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Asymmetric Learning and the CEO Labor Market

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Abstract

Many models of the CEO market build on the classic analyses of Lucas (1978) and Rosen (1982) characterized by full information, a limited role for firm-specific human capital, and efficient allocation of workers across jobs and firms. But empirical evidence is not consistent with this approach. We explore an alternative focused on asymmetry of information between an executive's prospective employer and other potential employers, and an important role for firm-specific human capital. We show that our model better captures findings in the empirical literature concerning the CEO labor market than both the full information and efficient assignment approach and alternative models based on asymmetric information and inefficiencies.

Keywords: CEOs, asymmetric employer learning, firm-specific human capital

JEL classifications: G14, G34, J62

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1 Introduction

The CEO of a firm has a large impact on the firm's likelihood of success. Given this, understanding how the market for CEOs operates is essential for understanding what leads to successful firms. Many previous authors who have modeled the CEO market have built on the approach pioneered in Lucas (1978) and Rosen (1982) characterized by full information concerning worker abilities, limited firm specific human capital, and the efficient assignment of workers to jobs and firms. This influential strand of the literature, represented by Tervio (2008), Gabaix and Landier (2008), and Edmans, Gabaix and Landier (2009), has been useful for understanding some aspects of the CEO labor markets, especially trends in the level of CEO compensation. However, various empirical papers concerning the market for CEOs contain findings that are inconsistent with models in which CEO ability is public knowledge and firm-specific human capital has limited importance. In particular, the CEO labor market empirical literature finds that:

1. most CEO positions are filled through internal promotions rather than by poaching executives from other firms (Parrino, 1997; Murphy and Zabojnik; 2007; and Cziraki and Jenter, 2022);

2. if a CEO position is filled by an external candidate, the candidate is typically not a sitting CEO at another firm (Cziraki and Jenter, 2022);

3. most CEOs hired externally are only partial outsiders in that they were previously employed by the hiring company, or worked with one of the hiring company's directors, or have some other tie to the hiring company (Cziraki and Jenter, 2022); and

4. compensation is higher for CEOs hired from outside than for those promoted internally (Murphy and Zabojnik, 2007; Cziraki and Jenter, 2022).

These empirical regularities suggest that there are significant frictions that inhibit the kind of efficient movement of CEOs across firms envisioned by the assignment models mentioned earlier. Rather, frictions limiting worker movements such as asymmetric information and firm specific human capital seem to be critical for understanding the CEO labor market.[1]

In this paper we build a theoretical framework in which firm specific human capital and asymmetric information (concerning worker ability levels) play central roles in markets for CEOs. In our approach we also assume that, if a firm considers an external candidate for its CEO position, the candidate is an executive below the CEO level as found by Cziraki and Jenter (2022); for example, someone who is currently employed as a COO or a CFO in another firm.[2] Our goal in building and analyzing this model is threefold.

First, we want to capture in a single framework the results listed above suggesting the importance of frictions, as well as show that our framework can capture other important findings in the CEO empirical literature. Other findings that our model is able to capture include:

5. turnover announcements are related to positive abnormal stock returns, especially when the sitting CEO is replaced by an outside candidate (Borokhovich et al, 1996; Huson et al., 2004);

6. on average, CEO turnover is followed by improved managerial quality and firm operating performance (Huson et al., 2004); and

7. most CEOs hired externally come from firms that are much larger than the hiring firm (Cziraki and Jenter, 2022).

Second, we investigate the efficiency properties of the market for CEOs within our framework and characterize the nature of the resulting distortions. Third, we derive new testable predictions.

In our model, a firm knows the ability level of each of its current employees. In contrast, for a worker currently employed elsewhere, the firm can learn the ability level of the worker by interviewing him, which entails a cost. Further, when a firm offers the CEO position to a worker, whether a current employee or a worker currently employed elsewhere, the offer is observed by

[1] This conclusion also fits with a number of empirical studies of non-CEO labor markets which have found evidence consistent with employer learning being asymmetric. See, for example, Gibbons and Katz (1991), Schönberg (2007), DeVaro and Waldman (2012), and Kahn (2013).

[2] This assumption is consistent with asymmetric information and firm specific human capital being important at the CEO level, but for tractability reasons we impose it as an assumption.

other firms in the market which can respond with their own offers to the worker. The asymmetry of information in combination with the public observability of offers to fill the CEO position means that an offer serves as a signal of worker ability as first investigated in Waldman (1984).

We start by considering equilibrium behavior when a firm's decision is whether to retain the current CEO without interviewing an external candidate as a possible replacement, retaining the current CEO after interviewing an external candidate, and replacing the current CEO with an external candidate after an interview. That is, we start by assuming that there are no internal candidates for the firm to consider. We show here that both the firm's interview decision as well as its hiring decision are inefficient. That is, the firm interviews a potential replacement candidate less often than is efficient, and conditional on an interview, the incumbent is replaced less often than is efficient. The latter follows from the signaling effect on outside wage offers when an interviewee is given an offer, which is that the marginal external candidate hired must be paid the productivity at an alternative employer of the average external candidate hired or the candidate will accept an alternative offer. The former follows both because hiring occurs less often than is efficient given an interview takes place, and because the firm looking to replace its CEO, relative to a social planner, does not benefit from having an interviewee accept a CEO position elsewhere. Both of these distortions lead to an endogenous entrenchment of the incumbent CEO. Moreover, we show that if the firm's board of directors derives a private benefit from retaining the incumbent, which we call exogenous entrenchment, then endogenous and exogenous entrenchments are substitutes in that an increase in the level of exogenous entrenchment leads to a decrease in the efficiency loss caused by endogenous entrenchment. This baseline model also yields results that speak to the facts 5 and 6 above, i.e., to the stock market's reaction to CEO replacement and to CEO quality and firm performance following CEO replacement.

We then show that our analysis easily captures 3 above, i.e., the finding in Cziraki and Jenter (2022) that external hires are typically partial outsiders rather than full outsiders, meaning that when a firm fills the CEO position with an external candidate it is typically someone with a connection to the firm. For example, the hire might have worked at the firm previously, although the individual was not an employee of the firm immediately prior to the individual becoming the new CEO. We capture this finding by extending our first model by allowing for external candidates who are partial outsiders and external candidates who are full outsiders, where the firm's cost of interviewing and learning the ability of partial outsiders is lower on average consistent with the firm having more information prior to the interview concerning the ability level of a partial outsider. Here we show that, given an external candidate is hired, the probability the hire is a partial outsider is higher than the proportion of partial outsiders in the pool of external candidates.

We then incorporate multiple firm sizes, where a firm's size affects the expected ability of the executives who are just below the CEO level in the given firm. Consistent with 7 above, we find here that when a firm hires an individual who is currently an executive just below the CEO level in some other firm to fill its own CEO position, it typically hires an executive from the largest available firm. This is because executives in larger firms are chosen from among a larger pool of lower-level employees and therefore possess higher expected managerial abilities than executives in smaller firms. They also command higher market wages, but this is more than offset by their higher productivity in the hiring firm.

In our final analysis we consider the case in which a firm has a vacant CEO position and chooses whether to fill the position with either an internal candidate or an external candidate. The ability of each candidate is drawn from the same distribution, where the firm knows the ability of the internal candidate but needs to conduct a costly interview to learn the ability of the external candidate. We also assume that alternative employers cannot directly observe the ability level of either candidate, so hiring serves as a signal of ability whether the internal candidate is hired or the external candidate is hired. Consistent with observation 1 above, we find that, as long as there is at least a small amount of firm specific human capital, there is a higher probability the internal candidate is hired. In addition, we show that CEOs hired externally are paid more than those promoted from within, which is in line with observation 4 suggested by the empirical findings in Murphy and Zabojnik (2007) and Cziraki and Jenter (2022). One factor behind this result is that the external candidate is only hired when his managerial ability exceeds that of the internal candidate plus the internal candidate's specific human capital, so the signal is stronger for external hires than for internal promotions.

Our analysis also yields two new testable predictions. First, we show that if a CEO is replaced before her normal retirement age, the new (external) CEO's pay should increase with the incumbent CEO's tenure in her firm. This is because tenure can proxy for both firm specific human capital and for exogenous entrenchment, both of which increase the new CEO's pay in our model. Second, CEOs hired externally should be paid more when they come from larger firms. This follows from our assumption that high level executives are promoted based on their abilities, and from the fact that the expected value of a maximum increases with the size of the set.

Related literature

Apart from the assignment models discussed earlier, our paper is closest to the papers that focus on CEO replacement while allowing for imperfect information and incorporating an element of learning. For example, in the classic analysis of Hermalin (2005), the intensity with which a firm's board of directors monitors the CEO determines the probability with which the board receives a signal about the CEO. In turn, based on the signal, the board decides whether to replace the CEO with a random outsider. Hermalin's focus is on explaining several stylized facts regarding trends in corporate governance and in CEO compensation. We do not address those trends.

In addition to Hermalin's (2005) paper, other important papers in this literature include Inderst and Mueller (2010), Garrett and Pavan (2012), and Cao and Wang (2013).[3] The last two papers build dynamic models of CEO incentives and turnover when the quality of the CEO's match with the firm changes stochastically over time and the CEO has private information about this quality. Garrett and Pavan show that the firm's optimal threshold for retaining a given CEO weakly decreases with the CEOs tenure at the firm, while the focus of Cao and Wang's analysis is on the slope of the CEO's optimal incentive contract and on how the slope depends on systematic and idiosyncratic risks. Inderst and Mueller (2010) show that when CEOs have private information

[3] Other papers in this literature include Taylor (2010), Chaigneau and Sahuguet (2018), and Geelen and Hajda (2023).

about the quality of their match, a firm can use a steep incentive contract to induce a poorly matched CEO to quit.

Both Inderst and Mueller (2010) and Garrett and Pavan (2012) find that in general the firm's retention policy is not socially efficient. This is also true in our framework, but in addition we show that the inefficiency permeates both the decision to initiate search for a new candidate and the decision to hire an interviewed candidate. Further, we provide an analysis of how the inefficiencies depend on the level of exogenous CEO entrenchment.[4]

More generally, we believe our paper provides the first theoretical framework that can capture all of the observations regarding CEO labor markets listed in 1 − 7 above. Furthermore, relative to earlier papers on learning and CEO replacement our paper has two novel features. First, while the existing models focus on learning about CEO ability after the CEO was appointed, we allow the firm to learn about the ability of an outside candidate via a costly interview, where this type of information acquisition is clearly an essential aspect of real-world CEO hiring decisions. Second, we incorporate the idea that hiring serves as a signal of the candidate's ability which in turn affects compensation through wage offers of alternative employers. This aspect of our model is consistent with extensive theoretical and empirical literatures concerning promotion signaling found in the personnel economics literature.

Our paper is also related to Murphy and Zabojnik (2004, 2007) and Frydman (2019). In those papers it is argued that over time the requirements of the CEO position have shifted towards less emphasis on firm specific skills and more emphasis on general skills. Further, Murphy and Zabojnik put forward this idea as an explanation for a growth in external hires in the CEO market between 1970 and 2000 which they document, and there are also other papers that find similar results. But even at its peak the percentage of external hires seems to be approximately 30 percent or below suggesting that, although it may have waned in importance over time, firm specific human capital arguably still plays a significant role. In our paper, firm-specific human capital plays a central role

[4] Our paper also contributes to the theory literature focused on the choice firms face concerning filling managerial positions (not necessarily at the CEO level) with internal or external candidates. See, for example, Chan (1996), Waldman (2003), DeVaro and Morita (2013), and Ke, Li, and Powell (2018). Note that none of these earlier papers focuses on interviews of external candidates and the signaling effect of hiring decisions.

in the result that firms prefer to fill their vacant CEO position through internal promotion rather than with an outside candidate.

Our paper is also related to a discussion in Cziraki and Jenter (2022). They argue that their empirical findings are not consistent with the standard approach to modeling the CEO market which assumes full information and frictionless mobility of workers, and hypothesize that their results can be explained with an approach emphasizing asymmetric information and firm specific human capital. But they do not provide any formal theoretical analysis. We provide such an analysis, where we also incorporate an interview/search process that allows the hiring firm to gain an informational advantage compared to other firms in the labor market, consistent with how the CEO market actually operates. We show that a model of the CEO market with these features does indeed match many of the findings in Cziraki and Jenter (2022), as well as in various other empirical studies of the CEO market. In addition, we are able to shed light on what we believe are the key mechanisms behind various empirical findings.

The outline for the paper is as follows. Section 2 presents the base model in which an employer considering replacing an incumbent CEO does not have any internal candidates to consider. Section 3 provides an analysis of the base model and characterizes the welfare properties of the equilibrium, as well as the stock market's reaction to the news that the incumbent CEO will be replaced. Section 4 allows for two types of external candidates: partial outsiders and complete outsiders. Section 5 introduces firm heterogeneity. Section 6 analyzes the model given there is an internal candidate. Section 7 compares our theoretical findings to evidence from the empirical literature. Section 8 presents concluding remarks.

2 The Model

A firm, labeled A, with an incumbent CEO (she) of known ability can choose to replace the incumbent with an outside hire (he). In this firm, the productivity of a CEO with general managerial ability a and firm-specific human capital δ is $k(a+\delta)$, with $k \geq 1$, $\delta = s_I \in (0,1)$ for the incumbent, and $\delta = 0$ for an outside hire.

