson (1960) using a system of
linear differential equations.6 More recent approaches use game theory, with models of arms
races between nations based on Cournot competition (Dumas 1979; Okuguchi 1981) and on
prisoner’s dilemma games (Brams 1985; Brams and Kilgour 1988). These arms race games have
been applied to settings outside of actual weapons buildup, including hospital technology
investments (Foote 1992; James 2002) and household vehicle size choices (White 2004).

The most recent game-theoretic model of an arms race was developed by Baliga and
Sjöström (2004), and we rely heavily upon their framework to construct a model of a CEO arms
race. In their model, each of two countries can choose to build new weapons or not, and

4 The Lake Wobegon effect is derived from Garrison Keillor’s radio program, A Prairie Home Companion. The town of
Lake Wobegon is described as a place where “all the women are strong, all the men are good looking, and all the
children are above average.”
5 This result is in line with an important insight from Carlsson and Van Damme (1993). They demonstrate that, under
asymmetric information about the opponent’s preferences, a nonzero probability that opponents will choose a
particular action a* may cause every player to follow suit.
6 Refer to Anderton (1989) for a comprehensive discussion on Richardson-type arms race models and applications.
countries benefit from having more weapons than their rivals. Nations differ in their costs of arming, with higher-cost nations preferring not to arm when they believe that their rivals will not build new weapons and lower-cost nations having a dominant strategy of always building new weapons. No matter what the cost, however, nations prefer to build more weapons when their rivals do. Baliga and Sjöström establish that if nations believe that there is even a small probability of facing a dominant-strategy rival, a multiplier effect occurs, and the unique Bayes-Nash equilibrium involves an arms race with probability one. We build on Baliga and Sjöström’s model by making firms heterogeneous in the benefit, not cost, from arming. We also generalize the model to the $n$ firms case and demonstrate the conditions under which an arms race occurs in this general scenario.

The article is organized as follows. Section 2 describes the conceptual framework for understanding the CEO pay game. Section 3 utilizes a two-firm setting to introduce the game firms play and identify the internal and external benefits of hiring a highly paid CEO. Section 4 generalizes the game to the $n$ firms case and also contains the main result, that is the conditions under which both the dominant-strategy firms and the non-dominant-strategy firms hire highly paid CEOs. Section 5 offers some conclusions.

## 2. Conceptual Framework

We construct a model in which each firm has rivals, and we abstract away from whether this rivalry occurs in product, input, employment, or capital markets. Firms choose what type of CEO to hire. They can hire a highly paid (high-type) CEO or a low-paid (low-type) CEO. A highly paid CEO can benefit the firm in two ways, one internal and one external.

The internal benefit is separate from the rivalry, and it arises as the higher-paid CEO runs the firm in a more efficient, more profitable way. This may occur, for example, through improved positioning in capital markets, improved bargaining power with suppliers or customers, increased social networks, or other factors that make the firm more profitable. The internal benefit is therefore anything that the conventional CEO pay literature describes as a reason for high CEO pay.\(^7\)

The external benefit arises from a higher-paid CEO providing a competitive advantage over rivals with a lower-paid CEO. This may occur, for example, because the higher-paid CEO provides more credibility in capital markets or signals higher quality to customers. This benefit could arise, for example, from the superstar effect of Malmendier and Tate (2009) or the Lake Wobegon effect of Hayes and Schaefer (2009). Firms with a lower-paid CEO facing rivals with a higher-paid CEO observe negative external effect. This can result from low pay being a signal of low firm value or low managerial quality (Hayes and Schaefer 2009), which makes investors prefer high-paying firms over their low-paying rivals.

We assume that the external effect is identical and commonly known but that the internal effect is private information. The nature of the game has every firm preferring a highly paid CEO when their rivals have highly paid CEOs, but this may or may not be a dominant strategy. When the internal effect is large enough such that the benefit provided by the highly paid CEO exceeds the wage difference, having a highly paid CEO dominates. On the other hand, when the

\(^7\) See the references cited in the second paragraph of the Introduction.
internal effect is smaller than the wage difference, firms would prefer a low-paid CEO when their rivals also have low-paid CEOs.

We show that if there are some firms with a large enough internal effect to make hiring a highly paid CEO a dominant strategy, and a sufficiently uniform distribution of internal effects across firms, an arms race ensues, and every firm chooses a highly paid CEO. The reasoning is as follows, and it matches the contagion story of Baliga and Sjöström (2004). When the internal effect is sufficiently large to make hiring a highly paid CEO a dominant strategy, the firm chooses a highly paid CEO. Now consider a firm for which the internal effect is just slightly lower than this. The firm will prefer to hire a low-paid CEO in response to its rivals hiring a low-paid CEO, while hiring a highly paid CEO is still a best response to other firms hiring highly paid CEO because of the external rivalry effect. This firm does not possess a dominant strategy, but we can think of such a firm as an “almost-dominant-strategy” firm because its internal effect is almost as large as that of a dominant-strategy firm.

For these “almost-dominant-strategy” firms, hiring a highly paid CEO is still a best response to other firms hiring a highly paid CEO, but hiring a low-paid CEO is a best response to other firms hiring a low-paid CEO. Choosing to hire a highly paid CEO, though, entails only a small loss if the rival hires a low-paid CEO, whereas choosing to hire a low-paid CEO results in large losses when the rival hires a highly paid CEO. When there is a sufficiently positive (but still small) probability that other firms have highly paid CEOs, the “almost dominant” firm will choose to hire a highly paid CEO to avoid the large losses. Thus, the firm becomes infected and mimics the dominant-strategy firms. The same reasoning then applies to firms with the next lowest internal benefits, and such contagion could eventually affect all firms. In this case, an arms race occurs.

Based on these arguments, the arms-race approach to CEO pay leads to a new understanding of why CEO pay is so high. It only takes a few firms hiring highly paid CEOs to make everyone hire highly paid CEOs, because these few firms are enough to start an “epidemic” of high hiring. Importantly, though, this prevalence of highly paid CEOs arises from equilibrium behavior, and no firm can gain from unilaterally lowering pay. Consequently, a typical firm’s correct rationale for hiring a highly paid CEO amounts to “because everyone else does.”

3. The CEO Hiring Game

Two firms compete in some relevant market, such as a product market, capital market, or labor market. Both firms maximize profit, and to do so, they choose what type of CEO to hire. Firms can draw CEOs from a market of high-type CEOs or from a market of low-type CEOs. We assume that firms pay competitive wages in both markets; however, high-type CEOs demand a wage premium (i.e., high market clearing wage), while low-type CEOs are paid standard wages (i.e., low market clearing wage). The premium (or wage differential) is fixed at \( w > 0 \). For the baseline case in which both firms choose to hire low-paid CEOs, we normalize profit to be 0.

Hiring a highly paid CEO does two things. First, it adds a firm-specific net increment \( x_i \in [\bar{x}, \bar{x}] \) to the firm’s profit.\(^8\) This increment is private information to the firm and drawn independently from the distribution \( F(x) \). This is the internal effect. We require \( \bar{x} > 0 \), but \( \bar{x} \)

\(^8\) One can interpret \( x_i \) as firm \( i \)'s net benefit above a firm-specific hiring cost.
may be positive or negative. Second, the highly paid CEO provides the firm with a competitive advantage if its rival chooses a low-paid CEO, with the highly paid CEO firm earning an extra $B > 0$ in gross profit and the low-paid CEO firm losing $N > 0$. This is the external effect. It is assumed to be identical across firms, which is consistent with the notion that the impact of having a higher-paid CEO than one’s rival is determined by the nature of the market pairing rather than the characteristics of the individual firm. The resulting payoffs generate the following normal form game.

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<td>Highly-Paid (H)</td>
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<td>Low-Paid (L)</td>
<td>$-N, x_j + B - w$</td>
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To understand the game, consider first a situation in which both $x_i$ and $x_j$ are zero. If firm $j$ hires a highly paid CEO, firm $i$’s choice is between hiring a highly paid CEO and earnings of $-w$, or a low-paid CEO and earnings of $-N$. If $w < N$, hiring a highly paid CEO is a best response to other firms hiring a highly paid CEO. On the other hand, if firm $j$ hires a low-paid CEO, firm $i$ faces a choice between a highly paid CEO and earnings of $B - w$, or a low-paid CEO and earnings of 0. If $B < w$, hiring a low-paid CEO is a best response to other firms hiring a low-paid CEO. Consequently, when $B < w < N$, there are two pure strategy equilibria in the special case where it is known that $x_i = x_j = 0$, and in these two pure strategy equilibria, both firms hire the same type of CEO.