In line with the evidence in Cziraki and Jenter (2022) who document that most CEOs hired externally come from below CEO positions in other firms, we assume that potential outside candidates for Firm A's CEO position are not currently employed as CEOs. Their CEO ability therefore cannot be directly observed either by Firm A or by other potential employers. Initially, they only know that each candidate's ability is drawn from $[0, 1]$ according to the uniform distribution. Firm A, however, can learn the candidate's ability by interviewing him, which costs $c > 0$.[5] The firm can interview at most one potential outside candidate.[6]

The candidate's output in his current position is given by $\beta(a_O + s_O)$, where a_O denotes the candidate's managerial ability, s_O is his firm-specific human capital pertaining to his current job, and $\beta \in (0, 1)$. This output is only observed by the candidate's current employer who we will refer to as Firm B. Firm B can therefore infer the candidate's managerial ability, but we assume that it does not wish to replace its sitting CEO. In wage competition with other firms, including Firm A, Firm B's willingness to bid for the candidate will therefore be given by the candidate's productivity in his current (non-CEO) position.

There are at least two other firms ready to compete for Firm A's incumbent CEO and two firms (possibly the same as the first two) ready to compete for the outside candidate. These firms will be referred to as the labor market. If hired by one of the labor market firms, the candidate's productivity is $\gamma_O a_O$, where $\gamma_O \in (0, 1)$. Similarly, the productivity of Firm A's incumbent CEO in one of the outside firms would be $\gamma_I a_I$, where a_I is the incumbent's managerial ability and $\gamma_I \geq \gamma_O$. The latter restriction captures the idea that CEOs tend to have outside opportunities that are no worse than those of non-CEO executives.

The identity of the outside candidate that Firm A is considering is initially known only to Firm A, but if A makes him an offer to be its CEO, this fact, along with the candidate's identity (but not his ability), is revealed to the labor market. The labor market firms then make simultaneous

[5] We conjecture that most of our qualitative results would hold if an interview improved the hiring firm's information concerning the candidate's ability, but did not provide full information. We assume the interview provides full information to simplify the math and the exposition.

[6] Allowing Firm A to interview multiple candidates would have predictable effects: An increase in the number of interviewed candidates would increase both the probability the incumbent is replaced and the wage paid to an outside hire.

wage offers to the candidate, after which the candidate decides which offer to accept. He accepts the highest offer and in the case of a tie goes to Firm A if Firm A was among the firms with the highest offer. If A was not among the firms with the highest offer, the candidate decides among the highest-offer firms randomly.

To eliminate less plausible equilibria, we assume that with a small exogenous probability ε the candidate randomly accepts an offer made by a firm other than A, even if A's was the highest offer.[7] If Firm A decides not to hire the outside candidate and does not make him an offer, his identity does not get revealed either to the outside labor market or to his current employer.

We also assume that the incumbent is entrenched. As in, for example, Taylor (2010), this is modeled as a private benefit, $e \geq 0$, that the firm's board of directors derives from retaining the current CEO. An alternative interpretation of e is that it represents the incumbent's severance package.[8] Exogenous entrenchment is not necessary for our main results, but it enriches the set of predictions delivered by our theory.

To allow for non-trivial insights and to limit the number of cases that need to be considered, we impose the following restrictions on the parameter values.

Assumption 1. $\frac{ks_I+e}{k-\gamma_O} < 1$.

Assumption 1 ensures that conditional on interviewing an outside candidate, Firm A finds it optimal to replace its incumbent CEO if her ability is low and the outside candidate's ability is high. The assumption also ensures that when the incumbent's ability is low (and the search cost is not too high), it is optimal for Firm A to initiate a search for an outside candidate to replace the incumbent. Observe that the assumption requires that γ_O is sufficiently smaller than k. If it were $\gamma_O > k$, the outside candidate's pay would always exceed his productivity in Firm A, making it unprofitable for the firm to hire him. Moreover, even with $\gamma_O < k$, γ_O cannot be too close to k because the unraveling due to asymmetric information would completely shut down the market for

[7] Formally, we focus on equilibrium behavior in the limit as ε approaches zero from above. Technically, this is equivalent to assuming Trembling Hand Perfection.

[8] Under this alternative interpretation, however, the efficiency benchmark of subsection 3.1 would have to be modified as in this case e is simply a transfer and does not affect welfare directly.

outside candidates. It is worth pointing out that it is not necessary to impose a similar constraint on γ_I; with some modifications to the analysis, our results would go through even for γ_I larger than k (but not too large). Nevertheless, to streamline the exposition, we will focus on $\gamma_I < k$.

Assumption 2. $\frac{1}{2} < \frac{\beta s_O}{\gamma_O - \beta}$.

This assumption says that the outside candidate's firm-specific human capital is important, so that his productivity in his current position in Firm B exceeds his unconditional expected productivity in an outside firm. The condition also implies $\gamma_O > \beta$, that is, managerial ability is more valuable in the CEO position in a market firm than in Firm B's non-CEO position.

Assumption 3. $\frac{k s_I + e}{k - \gamma_O} \geq \frac{\beta s_O}{\gamma_O - \beta}$.

Assumption 3 implies that conditional on the fact that the outside candidate has received a job offer from Firm A, his expected productivity in an outside firm exceeds his productivity in his current position in Firm B. Note that assumptions 1 and 3 together imply $\frac{\beta s_O}{\gamma_O - \beta} < 1$, which will allow for an interior solution in our efficiency benchmark.

The timing of events is summarized below:

t=1: Firm A decides whether to search for a new CEO. If it searches, it interviews a single candidate at cost c.

t=2: Firm A observes the candidate's ability and either makes him a (publicly observable) offer or stops the search process and retains the incumbent. If A does not proceed with an offer, the candidate's identity is not revealed to the market.

t=3: If A made an offer, the other firms, including the candidate's current employer, make simultaneous wage offers to the candidate.

t=4: The candidate decides which offer to accept (if he received any).

t=5: Production takes place, the firm's output is realized, and the firm's CEO gets paid.

The solution concept we use is Perfect Bayesian equilibrium.

3 Analysis

3.1 Efficiency benchmark

The efficiency benchmark we focus on is the constrained-efficient outcome that would obtain under the model's informational assumptions if Firm A's actions and the agents' job assignments were chosen by a social planner whose goal is to maximize welfare. Working backwards, suppose Firm A has spent the cost c to learn an outside candidate's ability, whose realization will be denoted by a_O. Define $\bar{a}_O$ as the ability at which the outside candidate is equally productive in his current non-CEO job as in the CEO job in one of the market firms, that is, $\gamma_O \bar{a}_O = \beta(\bar{a}_O + s_O)$, or

$$\bar{a}_O = \frac{\beta s_O}{\gamma_O - \beta}.$$

Suppose first that $a_O > \bar{a}_O$. In this case, if the social planner does not end up replacing the incumbent, efficiency requires that the outside candidate is reallocated to the CEO position in some other firm. If $a_O \leq \bar{a}_O$ and Firm A's incumbent is not replaced, the outside candidate stays in his current job. The planner therefore replaces the incumbent if and only if $ka_O + \gamma_I a_I > k(a_I + s_I) + e + \max\{\gamma_O a_O, \beta(a_O + s_O)\}$, or $a_O > \widehat{a}_O(a_I)$, where $\widehat{a}_O(a_I)$ is given by

$$\widehat{a}_O^1(a_I) \equiv \frac{k-\gamma_I}{k-\gamma_O} a_I + \frac{ks_I + e}{k - \gamma_O} \qquad \text{if } a_O > \bar{a}_O; \tag{1a}$$

$$\widehat{a}_O^2(a_I) \equiv \frac{k-\gamma_I}{k-\beta} a_I + \frac{ks_I + e + \beta s_O}{k - \beta} \qquad \text{if } a_O \leq \bar{a}_O. \tag{1b}$$

Observe that (1a-1b) are the same conditions that would be used by Firm A's board of directors if the outside candidate's ability were publicly revealed to both Firm A and the labor market.[9]

It is straightforward to check that Assumption 3 implies $\widehat{a}_O^1(a_I) > \widehat{a}_O^2(a_I) \geq \bar{a}_O$ for all a_I, which means that the case (1b), where $\widehat{a}_O(a_I) = \widehat{a}_O^2(a_I)$, is redundant. Thus, the constrained-efficient benchmark says that the incumbent is replaced if and only if $a_O > \widehat{a}_O^1(a_I)$. Given that $\widehat{a}_O^2(a_I)$ is no longer relevant for the analysis, we will henceforth write simply $\widehat{a}_O(a_I)$ or $\widehat{a}_O$ instead of $\widehat{a}_O^1(a_I)$.

[9] Suppose the ability of the outside candidate is revealed to be $a_O \geq \bar{a}_O$. Then his market wage is $\gamma_O a_O$ and Firm A replaces the incumbent iff $(k-\gamma_O)a_O > (k-\gamma_I)a_I + ks_I + e$, which yields (1a). Similarly, if $a_O \leq \bar{a}_O$ then Firm A would have to offer the outside candidate at least $\beta(a_O + s_O)$ to be able to hire him away from his current employer. In this case Firm A replaces the incumbent iff $ka_O - \beta(a_O + s_O) > (k-\gamma_I)a_I + ks_I + e$, which yields (1b).

That is,

$$\widehat{a}_O\left(a_I\right)=\frac{k-\gamma_I}{k-\gamma_O}a_I+\frac{ks_I+e}{k-\gamma_O}.$$

This conclusion is summed up in the following lemma.

Lemma 1. *Conditional on interviewing an outside candidate, in the constrained-efficient scenario the incumbent is replaced if and only if* $a_O>\widehat{a}_O\left(a_I\right)=\frac{k-\gamma_I}{k-\gamma_O}a_I+\frac{ks_I+e}{k-\gamma_O}$.

Now consider the decision to start a search for a replacement CEO, i.e., to spend c to learn an outside candidate's ability. If $\widehat{a}_O\left(a_I\right)\geq 1$, the incumbent is never replaced. If $\widehat{a}_O\left(a_I\right)<1$ and the firm interviews a candidate, then with probability $1-\widehat{a}_O$ the candidate's ability is sufficiently high to replace the incumbent. The average ability of such a successful outside hire is $\frac{1}{2}\left(\widehat{a}_O+1\right)$. With probability $\widehat{a}_O$ the candidate's ability is not high enough to replace the incumbent, so the candidate either stays in his initial job, where his productivity is $\beta(a_O+s_O)$, or is reassigned to the CEO position in another firm, where his productivity is $\gamma_O a_O$. If no outside candidate is interviewed, their output remains equal to $\beta(a_O+s_O)$. Search is therefore efficient if and only if

$$\begin{aligned}&\left(1-\widehat{a}_O\right)\left[k\frac{1+\widehat{a}_O}{2}+\gamma a_I\right]+\widehat{a}_O\left[k\left(a_I+s_I\right)+e+\mathbb{E}\left(\max\{\gamma_O a_O,\beta(a_O+s_O)\}|a_O<\widehat{a}_O\right)\right]-c\\ \geq\ &k\left(a_I+s_I\right)+e+\beta\left[\mathbb{E}(a_O)+s_O\right].\end{aligned}\tag{2}$$

Lemma 2. *There exist cutoff values of* c*, denoted* $\widehat{c}_1$ *and* $\widehat{c}_2$*,* $\widehat{c}_2>\widehat{c}_1\geq 0$*, such that the constrained-efficient search decision is characterized by (i)-(iii) below:*

(i) If $c\leq\widehat{c}_1$*, it is efficient to search.*

(ii) If $c\geq\widehat{c}_2$*, it is efficient not to search.*

(iii) If $c\in(\widehat{c}_1,\widehat{c}_2)$*, it is efficient to search if and only if* $a_I<\widehat{a}_I(c)$*, where* $\widehat{a}_I(c)>0$.

All proofs are in the Appendix.

From the planner's point of view, there are two potential benefits to interviewing an outside candidate. The first is that the candidate may turn out to be an efficient replacement for Firm A's incumbent. The second is that even if the candidate's ability is not high enough to replace Firm A's incumbent, he may be efficiently reassigned to the CEO position in some other firm. Thus, the planner may find it worthwhile to interview an outside candidate even if there is no chance that the incumbent would be replaced, i.e., if a_I is such that $\widehat{a}_O \geq 1$. This is the case if the search cost is sufficiently low, as in part (i) of Lemma 2. If the search cost is too high, as in part (ii) of the lemma, then searching is never efficient, even if the incumbent's ability is very low. Finally, part (iii) of the lemma says that for intermediate values of the search cost initiating a search for a new CEO is efficient if and only if the incumbent's managerial ability is sufficiently low.