Now suppose instead that firm $i$’s internal profitability increment $x_i$ satisfies $x_i + B > w$. Hiring a highly paid CEO remains a best response to other firms hiring a highly paid CEO, but firm $i$’s best response to firm $j$ hiring a low-paid CEO is for firm $i$ to hire a highly paid CEO, because the combination of the productivity increment and the competitive advantage more than offsets the extra CEO pay. Consequently, hiring a highly paid CEO is a dominant strategy when the firm’s private increment $x_i$ is sufficiently high.

We restrict the components of the game so that:

$$w < N + \bar{x} \quad (1)$$

and

$$\bar{x} + B < w < \bar{x} + B. \quad (2)$$

Condition 1 states that for firms with the smallest internal effect, hiring a highly paid CEO is a best response to the rival hiring a highly paid CEO. Higher values of the internal effect $x_i$ only enhance this incentive, so highly paid being a best response to highly paid holds for all values of $x_i \in [\bar{x}, \bar{x}]$. The first inequality in Condition 2 states that for the firm with the lowest internal effect, hiring a low-paid CEO is a best response to the rival hiring a low-paid CEO, while the second inequality, coupled with Condition 1, says that for the firm with the highest internal effect, hiring a highly paid CEO is a dominant strategy.
These two inequalities imply that $B < N$, that is, the benefit to the winner of the CEO-hiring competition is smaller than the loss to the loser. Such a condition is consistent with findings in the literature. According to Hayes and Schaefer (2009), CEO pay serves as a signal of managerial quality and firm value to stock market participants. The different magnitudes might reflect that positive signals attract less capital than negative signals deter. It might also reflect the countervailing effect caused by institutional investors moving away from firms with higher-paid CEOs, as documented by David, Kochhar, and Levitas (1998) and Hartzell and Starks (2003).

Conditions 1 and 2 imply that for low values of $x$, both types of hiring are rationalizable, but for high values of $x$, hiring a highly paid CEO becomes a dominant strategy. If there is a positive probability of some players being dominant-strategy firms, a contagion effect comes into play, and this can lead to a CEO arms race, with all firms hiring highly paid CEOs, even though for most of them it is not a dominant strategy.

To see how this contagion comes about, consider firm $i$’s decision of whether to hire a highly paid CEO or a low-paid CEO. Firm $i$ knows that if it finds it beneficial to hire a highly paid CEO, any firm with a larger internal effect than $x_i$ will also find it beneficial. Consequently, firm $i$ realizes that if it chooses a highly paid CEO, the probability that it will face a rival with a highly paid CEO is at least $1 - F(x_i)$. If the firm faces a high-hiring rival, hiring high itself generates a gain of $x_i - w + N$ compared to hiring low. If, instead, the firm faces a low-hiring rival, hiring high generates a gain of $x_i - w + B$. Because the probability of facing a high-hiring rival, conditional on $i$ choosing to hire a highly paid CEO itself, is at least $1 - F(x_i)$, the expected gain from hiring a highly paid CEO satisfies

$$E(H) - E(L) \geq [1 - F(x_i)](x_i - w + N) + F(x_i)(x_i - w + B),$$

where $E(H)$ is the expected payoff from hiring a highly paid CEO (i.e., the expected payoff from action $H$), and $E(L)$ is the expected payoff from hiring a low-paid CEO (i.e., the expected payoff from action $L$). The inequality holds because $N > B$ by Conditions 1 and 2. Firm $i$ chooses to hire the highly paid CEO if $E(H) - E(L) \geq 0$, which can be rearranged to

$$1 - F(x_i) \geq \frac{w - x_i - B}{N - B}.$$  \hspace{2cm} (3)

According to this expression, firm $i$ chooses to hire a highly paid CEO when there are “enough” firms with higher internal effects than it has. Essentially, firm $i$ hires the high-type CEO to defend itself against all the other firms hiring high-types. If Equation 3 holds for every value of $x$ in $[x, \bar{x}]$, then every firm hires highly paid CEOs, and the arms race ensues.