3.2 Firm A's decision to hire the outside candidate

Bertrand competition by the labor market for an incumbent of known ability a_I implies that her wage is $w_I = \gamma_I a_I$. Similarly, the wage that the labor market is willing to pay for the outside candidate if Firm A makes him an offer is $w_O^M = \gamma_O \mathbb{E}(a|\text{ offer})$. Suppose the labor market believes that if the firm interviews an outside candidate it will make him an offer if and only if $a_O \geq \widetilde{a}_O^*$, where $\widetilde{a}_O^*$ is to be solved for. Then

$$w_O^M = \gamma_O \mathbb{E}\left(a|\text{offer}\right) = \gamma_O \frac{\widetilde{a}_O^* + 1}{2}.$$

Assume for the moment that $w_O^M \geq \beta(a_O + s_O)$. Then to attract the candidate, it is enough for Firm A to offer him w_O^M. Thus, if Firm A searched, it will find it optimal to hire the outside candidate if and only if $ka_O - \gamma_O \frac{\widetilde{a}_O^*+1}{2} \geq (k - \gamma_I)a_I + ks_I + e$, or

$$a_O \geq s_I + \frac{e}{k} + \gamma_O \frac{\widetilde{a}_O^* + 1}{2k} + \frac{k - \gamma_I}{k} a_I \equiv a_O^*.$$

Imposing the equilibrium condition $\widetilde{a}_O^* = a_O^*$, we solve for a_O^* as

$$a_O^*\left(a_I\right) = \frac{2\left[(k - \gamma_I)a_I + ks_I + e\right] + \gamma_O}{2k - \gamma_O}. \tag{3}$$

To be able to conclude that $a_O^*\left(a_I\right)$ is indeed the equilibrium threshold ability for hiring the outside candidate, we need to confirm that $\beta(a_O + s_O) \leq w_O^M = \gamma_O \frac{a_O^*(a_I)+1}{2}$, as we have assumed.

Using (3), we see that a sufficient condition for this inequality to hold for all $a_I \geq 0$ is that

$$\beta s_O \leq \gamma_O \frac{ks_I + e + k}{2k - \gamma_O}.$$

Now, Assumption 1 implies $\gamma_O \frac{ks_I+e+k}{2k-\gamma_O} > \gamma_O \frac{ks_I+e}{k-\gamma_O}$ and Assumption 3 implies $\gamma_O \frac{ks_I+e}{k-\gamma_O} \geq \frac{\gamma_O}{\gamma_O-\beta}\beta s_O$. Since $\frac{\gamma_O}{\gamma_O-\beta} > 1$, this means that the above condition holds.

Before we state our next result, it is useful to define a cutoff level $\bar{a}_I$ as the largest a_I for which the *planner* might find it optimal to hire an outside candidate. That is, $\widehat{a}_O(\bar{a}_I) = 1$, from which

$$\bar{a}_I = \frac{k - \gamma_O - ks_I - e}{k - \gamma_I}. \tag{4}$$

Note that Assumption 1 implies $\bar{a}_I > 0$.

PROPOSITION 1. *Suppose Firm A, with an incumbent CEO of ability a_I, has interviewed an outside candidate for its CEO position. Then the firm's decision to replace its incumbent with the outside candidate is characterized as follows:*

(i) If $a_I \geq \bar{a}_I$, where $\bar{a}_I$ is given by (4), the incumbent CEO is never replaced.

(ii) If $a_I < \bar{a}_I$, the incumbent is replaced if and only if $a_O \geq a_O^*(a_I)$, where $a_O^*(a_I)$ is given by (3).

(iii) $a_O^*(a_I) > \widehat{a}_O(a_I)$.

(iv) $\frac{\partial}{\partial e}[a_O^*(a_I) - \widehat{a}_O(a_I)] < 0$.

The key results in Proposition 1 are the last two. Part (iii) says that even if the firm has initiated a search for a potential replacement for its incumbent CEO, it retains the incumbent inefficiently too often. Asymmetric information regarding the abilities of the outside candidates for the job therefore results in endogenous entrenchment of the incumbent CEO. Notice that this result is not driven by the assumption that the incumbent is entrenched due to the board's private benefits from retaining her, as it obtains even for $e = 0$. Rather, it is driven by a logic similar to that behind the inefficient job assignment result in Waldman (1984): An offer to an outside candidate is interpreted by the labor market as a good signal about the candidate's ability. Therefore, to outbid the labor market for the candidate's services Firm A has to bid the amount equal to the *average* ability of an outside candidate conditional on the candidate receiving an offer. For marginally efficient outside hires, this wage premium is too high.

Part (iv) shows that the gap between the efficient threshold for hiring the interviewed candidate and the threshold used by the firm's board decreases with the board's private benefit from retaining the incumbent. Thus, exogenous and endogenous entrenchment are to some extent substitutes, and an increase in exogenous entrenchment mitigates the inefficiency caused by endogenous entrenchment.

3.3 Decision to search

Moving backwards, we now examine Firm A's decision whether to initiate a search for an outside replacement of its sitting CEO. If a_I is such that the CEO is not replaced given any realization for the outside candidate's ability, i.e., $a_O^*(a_I) \geq 1$, the firm never searches. Thus, assume $a_O^*(a_I) < 1$, which holds if and only if $a_I < \bar{a}_I$, where $\bar{a}_I$ is as in Proposition 1. Then if Firm A interviewed an outside candidate, the candidate is hired to replace the incumbent with probability $1 - a_O^*$, and the average ability of such an outside hire is $\frac{1}{2}(a_O^* + 1)$. Searching is therefore optimal if and only if

$$(1 - a_O^*)(k - \gamma_O)\frac{(1 + a_O^*)}{2} + a_O^*[(k - \gamma_I)a_I + ks_I + e] - c \geq (k - \gamma_I)a_I + ks_I + e,$$

or

$$(1 - a_O^*)\left[(k - \gamma_O)\frac{1 + a_O^*}{2} - (k - \gamma_I)a_I - ks_I - e\right] \geq c. \qquad (5)$$

It is instructive to compare condition (5) with condition (2) from the constrained-efficient scenario. As shown in the proof of Lemma 2, condition (2) can be written as

$$(1 - \widehat{a}_O)\left[(k - \gamma_O)\frac{1 + \widehat{a}_O}{2} - (k - \gamma_I)a_I - ks_I - e\right] + \frac{\beta^2 s_O^2}{2(\gamma_O - \beta)} + \frac{\gamma_O}{2} - \beta(\frac{1}{2} + s_O) \geq c \qquad (2')$$

We see that conditions (2') and (5) are similar, with two differences. First, as one might expect, $\widehat{a}_O$ in (2') is replaced by a_O^* in (5). Second, the left hand side of condition (2') contains an additional term, $\frac{\beta^2 s_O^2}{2(\gamma_O-\beta)}+\frac{\gamma_O}{2}-\beta(\frac{1}{2}+s_O)$. This term captures the efficiency gain from reassigning the outside candidate from his current position to a CEO position in some other firm, which the planner would do if the outside candidate's ability is sufficiently high, but not high enough to replace Firm A's incumbent CEO. This term is missing in condition (5) because if Firm A decides not to make an offer to the outside candidate the labor market does not learn anything new about the candidate's managerial ability and therefore continues to believe that in expectation the candidate is most productive in his current job.

We thus get the next result.

Proposition 2. *There exists a cutoff value $c^* > 0$ such that Firm A's optimal decision to initiate a search for a replacement CEO is characterized as follows:*

(i) If $c \geq c^*$, Firm A finds it optimal not to search.

(ii) If $c < c^*$, Firm A finds it optimal to initiate a search if and only if $a_I < a_I^*(c)$, where $a_I^*(c) > 0$.

(iii) $c^* < \widehat{c}_2$ and $a_I^* < \widehat{a}_I$ for each $c < c^*$.

(iv) Keeping a_O^* and $\widehat{a}_O$ fixed, we have $\frac{\partial}{\partial e}\left[a_I^*(c) - \widehat{a}_I(c)\right] = 0$.

Proposition 2 says that the firm initiates a search for a possible replacement of its sitting CEO less often than would be efficient. This result is driven by two effects related to the two differences between conditions (2) and (5) pointed out earlier. First, given that conditional on searching the firm expects to replace its CEO less often than would be efficient (i.e., $a_O^* > \widehat{a}_O$), its expected benefit from searching is smaller than the efficiency gains from searching as perceived by a social planner. Second, if an outside candidate is interviewed but his managerial ability turns out to be insufficiently high to replace Firm A's incumbent CEO, the planner might find it optimal to reassign the candidate to the CEO position in some other firm. Such an efficiency improving reassignment is missing from Firm A's decision-making. Both of these effects dampen Firm A's incentives to initiate a search compared to those faced by the planner.

In part (iv), the proposition also tells us that exogenous CEO entrenchment affects the efficiency of the firm's decision to initiate a search for a new CEO solely through the effects that it has on the decision to hire an interviewed candidate. Thus, compared to previous models in which boards sometimes retain incumbent CEOs too often, such as Inderst and Mueller (2010) and Garrett and Pavan (2012), our theory suggests that when search is costly, to pin down the source of the inefficiency it is necessary to consider both stages of the replacement process, that is, both the decision to start looking for a new CEO and the decision to actually proceed with the replacement once a potential new CEO has been identified and interviewed. In our model, the source of the inefficiency caused by exogenous CEO entrenchment lies in the latter stage.

3.4 Wages

According to the analysis preceding Proposition 1, the equilibrium wage of a CEO hired externally is given by

$$\begin{aligned} w_O &= \gamma_O \frac{(1+a_O^*)}{2} \\ &= \gamma_O \frac{(k-\gamma_I)a_I + ks_I + e + k}{2k-\gamma_O} \end{aligned}$$

We thus get the following result.

PROPOSITION 3. *Suppose Firm A has replaced its initial CEO of ability a_I with an outside candidate of ability $a_O > a_O^*(a_I)$. Holding the new CEO's ability fixed, his equilibrium pay*

(i) *decreases in γ_I;*

(ii) *increases in s_I, e, γ_O, and a_I; and*

(iii) *decreases in k if $\gamma_I < \gamma_O + \frac{\gamma_O s_I}{2} + e$ and increases in k if the reverse is true.*

In the standard neoclassical model of wage determination an employee's wage is determined by her marginal productivity. In the current model, this is also true for the incumbent CEO, whose ability is known, and whose wage is therefore given by her marginal productivity as perceived by the labor market, $\gamma_I a_I$. Proposition 3 shows that when there is asymmetric information about the ability of the potential external hire, the pay of a CEO hired externally depends on variables that are not directly related to his marginal productivity and that are typically not considered to be determinants of executive pay.

In particular, the external CEO's pay is higher the higher is the *incumbent's* general human capital, a_I, her specific human capital, s_I, and her entrenchment, e. Note that the latter two variables do not affect the incumbent's pay. The reason they affect the new CEO's pay is that the labor market sets the new CEO's wage to be proportional to his expected ability, which the market infers from Firm A's hiring decision. In particular, the market interprets the fact that the outside candidate was hired as good news about his ability. Moreover, the news is more positive the more able and the more entrenched was the incumbent, and the higher was her firm-specific human capital.

In empirical studies, a worker's amount of firm-specific human capital is usually proxied for by the worker's tenure in the firm. Similarly, Hermalin and Weisbach (1988) have shown that the proportion of outside directors on a firm's board decreases with the tenure of the firm's CEO, which suggests that a CEO's tenure can also proxy for her level of entrenchment. Our theory thus yields the empirically testable prediction that if an incumbent CEO is replaced before her normal retirement age, given controls for the incumbent's ability (such as current or recent firm profitability), the new CEO's pay should be positively correlated with the incumbent's tenure in the firm.

The reason why the external CEO's pay decreases in the firm's productivity k if her outside opportunity γ_I is not too large is somewhat more subtle. The larger is k, the more important it is – from the point of view of the firm's output – to hire the candidate with the highest productivity. Furthermore, this effect is not tempered by a corresponding direct increase in the new CEO's pay because market wages are determined by the competing firms' productivity, γ_O. This increased importance of a good match induces the firm to decrease the threshold a_O^* for hiring the outside candidate, which dilutes the signal that the job offer provides to the outside firms.

3.5 Stock market reaction to CEO replacement

Since the investors can observe the incumbent CEO's ability, they can infer whether the firm is searching for her replacement. This expectation gets reflected in the price of the firm's shares, as does the firm's announcement (or a lack of it) that the incumbent will be replaced by an outside hire. Specifically, if $a_I < a_I^*$, the investors expect that the firm has initiated a search and that the incumbent will be replaced with probability $1 - a_O^*$. If the firm ends up replacing the incumbent, its expected profit is $\mathbb{E}\pi\left(a_O^*\right) = (k - \gamma_O)\frac{(1+a_O^*)}{2} - c$. Before $t = 2$, which is the date when the firm is expected to either make an offer to an outside candidate or to stop its search, its expected market value, denoted $\mathbb{E}\pi\left(a_I\right)$, is therefore

$$\mathbb{E}\pi\left(a_I\right) = a_O^*\left[k\left(a_I + s_I\right) - \gamma_I a_I\right] + \left(1 - a_O^*\right)\left(k - \gamma_O\right)\frac{\left(1 + a_O^*\right)}{2} - c.$$

Thus, if the firm makes an offer to an outside candidate, which in equilibrium means that the candidate will replace the firm's incumbent CEO, the firm's stock price increases by the amount

$$\begin{aligned} \triangle &\equiv \mathbb{E}\pi\left(a_O^*\right) - \mathbb{E}\pi\left(a_I\right) \\ &= a_O^*\left[(k - \gamma_O)\frac{(1 + a_O^*)}{2} - (k - \gamma_I)a_I - ks_I\right]. \end{aligned} \tag{6}$$

Proposition 4 below sums up this analysis and adds some comparative statics results.