Note that $N > B$ by Conditions 1 and 2, and that $w - x < N$ for all $x \in [\bar{x}, \bar{x}]$ by Condition 1, so that the right-hand side of Equation 3 lies between 0 and 1. Also, Condition 2 implies the existence of a value $\check{x} \in [\bar{x}, \bar{x}]$ such that $w - \check{x} = B$. Because the right-hand side of Equation 3 is decreasing in $x$ and equal to 0 when $x = \check{x}$, Condition 3 (Eqn. 3) is automatically satisfied for a firm with internal values in $[\check{x}, \bar{x}]$ but not for those in $[\bar{x}, \bar{x}]$.

4. The CEO Arms Race

We begin this section by extending the previous analysis to the case of more than two firms. To that end, suppose that $n \geq 2$ profit-maximizing firms compete in the relevant market.
Since it is a static game, the number of firms is fixed. Each firm chooses between hiring either a high-type (highly paid) CEO or a low-type (low-paid) CEO, with the wage premium \( w > 0 \) fixed across firms. If every firm chooses to hire the low-type CEO, profits are normalized to be 0.

Consider firm \( i \) and suppose that \( h_i \) of the other \( n - 1 \) firms hire high types and \( n - h_i - 1 \) hire low-types. When firm \( i \) hires a low type, it will lose the CEO-hiring competition and have a payoff of \(-r(h_i)N\), where \( r(h_i) \) is a function that determines firm \( i \)'s share of the total loss \( N \). When firm \( i \) hires a high type, its payoff is \( x_i + s(n - h_i - 1)B - w \), where \( s(n - h_i - 1) \) determines \( i \)'s share of total benefit.

Formally, the function \( r: [0, n - 1] \rightarrow [0, 1] \) is a loss-sharing rule if it is nondecreasing and onto. In particular, this requires \( r(0) = 0 \), so that a firm does not experience any external loss if it plays \( L \) when all other firms do, and \( r(n - 1) = 1 \) so that a firm suffers the entire external loss if it is the only firm to play \( L \) when everyone else plays \( H \). Similarly, the function \( s: [0, n - 1] \rightarrow [0, 1] \) is a benefit-sharing rule if it is nonincreasing and onto. This requires that \( s(n - 1) = 0 \), so that a firm gains no external benefit when it plays \( H \) when all other firms do, and it requires that \( s(0) = 1 \), so that a firm gains the entire external benefit by being the only firm to hire the highly paid CEO.

The requirements that \( r \) be a loss-sharing rule and \( s \) be a benefit-sharing rule allow for unique identification of the external loss and benefit parameters \( N \) and \( B \) from the cases where one firm acts differently from all of the others. Furthermore, other than the requirement that the functions be strictly monotone, the rules say nothing about whether total external losses and benefits increase or decrease as the number of firms hiring high-types changes.

One result relies on proportional scaling functions:

\[
r(h) = \frac{h}{n-1} \tag{4}
\]

and

\[
s(h) = \frac{n-h-1}{n-1}. \tag{5}
\]

These functions have intuitive appeal. Firm \( i \)'s payoff would be \(-Nh_i(n - 1)\) in the low-type case, and \( x_i + B(n - h_i - 1)/(n - 1) - w \) in the high-type case. Using these functions, if firm \( i \) is the only one to hire a low-type CEO, then \( h_i = n - 1 \), and its payoff is \(-N\), just as in the two-firm case. As fewer firms choose to hire a high-type CEO, however, \( i \)'s external loss is scaled back proportionally, so that if only one firm chooses to hire a high-type CEO, \( i \)'s payoff is \(-N/(n - 1)\). Similarly, if \( i \) is the only firm to hire a high-type CEO, its profit is \( x_i + B - w \), as in the two-firm case, but as more firms hire a high-type CEO, the external benefit is scaled back. If all firms hire the same type of CEO, the external effect is zero, and profit is either \( x_i - w \) when every firm hires a high-type CEO, or 0 when every firm hires a low-type CEO.