PROPOSITION 4. *Upon announcing that its incumbent will be replaced by an outside hire, the firm's stock price increases by the amount $\triangle > 0$ given by (6). The stock price increase $\triangle$ depends on a_I, s_I, and e as follows:*

(i) $\frac{\partial \triangle}{\partial e} > 0$.

(ii) There exists an $a_I^+ \in [0, 1]$ *such that*

a) $\frac{\partial \triangle}{\partial a_I} > 0$ *and* $\frac{\partial \triangle}{\partial s_I} > 0$ *for* $a_I < a_I^+$;

b) $\frac{\partial \triangle}{\partial a_I} < 0$ *and* $\frac{\partial \triangle}{\partial s_I} < 0$ *for* $a_I > a_I^+$;

(iii) If s_I and $k-\gamma_I$ are sufficiently small and e is sufficiently large, then $a_I^+ = 1$, that is, $\frac{\partial \triangle}{\partial a_I} > 0$ and $\frac{\partial \triangle}{\partial s_I} > 0$ for all a_I.

(iv) If s_I is sufficiently large and e is sufficiently small, then $a_I^+ = 0$, that is, $\frac{\partial \triangle}{\partial a_I} < 0$ and $\frac{\partial \triangle}{\partial s_I} < 0$ for all a_I.

Consistent with the available empirical evidence (e.g., Borokhovich et al, 1996, Huson et al., 2004), the first result in Proposition 4 says that the news of CEO replacement by an outsider elicits a positive stock market reaction because investors expect the firm's profit to increase. Interestingly, the expected ability of the new CEO does not necessarily exceed the incumbent's ability if the incumbent's labor market opportunities are much better than those of the outside candidate (i.e., if γ_I is much larger than γ_O). However, it is straightforward to show that when the two executives' outside opportunities are similar (γ_O is close or equal to γ_I), expected managerial ability increases following CEO turnover, in line with the evidence in Huson et al. (2004).[10]

Similarly, related to parts (i) and (ii) in the proposition, financial economists have documented that the stock market's reaction to the departure of an executive can depend on the executive's entrenchment (e.g., Salas, 2009) and on her level of firm-specific human capital (Johnson et al, 1985). Both Johnson et al (1985) and Salas (2009) study stock market's reactions in the context of unexpected senior executive deaths. Salas hypothesizes that the stock price reaction to the death of a senior executive should be positive if the executive was so entrenched that the board found it difficult to remove her. Our model predicts that the stock price reaction should increase in the CEO's entrenchment even if the board *does* remove the CEO. Johnson et al argue that the price reaction should be negatively related to the incumbent manager's firm-specific human capital because firm-specific human capital is costly to replace. Proposition 4 shows that in our model firm-specific human capital does not affect the stock price reaction in the monotonic way predicted by Johnson et al (1985); rather, the direction of the relationship depends on the executive's managerial ability and can be negative for high-ability executives.

[10] We have $\mathbb{E}\left(a_O|hired\right) > a_I$ if $\left(a_O^* + 1\right)/2 > \bar{a}_I$, where a_O^* and $\bar{a}_I$ are given by (3) and (4) respectively. When $\gamma_O = \gamma_I = \gamma$, this reduces to $(2k-\gamma)(e+ks_I) > 0$, which always holds.

4 Partial outsider vs complete outsider candidates

Empirical evidence suggests that when a firm fills its vacant CEO position with an outside candidate, it is often a partial outsider with some prior ties to the firm rather than a complete outsider. A possible explanation is that due to their prior ties to the firm, partial outsiders have firm-specific human capital that full outsiders do not possess. In this section we show that in our framework a preference for partial outsiders over full outsiders arises naturally, even without postulating that they possess firm-specific human capital. Rather, such a preference is a consequence of imperfect information about the candidates' managerial abilities.

The main modification here is that the firm is presented with a single outside candidate, and that with probability p the candidate is a full outsider and with probability $(1-p)$ he is a partial outsider. We will loosely interpret $1-p$ as the share of partial outsiders among the outside candidates.

The difference between full and partial outsiders is that the cost to Firm A of learning an outsider's ability is on average lower for partial than for full outsiders. Specifically, the interview cost c is a random variable distributed on $[0,\infty)$ according to a cumulative distribution function $H(.)$ for partial outsiders and a cumulative distribution function $\bar{H}(.)$ for full outsiders. The idea that this cost tends to be lower for partial outsiders is captured by the assumption that $\bar{H}(.)$ strictly first-order stochastically dominates $H(.)$, that is, $H(c) > \bar{H}(c)$ for all $c \in (0,\infty)$. The realization of c is publicly observed at the start of $t=1$, before Firm A makes its decision whether to interview the outside candidate.

The analysis of this setting draws heavily on the analysis of the main model. Note first that once Firm A has learned the outside candidate's managerial ability, the continuation game is identical to that in the main model. Hence, the firm's decision whether to make the outside candidate an offer is characterized by the same two cutoff levels $\bar{a}_I$ and $a_O^*(a_I)$ that were given in Proposition 1.

Next consider the firm's decision whether to learn the outside candidate's ability. Here again the firm's problem is exactly the same as in the main model and its decision to expend c to learn the outsider's ability is characterized by the cutoff level c^*, as described in Proposition 2. Thus, holding a_I fixed, a full outsider is interviewed with probability $\bar{H}(c^*)$, whereas a partial outsider is interviewed with probability $H(c^*) > \bar{H}(c^*)$. On the other hand, as we have already seen, conditional on being interviewed, full and partial outside candidates of the same ability are equally likely to receive an offer – in both cases this happens with probability a_O^*. We therefore get the following result.

Proposition 5. *Suppose Firm A has filled its CEO position with an outside candidate. The probability that the candidate was a partial outsider strictly exceeds $1-p$, the share of partial outsiders among the outside candidates.*

Proposition 5 says that, in expectation, and in line with empirical observations, firms have a natural inclination towards hiring outside candidates who are only partial outsiders.

5 Where do the outsider CEOs come from?

In their empirical study of the market for CEOs, Cziraki and Jenter (2022) document three pronounced regularities regarding the CEOs hired externally. First, as assumed in our model, most of the outsider CEOs are recruited from below-CEO executive positions rather than from the CEO position. Second, those who in their previous job were in the CEO position typically worked for a much smaller firm. Third, the outside CEOs who came from below-CEO positions were typically hired away from larger firms. Cziraki and Jenter conclude that these regularities reveal frictions in the reallocation of CEO talent across firms, and we agree with this interpretation of the evidence. In particular, the first and the second regularities suggest that firm-specific human capital plays an important role in the market for CEOs, which we believe is the case. The third regularity can be explained by the following enrichment of our asymmetric information model.

Suppose that the external firms from which Firm A can recruit its CEO differ in size. There are $N \geq 2$ possible firm sizes, indexed by $n \in \mathcal{N} \equiv \{1, 2, ..., N\}$, where a firm of size $n+1$ is larger than a firm of size n, $n = 1, 2, ..., N-1$. Specifically, an outside firm of size n has a single below-CEO executive position ("No. 2 position"), plus n lower-level employees from which it promotes one into its No. 2 position. This happens before firm A makes its interviewing decision. The managerial ability of each of the n lower-level employees is drawn independently from $[0, 1]$ according to the uniform distribution $U(.)$. Assume also that each outside firm observes a signal that is informative about each of its employees' managerial abilities and then uses this signal to choose the best candidate for its No. 2 executive position. For simplicity, assume that the signal is fully informative, i.e., the firm observes each of its employee's true ability a. Finally, each firm's size is common knowledge among the market participants, including Firm A.

The analysis of this enriched model follows similar steps as the analysis of the base model. In particular, suppose the labor market believes that if Firm A interviews an outside candidate from a firm of size $n \in \mathcal{N}$, it will make him an offer if and only if his ability a_O at least weakly exceeds some cutoff level $\widetilde{a}^*_{On}$. Then upon observing that the candidate has received an offer from Firm A, the market's wage bid is

$$w^M_{On} = \gamma_O \mathbb{E}_n \left(a | a \geq \widetilde{a}^*_{On}\right) = \frac{\gamma_O}{1 - F^n\left(\widetilde{a}^*_{On}\right)} \int_{\widetilde{a}^*_{On}}^{1} a dF^n(a),$$

where F^n denotes the cumulative distribution of managerial ability in a firm of size n as perceived by the rest of the market, including firm A, and $\mathbb{E}_n$ denotes the expectation operator with respect to F^n. Conditional on interviewing an outside candidate, Firm A therefore makes him an offer if and only if $ka_O - w^M_{On} \geq (k - \gamma_I)a_I + ks_I + e$, or

$$a_O \geq a^*_{On} \equiv s_I + \frac{e}{k} + \frac{1}{k} w^M_{On} + \frac{k - \gamma_I}{k} a_I.$$

In equilibrium, $\widetilde{a}^*_{On} = a^*_{On}$. Thus, a^*_{On} is implicitly given by

$$s_I + \frac{e}{k} + \frac{\gamma_O}{k} \mathbb{E}_n \left(a | a \geq a^*_{On}\right) + \frac{k - \gamma_I}{k} a_I - a^*_{On} = 0. \tag{7}$$

PROPOSITION 6. *Suppose that the ability of Firm A's incumbent CEO is $a_I < \bar{a}_I$, where $\bar{a}_I$ is as in Proposition 1. Suppose also that Firm A has interviewed an outside candidate employed by a firm of size $n \in \mathcal{N}$ and learned that his ability is a_O. Then there exists a continuation* *equilibrium such that the incumbent is replaced if and only if* $a_O \geq a^*_{On}(a_I)$, *where* $a^*_{On}(a_I) \in (0,1)$ *and satisfies (7).*[11]

5.1 Decision to search

The analysis of Firm A's decision whether to interview an outside candidate again follows similar steps as the analysis of the base model. However, in addition, we need to analyze Firm A's decision regarding the size of the firm from which to choose the outside candidate.

Conditional on interviewing an outside candidate employed in a firm of size n, Firm A makes him an offer with probability $1 - F^n(a^*_{On})$, and the expected ability of such an outside hire is $\mathbb{E}_n(a|a \geq a^*_{On})$. Interviewing an outside candidate employed in a firm of size n is therefore better than retaining the incumbent if and only if

$$[1 - F^n(a^*_{On})](k - \gamma_O)\mathbb{E}_n(a|a \geq a^*_{On}) + F^n(a^*_{On})[(k(a_I + s_I) + e - \gamma_I a_I] - c \geq (k - \gamma_I)a_I + ks_I + e. \tag{8}$$

The right hand side of (8) does not depend on n. Thus, if Firm A interviews an outside candidate, it chooses one from a firm size that maximizes the left hand side of (8) subject to a^*_{On} being given by (7). The firm's optimization problem is thus

$$\max_n [1 - F^n(a^*_{On})](k - \gamma_O)\mathbb{E}_n(a|a \geq a^*_{On}) + F^n(a^*_{On})[k(a_I + s_I) + e - \gamma_I a_I] - c, \tag{9}$$

with a^*_{On} given by (7).

Proposition 7. *If Firm A decides to interview an outside candidate, it will interview a candidate employed by a firm of size* $n = N$.

In line with Cziraki and Jenter's (2022) finding that external CEOs are typically hired from below-CEO positions in larger firms, Proposition 7 says that in a version of our model with multiple firm sizes, Firm A interviews a candidate from the largest available firm. The logic behind

[11] Equation (6) may not have a unique solution. In the cases where there are multiple solutions, we focus on the largest one, although a focus on the smallest one would leave the qualitative results unchanged. A sufficient (but not necessary) condition for uniqueness is that $\Omega^j(x)$ defined in the proof of the proposition is a strictly decreasing function. For this to hold it is enough if the hazard rate $\frac{f^j(x)}{1-F^j(x)}$ is sufficiently small for all $x \in (0,1)$.

this result has two parts. First, the larger the firm, the larger is the number of employees from among which the outside candidate was initially promoted into his No. 2 position in the outside firm. The expected ability of the outside candidate conditional on Firm A making him an offer, $\mathbb{E}_n(a|a \geq a^*_{On})$, therefore increases in the size of his current employer.[12] Since Firm A's expected payoff from hiring an outside candidate, given by (9), is directly proportional to the candidate's expected ability, this makes candidates from larger firms more attractive.

The second part of the logic that drives Proposition 7 is that as an outside candidate's expected ability increases in the size of his initial employer, so does the probability $1 - F^n(a^*_{On})$ that the candidate's ability exceeds the cutoff threshold a^*_{On}. In other words, the larger is the firm that employs the outside candidate, the more likely it is that Firm A will end up replacing its incumbent. As can be seen by inspecting the firm's payoff function (9), an increase in $1 - F^n(a^*_{On})$ puts more weight on the expected profit from hiring the outside candidate and less weight on the payoff from retaining the incumbent. Given that the outside candidate is hired only if the profit from doing so exceeds the payoff from retaining the incumbent, the weight shift further increases Firm A's expected profit.

Note that when the cutoff level a^*_{On} for making an offer to the outside candidate is held constant, the conclusions that $\mathbb{E}_n(a|a \geq a^*_{On})$ increases and $F^n(a^*_{On})$ decreases in n are intuitive order statistics results. The proof of Proposition 7 shows that these results continue to hold even when one takes into account the effects of n on the threshold a^*_{On}.

As a corollary to Proposition 7, our analysis in this section also yields the following prediction.

Corollary to Proposition 7. *w^M_{ON} increases in N. That is,outside hires from below CEO positions are paid more when they come from larger firms.*

This prediction follows immediately from the fact that the wage of an outside CEO, $w^M_{ON} =$

[12] There are other reasons why we would expect the abilities of high-level executives in large firms to stochastically dominate the abilities of high-level executives in small firms. First, as observed by Lucas (1978), Rosen (1982), and others, we should expect managerial ability to be more valuable in larger firms. Thus, in a world in which ability is not easily observed, larger firms should be more willing to invest in screening their employees based on managerial ability when filling their executive positions. Large firms should also be more willing to invest in training their employees. Finally, employees of large firms may have stronger incentives to invest in acquiring additional human capital than employees of smaller firms (Zabojnik and Bernhardt, 2001).

$\gamma_O \mathbb{E}_n \left(a | a \geq a^*_{ON}\right)$, is directly proportional to his expected ability, which, as we have already seen, is higher for candidates from larger firms.

6 An internal vs an external candidate

The analysis of our base model focused on an outside candidate. However, it should be clear that a similar analysis would go through if instead of an external candidate we assumed that the firm is considering replacing its sitting CEO with an internal candidate of unknown managerial ability. A more interesting question is how the firm chooses between an internal and an external candidate. To address this question, we now modify our base model by assuming that the firm's CEO position is vacant and that the firm has an internal candidate for the position, but it can also expand its search by interviewing an outside candidate. Analogous to the situation in the previous analysis, the labor market does not observe whether Firm A considers an external candidate, although it is aware of the fact that the firm has an internal candidate.

It seems likely that it is easier for a firm to learn the managerial ability of its internal candidate than to learn the ability of an external candidate. To keep things simple, we assume that the firm has already privately learned the ability of its internal candidate by virtue of employing her and observing her performance in her current job, as in Waldman (1984) and Greenwald (1986). In contrast, learning the managerial ability of an external candidate costs $c > 0$, as in the previous section. The labor market does not get to observe the ability of the firm's internal candidate, but believes that like the ability of an external candidate, it is drawn from $[0, 1]$ according to the uniform distribution.

Thus, there are two main differences between the model of this section and the one analyzed earlier. First, while previously the ability of the firm's incumbent CEO was publicly known, here the ability of the firm's internal candidate is the firm's private information. Second, in this section the internal candidate is not entrenched, that is, $e = 0$. In addition, we will simplify the exposition by setting $\gamma_I = \gamma_O = \gamma$.

The ability of the internal candidate will again be denoted by a_I, keeping in mind that the subscript I now stands for "internal" rather than "incumbent." Intuition suggests that if a_I is close to 1, the firm will be unwilling to expend resources to learn an outside candidate's ability. Thus, it is reasonable to conjecture that the firm will again interview an outside candidate if and only if a_I is below some cutoff level, a_I^{**}. Similarly, if the firm does interview an outside candidate, he will be hired only if his ability, a_O, is sufficiently large.

Given that the market does not know the managerial ability of either of the candidates, the equilibrium wage of the hired candidate can only depend on whether the candidate was hired internally or externally; it cannot depend on the candidate's true ability. Denote these two possible wages by w_O^{**} and w_I^{**}. Thus, if Firm A interviewed an outside candidate, it will hire him if and only if $ka_O - w_O^{**} > k\left(a_I + s_I\right) - w_I^{**}$, or $a_O > a_I + D$, where

$$D \equiv s_I + \frac{w_O^{**} - w_I^{**}}{k}.$$

Thus, the firm's hiring rule depends on the wages it expects the market to offer to the two types of candidates, while the wages in turn depend on the market's conjecture regarding the firm's hiring rule.

If $D \geq 1$, an outside candidate is never hired.[13] Suppose therefore that $D < 1$. Firm A then finds it optimal to interview an outside candidate if and only if

$$(1 - a_I - D)\left[k\frac{(1 + a_I + D)}{2} - w_O^{**}\right] + (a_I + D)\left[k\left(a_I + s_I\right) - w_I^{**}\right] - c > k\left(a_I + s_I\right) - w_I^{**},$$

or

$$a_I < 1 - \sqrt{\frac{2c}{k}} - D \equiv a_I^{**}. \tag{10}$$

Again, if $a_I^{**} \leq 0$, the firm never considers an outside candidate. To ensure that $a_I^{**} > 0$ is a possible equilibrium outcome, we introduce the following assumption:

[13] Such an equilibrium always exists if $s + \frac{1}{k} \geq 1$. Suppose this condition holds and suppose the market believes that $D \geq 1$ so that an outside candidate is never hired, even if interviewed. Suppose also that in an out-of-equilibrium event in which the firm makes an offer to an outside candidate the market believes that $a_O = 1$ and $a_I = 0$. Then $w_O^{**} = 1$ and $w_I^{**} = 0$. Now, as shown below, Firm A finds it optimal to interview an outside candidate only if $a_I < 1 - \sqrt{\frac{2c}{k}} - D$, which never holds in this case. Hence, given these beliefs, the firm has no incentive to interview an outside candidate, regardless of the ability level of its inside candidate.

Assumption 4. $2c < k$ and $s < (1 - \sqrt{\frac{2c}{k}})(1 - \frac{\gamma}{2k})$.

Thus, suppose $a_I^{**} > 0$. Then if the market observes that Firm A made an offer to an outside candidate, it concludes that the internal candidate's ability must be $a_I < a_I^{**}$. Bayes rule says that the probability density function of the outside candidate's ability conditional on being hired, $h\,(y|\text{hired}) = h\,(a_O = y|\text{hired})$, is given by[14]

$$h\,(y|\text{hired}) = \frac{\Pr\{\text{hired}|a_O = y\}.\Pr\{a_O = y\}}{\Pr\{\text{hired}\}}. \tag{11}$$

Denoting by $U(.)$ the cdf of the uniform distribution on $[0,1]$ and by $u(.)$ the corresponding pdf, we have[15]

$$\Pr\{a_O = y\} = u(y) = 1;$$

$$\begin{aligned} \Pr\{\text{hired}\} &= \int_0^{a_I^{**}} u(x)\,[1 - U(x+D)]\,dx \\ &= \int_0^{a_I^{**}} (1 - x - D)dx \\ &= a_I^{**}(1-D) - \frac{a_I^{**2}}{2}; \end{aligned}$$

and

$$\Pr\{\text{hired}|a_O = y\} = \begin{cases} \Pr\{a_I \leq a_I^{**}\} & \text{if } y > a_I^{**} + D \\ \Pr\{a_I \leq y - D\} & \text{if } y \in (D, a_I^{**} + D] \\ 0 & \text{if } y \leq D \end{cases} .$$

Defining $B \equiv a_I^{**}(1-D) - \frac{a_I^{**2}}{2}$, (11) then becomes

$$h\,(y|\text{hired}) = \begin{cases} \frac{a_I^{**}}{B} & \text{if } y > a_I^{**} + D \\ \frac{y-D}{B} & \text{if } y \in (D, a_I^{**} + D] \\ 0 & \text{if } y \leq D \end{cases} .$$

The labor market's expectation of the ability of the external candidate to whom Firm A made an

[14] In expressions for probabilities, "hired" stands for "outsider hired." Similarly, "promoted" means "insider promoted."

[15] Here we are assuming that $D < 1 - a_I^{**}$.

offer is therefore equal to

$$\begin{aligned}
\mathbb{E}\left(a_O|\text{hired}\right) &= \int_0^1 yh(y)dy \\
&= \frac{1}{B}\left[\int_D^{a_I^{**}+D} y(y-D)dy + a_I^{**}\int_{a_I^{**}+D}^1 ydy\right] \\
&= \frac{1-a_I^{**2}/3 - a_I^{**}D - D^2}{2\left(1-D-a_I^{**2}/2\right)}, \qquad (12)
\end{aligned}$$

and the market's wage bid for this candidate will be proportional to this expectation, i.e., $w_O^{**} = \gamma\mathbb{E}(a_O|\text{hired})$.

If Firm A instead makes an offer to its internal candidate, the market concludes that it was either $a_I \geq a_I^{**}$ (which happens with ex ante probability $1-a_I^{**}$) or that $a_I < a_I^{**}$ and $a_O < a_I + D$. Using

$$\Pr\{a_I = y\} = u(y) = 1;$$

$$\begin{aligned}
\Pr\{\text{promoted}\} &= 1 - a_I^{**} + \int_0^{a_I^{**}} u(x)U(x+D)dx \\
&= 1 - a_I^{**} + \int_0^{a_I^{**}} (x+D)dx = 1 - B;
\end{aligned}$$

and

$$\Pr\{\text{promoted}|a_I = y\} = \begin{cases} \Pr\{a_0 \leq y + D\} & \text{if } y < a_I^{**}; \\ 1 & \text{if } y \geq a_I^{**}; \end{cases}$$

the probability density function of the internal candidate's ability conditional on being promoted, $\eta(.)$, is given by

$$\eta\left(y|\text{promoted}\right) = \begin{cases} \frac{y+D}{1-B} & \text{if } y < a_I^{**}; \\ \frac{1}{1-B} & \text{if } y \geq a_I^{**}. \end{cases}$$

The market's expectation of the ability of the internal candidate is therefore

$$\begin{aligned}
\mathbb{E}\left(a_I|\text{promoted}\right) &= \frac{1}{1-B}\left[\int_0^{a_I^{**}} y(y+D)dy + \int_{a_I^{**}}^1 ydy\right] \\
&= \frac{\frac{1}{2} + a_I^{**2}/3 - (1-D)a_I^{**2}/2}{1-B}, \qquad (13)
\end{aligned}$$

and the market's wage bid for the internal candidate is $w_I^{**} = \gamma\mathbb{E}(a_I|\text{promoted})$.

The candidates' respective equilibrium wages are then pinned down by condition (10), which defines a_I^{**}. Substituting $D = s_I + \frac{w_O^{**} - w_I^{**}}{k}$, $w_O^{**} = \gamma \mathbb{E}(a_O|\text{hired})$, and $w_I^{**} = \gamma \mathbb{E}(a_I|\text{promoted})$ into equations (10), (12) and (13) and rearranging yields

$$a_I^{**} = 1 - s_I - \frac{w_O^{**} - w_I^{**}}{k} - \sqrt{\frac{2c}{k}} \tag{14}$$

$$2w_O^{**}\left(1 - s_I - \frac{w_O^{**} - w_I^{**}}{k} - \frac{a_I^{**}}{2}\right) = \gamma\left[1 - \frac{a_I^{**2}}{3} - a_I^{**}\left(s_I + \frac{w_O^{**} - w_I^{**}}{k}\right) - \left(s_I + \frac{w_O^{**} - w_I^{**}}{k}\right)^2\right] \tag{15}$$

$$w_I^{**}\left(1 + \frac{a_I^{**2}}{2}\right) = \gamma\left(\frac{1}{2} + \frac{a_I^{**3}}{3}\right) + a_I^{**}\left(w_I^{**} - \gamma\frac{a_I^{**}}{2}\right)\left(1 - s_I - \frac{w_O^{**} - w_I^{**}}{k}\right) \tag{16}$$

Any Perfect Bayesian Equilibrium in which $D \in [0, 1)$ is given by a solution $(a_I^{**}, w_O^{**}, w_I^{**})$ to conditions (14) - (16), along with the beliefs given by the density functions $h(.)$ and $\eta(.)$. Notice that equations (14) - (16) contain non-linear functions of a_I^{**}, w_O^{**} and w_I^{**}, which means that there may exist multiple equilibria. A further complication stems from the fact that D could be negative, that is, the firm could have a hiring rule where it promotes the internal candidate only if her ability is sufficiently higher than the ability of the external candidate. For most of the parameter space of interest, this latter complication is ruled out by the following result.

LEMMA 3. *Suppose Firm A's CEO position is vacant. There is an s_{I1}^* such that for all $s_I \geq s_{I1}^*$ it must be $D > 0$. Furthermore, $s_{I1}^* < 0.06$.*

That is, for $s_I \geq s_{I1}^*$, the firm hires an outside candidate only if his ability is higher than the ability of the internal candidate. Equipped with Lemma 3, we will restrict our attention to $s_I \geq s_{I1}^*$, that is, to settings where the importance of a CEO's specific human capital is non-negligible. We are now ready to present the main result of this section, which is stated in the next proposition.

PROPOSITION 8. *Suppose Firm A's CEO position is vacant and $s_I \geq s_{I1}^*$. Then*

(i) *the firm is more likely to fill the vacant CEO position by promoting the internal candidate than by hiring an external candidate, and*

(ii) *if Assumption 4 holds, there is an* s^*_{I2} *such that for* $s_I > s^*_{I2}$ *there is a Perfect Bayesian Equilibrium in which* $a^{**}_I \in (0,1)$ *and* $w^{**}_O > w^{**}_I$*. Furthermore,* $s^*_{I2} < 0.08$.