As before, assume that firms draw the internal effect \( x_i \) independently from \( F(x) \) with support \([x,\bar{x}]\). Conditions 1 and 2 now have different interpretations. With more than two firms, condition 1 states that the negative external effect is large enough to make a firm with the smallest internal effect hire a high-type CEO when all other firms hire a high-type CEO. The first inequality in condition 2 states that for the firm with the lowest internal effect, hiring a low-type CEO is a best response to hiring a low-type CEO, even if no other firm hires a highly paid CEO. The second inequality makes the firm with the highest internal effect hire a highly paid CEO even when it is the only one to do so.
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PROPOSITION 1. Suppose that conditions 1 and 2 hold. Then for any pair of loss- and benefit-sharing rules, there exists a Bayes-Nash equilibrium in which every firm chooses to hire a highly paid CEO, but there does not exist a Bayes-Nash equilibrium in which all firms choose to hire a low-paid CEO.

PROOF. To show that there exists a Bayes-Nash equilibrium in which every firm plays $H$, note that if everyone else plays $H$, then the lowest internal effect firm $\bar{x}$ prefers $H$ to $L$ if and only if
\[ x - w \geq -r(n-1)N = -N, \]
where the last equality comes from the requirement that $r$ be a loss-sharing rule.

Condition 1 then guarantees that the lowest-internal-effect firm plays $H$ in response to the other $n - 1$ firms playing $H$. However, if Equation 6 holds for the firm with $\bar{x}$, it also holds for any other firm with $x > \bar{x}$. Thus, $H$ is a best response to $H$ for all firms, and so there exists a Bayes-Nash equilibrium in which all firms play $H$.

To show that there is no Bayes-Nash equilibrium in which all firms play $L$, note that if $h = 0$, a firm with internal effect $x$ plays $H$ if and only if
\[ 0 \leq x + s(0)B - w = x + B - w. \]

Condition 2 guarantees that a strict version of the inequality (Eqn. 7) holds for $x = \bar{x}$, and firms with internal effect in the interval $[\bar{x}, \bar{x}]$ play $H$ even when no other firms do. Therefore, any Bayes-Nash equilibrium must have at least some firms playing $H$ and consequently cannot have every firm playing $L$.

This proposition establishes that equilibria of the game exist, and it begins to narrow down the types of behavior that can occur in equilibrium. The next proposition characterizes equilibrium behavior further.

PROPOSITION 2. Suppose that conditions 1 and 2 hold. Then for any pair of loss- and benefit-sharing rules, in every Bayes-Nash equilibrium there exists an $x^* \in [\bar{x}, \bar{x}]$ such that every firm with internal effect in the interval $[\bar{x}, x^*]$ chooses to hire a highly paid CEO, and every firm with internal effect in the interval $[x^*, \bar{x}]$ chooses to hire a low-paid CEO.

PROOF. In a Bayes-Nash equilibrium, strategies must respond optimally with their beliefs. Beliefs, in turn, must be consistent with equilibrium strategies. For each firm with internal effect $x$, then, Bayes-Nash equilibrium specifies an action from $\{H, L\}$ and a belief $\hat{h}$ about the random variable governing the number of firms playing $H$. Because internal effects are drawn independently, no firm’s $x$ provides any information about the posterior distribution of drawn internal effects. Consequently, $\hat{h}$ is independent of $x$.

To prove the assertion, suppose, to the contrary, that there exist two firms such that firm 1 with internal effect $x_1$ plays $H$, and firm 2 with internal effect $x_2 > x_1$ plays $L$. Given the common beliefs $\hat{h}$, firm 1 plays $H$ if and only if
\[ E \left[ x_1 + s(n - \hat{h} - 1)B - w \right] \geq E \left[ -r(\hat{h})N \right], \]
where the expectation is taken over $\hat{h}$. Rearranging yields
\[ x_1 \geq E \left[ -r(\hat{h})N \right] - E \left[ s(n - \hat{h} - 1)B - w \right]. \]
Note that the right-hand side of Equation 8 is independent of type. Consequently, 
\[ x_2 > x_1 \geq E[-r(\hat{h})N] - E[s(n - \hat{h} - 1)B - w], \]
and firm 2 strictly prefers to play \( H \). This provides a contradiction, thereby establishing the assertion.