Part (i) of Proposition 8 shows that when firm-specific human capital is important, then, consistent with empirical evidence, firms with vacant CEO positions will tend to fill them with internal candidates rather than with external hires. Part (ii) of the proposition tells us that if firm-specific human capital is sufficiently important, but not so important that an external candidate is never considered, then CEOs hired externally will get paid more than CEOs promoted internally.

In a symmetric information framework, the conclusions of Proposition 8 (in the case of part (ii) expressed in terms of average wages) would be rather straightforward, and we would expect them to hold for arbitrarily small levels of firm-specific human capital. In a world with asymmetric information about candidates' managerial abilities these results are much less immediate. The reason is that the firms' hiring and wage-setting strategies depend in a complicated way on their beliefs, which, as already pointed out, can lead to multiple equilibria. Proposition 8 shows that when the internal candidate's firm-specific human capital is sufficiently large, any equilibrium in which the firm is more likely to fill its CEO position with an external candidate than with an internal one, or to pay the internal CEO more than the external one, can be ruled out. Observe that at 8 percent of the maximum possible value of general human capital a, the specific human capital sufficient for these results does not appear to be unrealistically large.

Let us conclude this section by commenting briefly on the efficiency properties of the equilibrium outcome in this version of the model. While the model is not sufficiently tractable to allow for a complete comparison with the efficient benchmark of Section 3.1, it can be readily seen that the outcome is in general again inefficient. However, in contrast to the main model, our numerical simulations indicate that here the firm tends to hire the outside candidate more often than would be efficient. For example, if $\gamma = 1$, $k = 2$, $c = 0.5$, and $s_I = 0.2$, the equilibrium is given by $w^{**}_I \approx 0.510122$, $w^{**}_O \approx 0.63932$, $a^{**}_I \approx 0.0282903$, and $D \approx 0.2646$. Thus, for $a_I < a^{**}_I$, and conditional on interviewing an outside candidate, Firm A hires the outside candidate if his ability is $a_O > a_I + 0.2646$. In contrast, the efficient decision rule is to hire the outside candidate if

$a_O > a_I + \frac{ks_I}{k-\gamma} = a_I + 0.4$.

The reason why in the current setting the deviation from efficiency tends to go in the opposite direction to that in the main model is that here not only the ability of the outside candidate but also the ability of the internal candidate is Firm A's private information. Hence, both the external and the internal candidate's market wage is based on their average rather than on their true productivity. Firm A's profit from the internal candidate is now therefore affected by an adverse selection problem that mitigates against a similar distortion in its profit from the outside candidate.

7 Discussion

In this section we discuss the extent to which the predictions of our theoretical model/approach match existing empirical evidence. As indicated in the Introduction, the model was designed to capture some findings that the standard full information approach has trouble matching. But the approach has a number of predictions and it is of interest to consider how well the large set of predictions matches empirical evidence.

The model predicts that external hires into the CEO position should be rare, which in a sense is the prediction the model was designed to produce. This arises in our setting both because of the better information firms have about their own employees and because of firm specific human capital. This prediction is consistent with findings in a number of studies including Parrino (1997), Graham, Kim, and Kim (2020), and Cziraki and Jenter (2022). A related prediction is that outside hires into the CEO position should, on average, earn more than those promoted from within if firm specific human capital is sufficiently important. This occurs because a firm hiring a new CEO must match the wage offers of other firms, and an offer to an external candidate is a more positive signal concerning productivity at these other firms when firm specific human capital is important. This prediction is consistent with evidence in Murphy and Zabojnik (2007) and Cziraki and Jenter (2022). Also, Custodio, Ferreira, and Matos (2013) find that generalist CEOs are paid more than specialist CEOs. This is also potentially consistent with the prediction given that generalists are more likely to be external hires.

Our theoretical approach is also consistent with results in the empirical literature that firm performance is important for understanding which firms are more likely to replace their CEO, which are more likely to promote internally, which are more likely to hire an outsider, and also which firms outsiders hired into CEO positions typically move from. For example, a poorer performing firm is likely one in which the expected ability of the best insider is likely lower since the abilities of lower level executives should affect firm performance. Our analysis of internal versus external candidates thus suggests that external candidates should be hired more often when the firm is poorly performing both because the firm is more likely to hire an external candidate, and because an interview is more likely to lead to the external candidate being hired. Similar logic leads to the prediction that poorly performing firms are more likely to replace their CEO, and that external hires should typically move from better performing firms. Empirical results along these lines can be found in Parrino (1997), Murphy (1999), Fee and Hadlock (2003), Jenter and Lewellen (2020), and Cziraki and Jenter (2022).

Our model is also consistent with results concerning stock price changes following CEO replacement. For example, Borokhovich et al (1996) find that for outside successions turnover announcements are related to positive abnormal stock returns.[16] This is consistent with our analysis of the choice of replacing a sitting CEO with an external (or internal) candidate. That is, choosing to replace the CEO means that the firm hired an individual with higher expected ability than the previous CEO, so news about the replacement should be taken as positive information about future profitability which, in turn, should lead to higher stock prices.

The model also makes a number of predictions for which we could not find existing evidence. For example, we find that when hiring an external candidate who is currently in a position below the CEO level, the individual's compensation should be positively related to the size of the firm the individual is moving from. This prediction should be easy to investigate, although as indicated we are not familiar with any prior study that reports evidence supporting or refuting this prediction.

[16] See also Huson et al (2004).

Further, the model predicts that in situations where an incumbent CEO is replaced by an external hire, the pay of the newly hired CEO should be related not only to her own characteristics, but also to the human capital and the entrenchment degree of the CEO who is being replaced. This prediction should also be amenable to empirical validation.

As a final point concerning empirical evidence, our theoretical approach is also consistent with the Murphy and Zabojnik (2004, 2007) argument concerning the growth in external hires in the CEO market between 1970 and 2000. As discussed briefly in the introduction, their argument is that during this time period there was a growing emphasis on general skills for the CEO position, and this is what led to the growth in external hires during this time period. Although we do not show it formally, our analysis of a firm choosing between an internal and an external candidate is consistent with the idea that a decrease in the importance of firm specific skills for the CEO position will result in an increase in the frequency with which firms choose to hire an external candidate.

8 Conclusion

Much of the prior theoretical literature concerning the CEO labor market builds on the classic analyses of Lucas (1978) and Rosen (1982) characterized by full information, limited firm specific human capital, and the efficient assignment of heterogeneous workers to jobs and firms. However, substantial empirical evidence such as found in Graham, Kim, and Kim (2020) and Cziraki and Jenter (2022) is inconsistent with various predictions of this theoretical approach. For example, the approach predicts frequent movement of individuals from one CEO position to another as worker productivity improves due to learning-by-doing, while empirical evidence indicates that such moves are, in fact, rare.

In this paper we construct and analyze a model of the CEO labor market characterized by asymmetric employer learning and firm specific human capital, building on classic analyses of Becker (1962), Waldman (1984), and Greenwald (1986). In our analysis a firm has better information concerning the ability levels of its current workers, but can acquire information concerning an external candidate by interviewing the candidate at a cost. We also assume that an offer to fill the CEO position is observed by other labor market participants, so in filling a CEO position a firm needs to match potential offers made by alternative employers. We show that this approach better captures findings in the empirical literature concerning CEO labor markets than both the full information and efficient assignment approach and alternative models based on asymmetric information and inefficiencies. For example, empirical findings our approach can explain include: i) external hires are rare; ii) CEOs hired from the outside, on average, are paid more; iii) external hires are typically partial outsiders rather than full outsiders; and iv) external hires who were in jobs below the CEO level are typically moving from larger firms.

The analysis in this paper could be extended in various ways. We believe there are two of particular interest. The first is to allow for more heterogeneity concerning internal candidates. In our current analysis internal candidates vary in terms of ability, but not on any other dimension. But theory and empirical work on promotions at lower levels of internal labor market job ladders such as Milgrom and Oster (1987), Bernhardt (1995), DeVaro and Waldman (2012), and Bates (2020) finds that worker visibility and educational attainment can be important for the likelihood of promotion, even holding worker ability fixed. We think it would be of interest to investigate both theoretically and empirically whether these types of factors are also important for promotion to the CEO position.

The second is to investigate how the manner in which the CEO position is filled affects effort choices of high level executives just below the CEO level. Starting with Lazear and Rosen (1981) an extensive literature, both theoretical and empirical, explores the role of promotions in creating incentives for effort. Most importantly, papers such as Kwon (2006), Miklós-Thal and Ullrich (2016), and Benson, Li, and Shue (2019) provide empirical evidence consistent with promotions being important for effort provision. We feel that incorporating effort by internal candidates into our model has the potential to yield important additional insights.

Appendix: Proofs

Proof of Lemma 2: Under Assumption 3 it must be $\widehat{a}_O > \bar{a}_O$ for all a_I. Hence,

$$\begin{aligned} \widehat{a}_O \mathbb{E}(\max\{\gamma_O a_O, \beta(a_O+s_O)\}|a_O &< \widehat{a}_O) = (\widehat{a}_O - \bar{a}_O)\,\gamma_O \frac{(\widehat{a}_O + \bar{a}_O)}{2} + \bar{a}_O \beta(\frac{\bar{a}_O}{2} + s_O) \\ &= \frac{1}{2}\left[\gamma_O \widehat{a}_O^2 + \frac{\beta^2 s_O^2}{\gamma_O - \beta})\right]. \end{aligned}$$

Condition (2) can therefore be rewritten as

$$\begin{aligned} (1-\widehat{a}_O)\left[k\frac{1+\widehat{a}_O}{2} - (k-\gamma_I)a_I - ks_I - e\right] + \frac{1}{2}\left[\gamma_O \widehat{a}_O^2 + \frac{\beta^2 s_O^2}{\gamma_O - \beta})\right] - \beta(\frac{1}{2} + s_O) \\ = \Phi\left(\widehat{a}_O, a_I\right) + \frac{1}{2}\frac{\beta^2 s_O^2}{\gamma_O - \beta} + \frac{\gamma_O}{2} - \beta(\frac{1}{2} + s_O) \geq c \qquad \text{(A1)} \end{aligned}$$

where

$$\Phi(x,z) \equiv (1-x)\left[(k-\gamma_O)\frac{1+x}{2} - (k-\gamma_I)z - ks_I - e\right]. \qquad \text{(A2)}$$

Suppose first $a_I = 0$. Then $\widehat{a}_O = \frac{ks_I+e}{k-\gamma_O}$, which by Assumption 1 is strictly less than 1. Assumption 1 also implies that, at $a_I = 0$, we have

$$(k-\gamma_O)\frac{1+\widehat{a}_O}{2} - (k-\gamma_I)a_I - ks_I - e = \frac{k-\gamma_O-ks_I-e}{2} > 0$$

Hence, $\Phi\left(\widehat{a}_O, 0\right) > 0$.

Next suppose $a_I = \bar{a}_I$, where $\bar{a}_I$ is given by $\widehat{a}_O\left(\bar{a}_I\right) = 1$, that is, $\bar{a}_I = \frac{k-\gamma_O-ks_I-e}{k-\gamma_I} > 0$. (The cutoff level $\bar{a}_I$ is the largest a_I for which the planner might find it optimal to hire an outside candidate.) In this case, $\Phi\left(\widehat{a}_O, \bar{a}_I\right) = 0$.

Finally, using $\widehat{a}_O = \frac{k-\gamma_I}{k-\gamma_O}a_I + \frac{ks_I+e}{k-\gamma_O}$ and $\frac{\partial \widehat{a}_O}{\partial a_I} = \frac{k-\gamma_I}{k-\gamma_O}$, we get

$$\begin{aligned} \frac{\partial \Phi\left(\widehat{a}_O, a_I\right)}{\partial a_I} &= -(k-\gamma_O)\widehat{a}_O\frac{k-\gamma_I}{k-\gamma_O} - (k-\gamma_I)\left(1-\widehat{a}_O\right) + (k-\gamma_I)a_I\frac{k-\gamma_I}{k-\gamma_O} + \frac{k-\gamma_I}{k-\gamma_O}\left(ks_I+e\right) \\ &= -(k-\gamma_I)\left(1-\widehat{a}_O\right) \\ &< 0. \end{aligned}$$

Hence, the left hand side of (A1) is continuous in a_I, strictly decreasing in a_I on the interval $[0, \bar{a}_I)$, and equal to $\frac{\beta^2 s_O^2}{2(\gamma_O-\beta)} + \frac{\gamma_O}{2} - \beta(\frac{1}{2} + s_O) \geq 0$ at $a_I = \bar{a}_I$. To see that $\frac{\beta^2 s_O^2}{2(\gamma_O-\beta)} + \frac{\gamma_O}{2} - \beta(\frac{1}{2} + s_O) \geq 0$, note that due to $\gamma_O > \beta$ this inequality holds if and only if

$$V(\gamma_O) \equiv \beta^2 s_O^2 + \gamma_O (\gamma_O - \beta) - \beta (\gamma_O - \beta)(1 + 2s_O) \geq 0.$$

Differentiating the left hand side with respect to γ_O yields $V'(\gamma_O) = 2(\gamma_O - \beta - \beta s_O)$, which is strictly positive because assumptions 1 and 3 together imply $\beta s_O < \gamma_O - \beta$. Hence, $V(\gamma_O)$ is minimized at $\gamma_O = 0$, where its value is $V(0) = 2s_O\beta\left(\frac{1}{2}\beta s_O + \beta\right) + \beta^2 > 0$. Hence, $V'(\gamma_O) > 0$ implies $V(\gamma_O) > 0$ for all $\gamma_O \geq 0$.

Setting $\widehat{c}_1 = \frac{\beta^2 s_O^2}{2(\gamma_O - \beta)} + \frac{\gamma_O}{2} - \beta(\frac{1}{2} + s_O)$ and $\widehat{c}_2 = \Phi(\widehat{a}_O, 0) + \frac{\beta^2 s_O^2}{2(\gamma_O - \beta)} + \frac{\gamma_O}{2} - \beta(\frac{1}{2} + s_O)$ concludes the proof. Q.E.D.

Proof of Proposition 1: The analysis preceding the proposition shows that conditional on Firm A initiating a search the incumbent is replaced if and only if $a_O \geq a_O^*(a_I)$, where $a_O^*(a_I)$ is given by (3). This is part (ii) of the proposition. Thus, if Firm A initiates a search, the probability that it finds it optimal to replace the incumbent CEO is positive only if $a_O^* < 1$, that is, if

$$\frac{2[(k - \gamma_I)a_I + ks_I + e] + \gamma_O}{2k - \gamma_O} < 1$$

This holds if and only if

$$a_I < \frac{k - \gamma_O - ks_I - e}{k - \gamma_I} = \bar{a}_I, \tag{A3}$$

which proves part (i). Now, $a_O^* > \widehat{a}_O$ if and only if

$$\frac{2[(k - \gamma_I)a_I + ks_I + e] + \gamma_O}{2k - \gamma_O} > \frac{(k - \gamma_I)a_I + ks_I + e}{k - \gamma_O},$$

which simplifies to condition (A3) and yields part (iii) of the proposition. Part (iv) follows from $\frac{\partial a_O^*(a_I)}{\partial e} = \frac{2}{2k - \gamma_O} < \frac{1}{k - \gamma_O} = \frac{\partial \widehat{a}_O(a_I)}{\partial e}$. Q.E.D.

Proof of Proposition 2: Given that the firm would consider interviewing an outside candidate only if $a_O^* < 1$, it is enough to restrict attention to a_I such that $a_I < \bar{a}_I$, where $\bar{a}_I$ is as in Proposition 1.

Using $\Phi(x, z)$ defined in (A2), conditions (5) and (2') become, respectively,

$$\begin{aligned} \Phi\left(a_O^*, a_I\right) &\geq c, \text{ and} \\ \Phi\left(\widehat{a}_O, a_I\right) + \frac{\beta^2 s_O^2}{2\left(\gamma_O - \beta\right)} + \frac{\gamma_O}{2} - \beta\left(\frac{1}{2} + s_O\right) &\geq c. \end{aligned}$$

Using (3) and differentiating $\Phi\left(a_O^*, a_I\right)$ with respect to a_I, we get

$$\frac{\partial \Phi\left(a_O^*, a_I\right)}{\partial a_I} = \frac{4k\left(k - \gamma_I\right)}{\left(\gamma_O - 2k\right)^2}\left[ks_I + e + \gamma_O - k + \left(k - \gamma_I\right)a_I\right].$$

Simple algebra yields that $\frac{\partial \Phi\left(a_O^*, a_I\right)}{\partial a_I} < 0$ for all $a_I < \frac{k - \gamma_O - ks_I - e}{k - \gamma_I} = \bar{a}_I$. Furthermore, at $a_I = 0$ we have

$$\Phi\left(a_O^*, 0\right) = \frac{2k}{\left(2k - \gamma_O\right)^2}\left(k - \gamma_O - ks_I - e\right)^2 > 0,$$

where the strict inequality follows from Assumption 1.

Next, differentiating $\Phi\left(x, a_I\right)$ with respect to x, we get

$$\frac{\partial \Phi\left(x, a_I\right)}{\partial x} = \left(k - \gamma_I\right)a_I - \left(k - \gamma_O\right)x + ks_I + e < 0 \text{ for all } x > a_I + \frac{ks_I + e}{k - \gamma} = \widehat{a}_O.$$

It was shown in Proposition 1 that $a_O^* > \widehat{a}_O$; we therefore have $\Phi\left(a_O^*, a_I\right) < \Phi\left(\widehat{a}_O, a_I\right)$ for any given a_I. In particular, this also holds for $a_I = \bar{a}_I$. Given that $\bar{a}_I$ was defined by $\widehat{a}_O\left(\bar{a}_I\right) = 1$, we thus get $\Phi\left(a_O^*, \bar{a}_I\right) < \Phi\left(\widehat{a}_O, \bar{a}_I\right) = 0$.

To sum up, $\Phi\left(a_O^*, a_I\right)$ strictly decreases in a_I for all $a_I \leq \bar{a}_I$, with $\Phi\left(a_O^*, 0\right) > 0$ and $\Phi\left(a_O^*, \bar{a}_I\right) < 0$. This implies that there must exist a $c^* > 0$ as in parts (i) and (ii) of the proposition, with $c^* = \Phi\left(a_O^*, 0\right)$. Note that $\widehat{c}_2$ is similarly given by $\widehat{c}_2 = \Phi\left(\widehat{a}_O, 0\right) + \frac{\beta^2 s_O^2}{2(\gamma_O - \beta)} + \frac{\gamma_O}{2} - \beta(\frac{1}{2} + s_O)$. Thus, we have $c^* < \widehat{c}_2$ as claimed in part (iii).

To prove the second claim in part (iii), we use the fact that $a_I^*(c)$ is uniquely determined by $\Phi\left(a_O^*, a_I^*(c)\right) = c$ and that $\widehat{a}_I(c)$ is uniquely determined by $\Phi\left(\widehat{a}_O, \widehat{a}_I(c)\right) + \frac{\beta^2 s_O^2}{2(\gamma_O - \beta)} + \frac{\gamma_O}{2} - \beta(\frac{1}{2} + s_O) = c$, where in both cases uniqueness follows from Φ being downward-sloping in a_I. Given that $\Phi\left(\widehat{a}_O, a_I\right)$ is downward sloping in a_I and that $\Phi\ \left(\widehat{a}_O, \widehat{a}_I(c)\right) + \frac{\beta^2 s_O^2}{2(\gamma_O - \beta)} + \frac{\gamma_O}{2} - \beta(\frac{1}{2} + s_O) > \Phi\left(a_O^*, a_I\right)$, it therefore has to be $a_I^*(c) < \widehat{a}_I(c)$.

Finally, applying the Implicit Function Theorem to the above two conditions that determine $\widehat{a}_I$ and a_I^* while holding $a_O^* = \widehat{a}_O$ constant, part (iv) obtains from $\frac{\partial \widehat{a}_I}{\partial e} = \frac{\partial a_I^*}{\partial e} = -\frac{1}{k-\gamma_I}$. Q.E.D.

Proof of Proposition 3: The comparative statics with respect to s_I, e, γ_O, γ_I, and a_I are immediate. The one with respect to k is also straightforward:

$$\begin{aligned}\frac{\partial w_O}{\partial k} &= -\frac{\gamma_O}{(2k-\gamma_O)^2}\left(2e+\gamma_O s_I+\gamma_O+\gamma_O a_I-2\gamma_I a_I\right)\\ &\leq -\frac{\gamma_O}{(2k-\gamma_O)^2}\left(2e+\gamma_O s_I+2\gamma_O-2\gamma_I\right)\\ &< 0 \text{ iff } \gamma_I<\gamma_O+\frac{\gamma_O s_I}{2}+e.\end{aligned}$$

Q.E.D.

Proof of Proposition 4: We first prove the claim that $\triangle > 0$. It is clear from (3) that $a_O^*(a_I) > 0$. Moreover, the fact that Firm A is willing to replace its incumbent with an outside candidate means that $a_O^*(a_I) < 1$. Therefore, by the definition of a_O^*, at $a_O = a_O^*$ the firm must be indifferent between keeping and replacing the incumbent. That is, it must be $ka_O^* - \gamma_O\frac{1+a_O^*}{2} = k(a_I+s_I)+e-\gamma_I a_I$, or $ka_O^* - \gamma_O\frac{1+a_O^*}{2} - (k-\gamma_I)a_I - ks_I = e$. This implies

$$(k-\gamma_O)\frac{(1+a_O^*)}{2}-(k-\gamma_I)a_I-ks_I>0.$$

Hence, $\triangle > 0$.

(i) As can be seen from (6), $\triangle$ depends on e only through a_O^*. Since $\triangle$ increases in a_O^* and a_O^* in turn increases in e, it must be $\frac{\partial\triangle}{\partial e} > 0$.

(ii) Using the chain rule and (3) to differentiate (6), we get

$$\frac{\partial\triangle}{\partial a_I}=\frac{k-\gamma_I}{(2k-\gamma_O)^2}\left(2k^2+4k\gamma_I a_I-2e\gamma_O-3k\gamma_O-4k^2a_I-4k^2s_I\right).$$

Since $k-\gamma_I>0$, we have that $\frac{\partial\triangle}{\partial a_I} > 0$ if

$$a_I<\frac{2k^2-2e\gamma_O-3k\gamma_O-4k^2s_I}{4k(k-\gamma_I)}\equiv a_I^{++} \tag{A4}$$

and $\frac{\partial\triangle}{\partial a_I} < 0$ if $a_I > a_I^{++}$. If we let $a_I^+ = a_I^{++}$ for $a_I^{++}\in[0,1]$, $a_I^+ = 0$ for $a_I^{++} < 0$, and $a_I^+ = 1$ for $a_I^{++} > 1$, the claim in (ii) regarding the sign of $\frac{\partial\triangle}{\partial a_I}$ follows from (A4).

Next, differentiating $\triangle$ with respect to s_I, we find that

$$\frac{\partial \triangle}{\partial s_I} = \left(\frac{k}{k-\gamma_I}\right)\frac{\partial \triangle}{\partial a_I}.$$

Since $k-\gamma_I > 0$, $\frac{\partial \triangle}{\partial s_I}$ always has the same sign as $\frac{\partial \triangle}{\partial a_I}$.

(ii) Let $s_I \to \frac{1}{2} - \frac{\gamma_O}{2k} - \frac{e}{k}$ from above (for s_I smaller, either Assumption 2 or Assumption 3 would be violated). Then $k > \gamma_O$ implies

$$\begin{aligned} a_I^{++} &\to \frac{4ke - k\gamma_O - 2e\gamma_O}{4k\left(k-\gamma_I\right)} \\ &> \frac{2e-\gamma_O}{4\left(k-\gamma_I\right)}. \end{aligned}$$

This expression is positive if $e > \frac{\gamma_O}{2}$ and grows without bounds as $(k-\gamma_I) \to 0$. Hence, for e large and for s_I and $(k-\gamma_I)$ small, we have $a_I^{++} \geq 1$, that is, $a_I^{+} = 1$.

Next, set $e = 0$ and let $s_I \to 1 - \frac{\gamma_O}{k}$ from below (for s_I larger, Assumption 1 would be violated). Then

$$a_I^{++} \to \frac{\gamma_O - 2k}{4\left(k-\gamma_I\right)} < 0,$$

that is, $a_I^{+} = 0$. Q.E.D.

Proof of Proposition 5: Based on the arguments preceding the proposition, the probability that the outside candidate is hired if he is a full outsider is $a_O^* H\left(c^*\right)$. Similarly, the probability that the outside candidate is hired if he is a partial outsider is $a_O^* \bar{H}\left(c^*\right)$. Bayes rule then says that conditional on an outsider being hired the probability that he is a partial outsider is

$$\frac{(1-p)a_O^* H\left(c^*\right)}{p a_O^* \bar{H}\left(c^*\right) + (1-p)a_O^* H\left(c^*\right)} > 1-p,$$

where the inequality follows from $H\left(c^*\right) > \bar{H}\left(c^*\right)$ established in the text. Q.E.D.

Proof of Proposition 6: The claim that the incumbent is replaced if and only if $a_O \geq a_{On}^*\left(a_I\right)$, where $a_{On}^*\left(a_I\right)$ satisfies (7), follows from the analysis in the text. To see that $0 < a_{On}^*\left(a_I\right) < 1$ for all $n \in \mathcal{N}$, define a function $\Omega(x,n)$ by

$$\Omega(x,n) \equiv s_I + \frac{e}{k} + \frac{\gamma_O}{k}\mathbb{E}_n\left(a|a \geq x\right) + \frac{k-\gamma_I}{k}a_I - x,$$

so that a_{On}^{*} is a solution to

$$\Omega(x,n)=0. \tag{A5}$$

By the differentiability of $F^n(.)$, $\Omega(x,n)$ is continuous in x on $(0,1)$. Next, note that, for any $n\geq 1$, $\lim_{x\to 0}\mathbb{E}_n\left(a|a\geq x\right)=\mathbb{E}_n(a)$, which implies $\lim_{x\to 0}\Omega(x,n)=s_I+\frac{e}{k}+\frac{\gamma_O}{k}\mathbb{E}_n(a)+\frac{k-\gamma_I}{k}a_I>0$. Similarly, $\lim_{x\to 1}\mathbb{E}_n\left(a|a\geq x\right)=1$. This implies $\lim_{x\to 1}\Omega(x,n)=s_I+\frac{e}{k}+\frac{\gamma_O}{k}+\frac{k-\gamma_I}{k}a_I-1<0$, where the inequality follows from $a_I<\bar{a}_I$, where $\bar{a}_I$ is given by (4). Thus, for any $a_I<\bar{a}_I$ and any $n\in\mathcal{N}$, (A5) has a solution $a_{On}^{*}\left(a_I\right)\in(0,1)$. Q.E.D.