This result shows that in every equilibrium, the firms hiring high-type CEOs are those with large internal effects, and that firms hiring low-type CEOs have smaller internal effects. This is intuitively plausible. It also states that in every equilibrium, there is at least a partial arms race, as the firms with the largest internal effects choose to hire highly paid CEOs, and those with slightly smaller internal effects choose to hire highly paid CEOs in defense. The next proposition establishes circumstances under which an arms race must impact the entire population. It also establishes that, under those circumstances, a CEO arms race must occur because it is the only Bayes-Nash equilibrium.

**Proposition 3.** If conditions 1 and 2 hold, if \( r(\tilde{h}) = \hat{h}(n - 1) \) and \( s(\tilde{h}) = (n - \hat{h} - 1)(n - 1) \), and if
\[
F(x) < \frac{N - (w - x)}{N - B} \quad (9)
\]
for all \( x \in [\hat{x}, \tilde{x}] \), then the Bayes-Nash equilibrium is unique, and all firms choose to hire a highly paid CEO.

**Proof.** We first show that using proportional scaling functions (Eqns. 4 and 5), the condition given in Equation 8, the circumstance under which firm \( i \) chooses to play \( H \), reduces to a simpler expression. Notice that \( E[\hat{h}] = (n - 1)(1 - F[x^*]) \). Then:
\[
E[-r(\tilde{h})] = \frac{(n-1)(1-F(x^*))}{n-1} = F(x^*) - 1
\]
and
\[
E[s(n - \hat{h} - 1)] = \frac{n-1 - (n-1)(1-F(x^*))}{n-1} = F(x^*).
\]
The inequality in Equation 8 for any firm \( i \) becomes
\[ x_i \geq (F(x^*) - 1)N - F(x^*)B + w. \quad (10) \]
Rearranging we get:
\[
F(x^*) \leq \frac{N - (w - x_i)}{N - B}.
\]
For this special case of proportional scaling functions, we show that if the distribution of internal effects satisfies Equation 9, there is no equilibrium in which \( L \) is played with positive probability. Suppose not, so that firm \( i \) plays \( L \) with positive probability. Because \( H \) is a best response to \( H \), for \( i \) to play \( L \) with positive probability, \( i \) must place positive probability on some of its rivals also playing \( L \). Because the \( x_i \) values are drawn independently, and players must follow a cutoff strategy, there exists an interval \([\hat{x}_i, \tilde{x}_i]\) such that \( i \) believes that rivals who draw values \( x \in [\hat{x}_i, \tilde{x}_i]\) play \( L \), and those who draw \( x \in [\hat{x}_i, \tilde{x}_i]\) play \( H \). Furthermore, there exists an interval \([\hat{x}, \tilde{x}]\) such that player \( i \) plays \( L \) if and only if \( x \in [\hat{x}, \tilde{x}] \). Then for player \( i \),
Suppose that \( x_i^* \geq \xi_i \). Then
\[
x_i^* = w - N + F(\xi_i)(N - B) \leq w - N + F(x_i^*)(N - B),
\]
which implies that
\[
F(x_i^*) \geq \frac{N - (w - x_i^*)}{N - B}
\]
and violates the condition in Equation 9. Consequently, it must be the case that \( x_i^* < \xi_i \) for firm \( i \) to play \( L \) with positive probability. This same condition must hold for every player, which means that every player believes that its rivals use a higher cutoff point than they do. Such beliefs cannot be consistent with Bayes-Nash equilibrium. This establishes a contradiction to the hypothesis that firms play \( L \) with positive probability. Thus, when Equation 9 holds, there is a unique Bayes-Nash equilibrium, and every firm chooses \( H \).

The three propositions establish conditions under which an arms race for CEO hiring occurs, and under which it is the only equilibrium. In particular, the uniqueness result of Proposition 3 establishes conditions under which firms cannot avoid a CEO arms race. To help understand their meaning, it is beneficial to see how the different assumptions impact the outcome. The first assumption was the existence of idiosyncratic internal effects, captured by \( x_i \).

Suppose instead that \( x_i \) is fixed at \( x \) for all \( i \), with the added assumption that \( x > w - N \), consistent with condition 1. This condition implies that \( H \) is a best response to \( H \), which we had assumed to hold for all types. Two possibilities emerge. If \( x \geq w - B \), then \( H \) is a (weak) best response to \( L \), so that \( H \) is a (weakly) dominant strategy. No arms race explanation is required here, though, because high-type CEO hiring arises entirely from the internal effect, that is, highly paid CEOs add enough to the firm’s profit to justify the high wage regardless of what rivals do. The second case has \( x < w - B \), in which case \( L \) is a best response to \( L \). The game has two pure strategy equilibria, in which case high-type CEO hiring occurs not because of an arms race but simply as a result of the solution to a coordination problem. Idiosyncratic internal effects prove necessary for the explanation of high-type CEO hiring to come from an arms race. Furthermore, firms must face the possibility that some of their rivals have a sufficiently large internal effect to make hiring a highly paid CEO a dominant strategy. In this case, if idiosyncratic internal effects are distributed according to Equation 9, even the small possibility of facing a dominant-strategy opponent will cause contagion. The small group of dominant-strategy players will induce the rest of the firms to hire highly paid CEOs.

The second assumption was that the external effect consisted of a larger loss from having the lower-paid CEO than the gain from having the higher-paid CEO, that is, \( N > B \). If this fails, Equation 9 would require that \( f(x) \) be negative, which is impossible. As Proposition 3 proves, when Equation 9 fails, no arms race occurs. Consequently, asymmetric impacts of CEO type differences, with losers losing more than winners gain, prove crucial for the existence of an arms race in CEO hiring.

We introduce the loss-sharing (benefit-sharing) rule functions that only need to be nondecreasing (nonincreasing) and onto for Propositions 1 and 2 to hold. For Proposition 3,
we reduce the set of possible functions to linear form in order to be able to calculate their expectations more easily. However, the inequality in Equation 10 holds for a more general set of concave functions.  

Concavity means that losses (benefits) of firms that pay low wage (high wage) exceed losses (benefits) that are generated by linear proportional scaling functions.

Finally, Proposition 3 links a CEO arms race to the condition given in Equation 9, about which more must be said. The left-hand side, $F(x)$, measures the fraction of firms that have internal effects no larger than $x$, while the right-hand side is an increasing function of $x$, and both functions are depicted in Figure 1. The key to the condition is the right-hand-side function $(N - [w - x])/N - B$. This function takes the value zero when $w - x = N$. Condition 1 states that $w - x < N$ for all $x \in [\bar{x}, \tilde{x}]$, and so the function $(N - [w - x])/N - B$ crosses the horizontal axis to the left of $\bar{x}$. The function takes the value 1 when $w - x = B$, and by Equation 2, this occurs for some value of $x$ between $\bar{x}$ and $x$, as shown. Thus, the “support” of the function $(N - [w - x])/N - B$ is shifted to the left of the support of $F(x)$. As the figure shows, Equation 9 is satisfied as long as $F(x)$ does not place too much weight in its left tail, and the figure is drawn for a bell-shaped density. Furthermore, in the special case in which $x$ is uniformly distributed, so that $F(x)$ is linear, Equation 9 is automatically satisfied. Consequently, one can interpret the condition in Equation 9 as saying that the distribution of the internal effect must be “close” to uniform without too much weight, or too large of a spike, in its lower tail. Any distribution that shifts mass rightward from the uniform distribution will automatically satisfy the condition as well. As Proposition 3 proves, such distributions of internal effect lead to a CEO arms race.

5. Concluding Remarks

This article identifies circumstances under which firms might engage in an arms race to have higher paid CEOs. Such an arms race requires both an internal effect and an external

\[ \frac{N - (w - x)}{N - B} \]

Figure 1. The Main Result Illustrated

\[ x \]

\[ \bar{x} \]

\[ w - B \]

\[ w - N \]

\[ 1 \]

\[ F(x) \]

10 By Jensen’s inequality, $x_i + s(n - E[\tilde{h}]) - 1)B - w \geq E[x_i + s(n - \tilde{h} - 1)B - w]$ and $E[-r(\tilde{h})N] \geq -r(E[\tilde{h}])N$, so $x_i + F(x^*)B - w \geq (F(x^*) - 1)N$, which is the same as the inequality given in Equation 10.
effect from hiring a highly paid CEO. The internal effect arises when marginal improvements in a firm’s own CEO type (or quality) generate marginal increases in its own profit, holding rival CEO type constant. The external effect provides a profit boost to firms with higher-paid CEOs and a loss to those with lower-paid CEOs. Arms races occur when the following circumstances hold: (i) the magnitude of the internal effect is heterogeneous, based on private information, and sufficiently uniform, (ii) there is positive probability that some firms have large enough internal effects that they find it worthwhile to hire high-type (highly paid) CEOs regardless of what their rivals do, and (iii) the external effect is homogeneous and causes firms to lose more from having the lower-paid CEO than they would gain from having the higher-paid CEO.

For CEOs, the internal effect arises as a higher-paid CEO runs the firm in a more efficient, more profitable way, perhaps because of improved access to capital markets or increased bargaining power with suppliers or labor. The external effect occurs because a higher-paid CEO provides a competitive advantage over a rival with a lower-paid CEO, perhaps because of signaling to customers. Under appropriate distributional assumptions, these two effects can lead to an arms race for CEO pay. The arms race itself arises out of a kind of contagion, albeit one that occurs instantly rather than through time. The firms with the highest internal effects have an incentive to hire highly paid CEOs, which provides the firms with the next highest internal effects with an incentive to also hire a highly paid CEO, and so on, until every firm hires a highly paid CEO.

One implication of the model is that firms hire highly paid CEOs regardless of their internal effects. Instead, these CEOs are hired not because of what they can do for the firm but what their type, in and of itself, does for the firm. Essentially, the firm needs a highly paid CEO to protect its competitive position. This may shed light on one particularly prominent instance of high CEO pay. In 2001, the legendary Jack Welch retired from his CEO position at General Electric. GE chose his successor from among three well-qualified, internal candidates: Jeffrey Immelt, Jim McNerney, and Robert Nardelli. GE promoted Immelt to CEO, while McNerney left to become CEO of 3M and Nardelli left to become CEO of Home Depot. GE and 3M have many similarities, using technological innovation to develop new products in many diverse markets, so one can imagine why McNerney would generate a large, positive internal effect at 3M. It is much harder for one to see how the skills from running GE Power Systems would translate into strong internal effects in the world of big-box retailing at Home Depot. The arms race model predicts that Nardelli’s pay would be high anyway, and it was.

The increased relevance of external effects may be one of the drivers why CEO pay has increased so dramatically over the last 20 years. An event that possibly made external effects more relevant was the adoption of amendments to the executive compensation disclosure approach by the Securities and Exchange Commission in 1992. The amendments required highly formatted disclosure to facilitate the comparison of annual compensation among companies. Examples of external effects given earlier in the article included higher-paid CEOs having more credibility in capital markets or signaling higher quality to customers. For these channels to operate, outsiders must be able to verify the CEO’s pay, and the new disclosure requirements allow this channel to open.

An identical setting, with identical results, could be applied to markets other than that for CEOs. Perhaps the most obvious is the market for mutual fund managers. A highly paid mutual fund manager might be able to generate higher return on the portfolio, which is the internal effect. At the same time, a highly paid manager might attract customers away from a rival, whereas a fund with a low-paid manager might lose investors not just to a single rival but
to the industry as a whole. This creates an asymmetry for the external effect, with the losses from having a low-paid manager outpacing the gains from having a highly paid one. Given these circumstances, one might expect to see an arms race for mutual fund managers.

The arms race analysis cannot, however, explain high salaries in professional sports, or for that matter high salaries for collegiate coaches. Hiring marquee athletes or coaches may generate an external effect as the fan base and team revenue may respond to the league’s distribution of superstars. At the same time, individual athletes or coaches certainly have an internal effect, but one would be hard pressed to argue that these internal effects are private information, given the very public nature of the profession. Consequently, player salaries are unlikely to be driven by an arms race.

Comparing these settings leads to an empirical approach. The article’s main proposition states that when the conditions for an arms race arise, the only outcome is an arms race. An appropriate empirical strategy, then, concentrates on the conditions for an arms race rather than an arms race itself, identifying both internal and external benefits of hiring highly paid CEOs.

References


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