Proof of Proposition 7: Given the uniform distribution of underlying abilities, we have $F^n(a)=U^n(a)=a^n$ and $\mathbb{E}_n\left(a|a\geq a_{On}^{*}\right)=\left(\frac{n}{n+1}\right)\left(\frac{1-a_{On}^{*n+1}}{1-a_{On}^{*n}}\right)$. Using $x=a_{On}^{*}$ to economize on notation, Firm A's optimization problem in this setting becomes

$$\max_n\left(1-x^n\right)(k-\gamma_O)\mathbb{E}_n\left(a|a\geq x\right)+x^n\left[(k-\gamma_I)a_I+ks_I+e\right]-c, \tag{A6}$$

with x given by

$$\Omega(x,n)\equiv\frac{\gamma_O}{k}\left(\frac{n}{n+1}\right)\left(\frac{1-x^{n+1}}{1-x^n}\right)+\frac{k-\gamma_I}{k}a_I+s_I+\frac{e}{k}-x=0. \tag{A7}$$

We want to prove that (A6) is solved by $n=N$, which we will do in four steps.

<u>Step 1:</u> $(k-\gamma_O)\mathbb{E}_n\left(a|a\geq x\right)>(k-\gamma_I)a_I+ks_I+e$ for any $n\in\mathcal{N}$ and $x\in(0,1)$. This follows because, for a given n, Firm A hires the outside candidate only if $ka_O-w_{On}^{M}\geq(k-\gamma_I)a_I+ks_I+e$. This immediately implies that its expected profit conditional on hiring an outsider, $(k-\gamma_O)\mathbb{E}_n\left(a|a\geq x\right)$, exceeds its payoff from keeping the insider, $(k-\gamma_I)a_I+ks_I+e$.

<u>Step 2:</u> $\mathbb{E}_n\left(a|a\geq x\right)$ increases in n for any given $x\in(0,1)$. We have $\mathbb{E}_n\left(a|a\geq x\right)>\mathbb{E}_{n+1}\left(a|a\geq x\right)$ if and only if $\left(\frac{n}{n+1}\right)\left(\frac{1-x^{n+1}}{1-x^n}\right)>\left(\frac{n-1}{n}\right)\left(\frac{1-x^n}{1-x^{n-1}}\right)$, which reduces to

$$t(x,n)\equiv n^2\left(1-x^{n+1}\right)\left(1-x^{n-1}\right)-\left(n^2-1\right)\left(1-x^n\right)^2>0. \tag{A8}$$

Partially differentiating with respect to x yields

$$\begin{aligned} t_x(x,n) &= nx^{n-2}g(x,n),\text{ where } g(x,n)\equiv 2n^2x-2x+n-nx^2+2x^{n+1}-n^2x^2-n^2; \\ g_x(x,n) &= 2(n+1)\left(n-nx+x^n-1\right);\text{ and} \\ g_{xx}(x,n) &= 2(n+1)n\left(x^{n-1}-1\right)<0. \end{aligned} \tag{A9}$$

Inequality (A9) implies that, for any given $n \in \mathcal{N}$, $g_x(x,n)$ decreases in x and is minimized at $x=1$, where $g_x(1,n)=0$. Hence, $g_x(x,n)>0$ for all $x\in(0,1)$, which means that g is strictly increasing in x for any n and therefore maximized at $x=1$, with $g(1,n)=0$. Consequently, $g(x,n)<0$, and therefore also $t_x(x,n)<0$, for all $x\in(0,1)$. This in turn implies that $t(x,n)$ strictly decreases in x and is minimized at $x=1$. Since $t(1,n)=0$ for any n, we conclude that (A8) holds.

Step 3: $\frac{d}{dn}\mathbb{E}_n(a|a\geq x)>0$ for all $n\in\mathcal{N}$ and $x\in(0,1)$, where $\frac{d}{dn}$ denotes total derivative (treating n as continuous and x as a function of n). We have

$$\frac{d}{dn}\mathbb{E}_n(a|a\geq x)=\frac{\partial}{\partial x}\mathbb{E}_n(a|a\geq x)\frac{dx}{dn}+\frac{\partial}{\partial n}\mathbb{E}_n(a|a\geq x).$$

From Step 2, we already know that $\frac{\partial}{\partial n}\mathbb{E}_n(a|a\geq x)>0$. Now, holding n fixed, the arguments in the proof of Proposition 6 imply that at the largest x that solves (A7), $\Omega(x,n)$ must intersect the horizontal axis from above; that is, it must be $\Omega_x(x,n)<0$. Applying the Implicit Function Theorem to (A7) therefore yields $sign\left(\frac{dx}{dn}\right)=sign\left(\Omega_n(x,n)\right)=\frac{\partial}{\partial n}\mathbb{E}_n(a|a\geq x)>0$. Thus, it remains to sign $\frac{\partial}{\partial x}\mathbb{E}_n(a|a\geq x)$. We have

$$\frac{\partial}{\partial x}\mathbb{E}_n(a|a\geq x)=\left(\frac{n}{n+1}\right)\frac{\partial}{\partial x}\left(\frac{1-x^{n+1}}{1-x^n}\right)=\left(\frac{n}{n+1}\right)\frac{x^{n-1}}{(1-x^n)^2}\left(n-nx-x+x^{n+1}\right)$$

and

$$\frac{\partial}{\partial x}\left(n-x+x^{n+1}-nx\right)=(x^n-1)(n+1)<0.$$

Hence, $n-x+x^{n+1}-nx$ is minimized at $x=1$, where it equals 0. This implies $\frac{\partial}{\partial x}\mathbb{E}_n(a|a\geq x)>0$ for all $x<1$, which in turn yields $\frac{d}{dn}\mathbb{E}_n(a|a\geq x)>0$.

Step 4: $\frac{d}{dn}x^n<0$ (where $\frac{d}{dn}$ again denotes total derivative). Let $\omega=x^n$. Then $x=\omega^{\frac{1}{n}}$, $\omega\in(0,1)$, and (A7) becomes

$$\Theta(\omega,n)\equiv\frac{\gamma_O}{k}\left(\frac{n}{n+1}\right)\left[1+\frac{\omega}{1-\omega}\left(1-\omega^{\frac{1}{n}}\right)\right]+\left(\frac{k-\gamma_I}{k}\right)a_I+s_I+\frac{e}{k}-\omega^{\frac{1}{n}}=0.$$

Thus, the same logic as in Step 3 says that $sign\left(\frac{d\omega}{dn}\right)=sign\left(\Theta_n(\omega,n)\right)$. Straightforward but tedious calculations show that $\Theta_n(\omega,n)<0$ if and only if

$$\left(\frac{n}{n+1}\right)^2\gamma_O\left(1-\omega^{\frac{n+1}{n}}\right)+\left[k(1-\omega)+\frac{n}{n+1}\omega\gamma_O\right]\omega^{\frac{1}{n}}\ln\omega<0,$$

or, after switching back to x,

$$\left(\frac{n}{n+1}\right)^2 \gamma_O \left(1-x^{n+1}\right) + \left[k\left(1-x^n\right) + \frac{n}{n+1}\gamma_O x^n\right] nx\ln x < 0. \tag{A10}$$

Now, $\frac{\partial}{\partial\gamma}LHS(\text{A10}) = \frac{n^2}{(n+1)^2}\varphi(x,n)$, where

$$\varphi(x,n) \equiv (n+1)x^{n+1}\ln x + 1 - x^{n+1}.$$

Given that $\varphi_n(x,n) = x^{n+1}\left(\ln^2 x\right)(n+1) > 0$, we have that $\varphi(x,n)$ is minimized at $n=1$, at which point $\varphi(x,1) = 2x^2\ln x + 1 - x^2$. Differentiating $\varphi(x,1)$ with respect to x we get $\varphi_x(x,1) = 4x\ln x < 0$ for all $x \in (0,1)$. This means that $\varphi(x,1)$ is minimized at $x=1$, at which point $\varphi(1,1) = 0$. Thus, $\varphi(x,1) > 0$ for all $x \in (0,1)$, which in turn implies that $\varphi(x,n) > 0$ for all $x \in (0,1)$ and all $n \in \mathcal{N}$. The left hand side of (A10) (LHS(A10)) is therefore maximized at $\gamma_O = 1$. Similarly, LHS(A10) clearly decreases in k and is therefore maximized at $k=1$. Thus, (A10) holds as long as it holds for $k = \gamma_O = 1$. Plugging both of these values into (A10) and multiplying by $(n+1)$, the condition becomes

$$\left(\frac{n}{1+n}\right)\left(1-x^{n+1}\right) + \left(1+n-x^n\right)x\ln x < 0. \tag{A11}$$

Differentiating the left hand side of (A11) with respect to x yields $\frac{\partial}{\partial x}\left(LHS(\text{A11})\right) = \left(1-x^n\right)(n+1)(\ln x + 1)$, which means $\frac{\partial}{\partial x}\left(LHS\left(\text{A11}\right)\right) < 0$ for $x < e^{-1}$ and $\frac{\partial}{\partial x}\left(LHS\left(\text{A11}\right)\right) > 0$ for $x > e^{-1} \approx 0.368$.

We now show that the latter case applies, because under Assumption 2 it must be $x > 1/2$. To see this, note first that combining Assumptions 2 and 3 implies $\frac{\gamma_O}{k} > (1-2s_I)$. Moreover, we have $\left(\frac{n}{n+1}\right)\left(\frac{1-x^{n+1}}{1-x^n}\right) > \frac{1}{2}$ for any $x \in (0,1)$ and any $n \geq 1$. For $s_I < 1/2$, (A7) therefore yields

$$\begin{aligned} x &> (1-2s_I)\left(\frac{n}{n+1}\right)\left(\frac{1-x^{n+1}}{1-x^n}\right) + s_I \\ &> \frac{1}{2}. \end{aligned}$$

Condition (A7) also implies $x > s_I$. Thus, for $s_I \geq 1/2$ we again get $x > 1/2$. Hence, $\frac{\partial}{\partial x}\left(LHS\left(\text{A11}\right)\right) > 0$ for all relevant values of x, which means that LHS(A11) is maximized at

$x = 1$, at which point $LHS(\text{A11}) = 0$. Therefore, (A11) holds for all $x \in (0, 1)$. This means that (A10) also holds, which in turn implies $\frac{d\omega}{dn} < 0$, that is, x^n decreases in n.

Steps 1, 3, and 4 together imply that the firm's objective function increases in n and is therefore maximized at $n = N$. Q.E.D.

Proof of Lemma 3: Suppose $D \leq 0$ and define $M \equiv -D$, so that if the firm interviews an outsider, he is hired if and only if $a_I \leq a_O + M$. We need to consider two cases.

Case 1: $M \geq a_I^{**}$. In this case, whenever the firm interviews an outsider, the outsider gets hired; that is,

$$\Pr\{\text{hired}\} = \int_0^{a_I^{**}} u(x)dx = a_I^{**}.$$

Moreover,

$$\Pr\{\text{hired}|a_O = y\} = \Pr\{a_I \leq a_I^{**}\} = a_I^{**} \text{ for all } y.$$

Thus, (11) yields $h(y|\text{hired}) = 1$ for all y, so that $\mathbb{E}(a_O|\text{hired}) = \int_0^1 yh(y)dy = 1/2$.

Now, $\Pr\{\text{promoted}\} + \Pr\{\text{hired}\} = 1$ implies $\Pr\{\text{promoted}\} = 1 - a_I^{**}$. Since $M = \frac{w_I^{**} - w_O^{**}}{k} - s_I$, it has to be $M < w_I^{**} = \gamma\mathbb{E}(a_O|\text{hired}) < 1/2$. Moreover, $M \geq 0$ requires $w_I^{**} > w_O^{**}$, which implies $a_I^{**} > 1/2$. But this, combined with $M < 1/2$, contradicts $M \geq a_I^{**}$, which means this case cannot occur.

Case 2: $M < a_I^{**}$. In this case, we have

$$\begin{aligned}
\Pr\{\text{hired}\} &= \int_0^M u(x)dx + \int_M^{a_I^{**}} u(x)\left[1 - U(x - M)\right]dx \\
&= M + \int_M^{a_I^{**}} (1 - x + M)dx \\
&= Q,
\end{aligned}$$

where

$$Q \equiv a_I^{**} - \frac{1}{2}\left(a_I^{**} - M\right)^2.$$

Also,

$$\Pr\{\text{hired}|a_O = y\} = \begin{cases} \Pr\{a_I \leq y + M\} = y + M & \text{if } y \leq a_I^{**} - M \\ \Pr\{a_I \leq a_I^{**}\} = a_I^{**} & \text{if } y > a_I^{**} - M \end{cases}.$$

Using (11), we then get

$$h\left(y|\text{hired}\right)=\begin{cases}\frac{y+M}{Q} & \text{if } y\leq a_I^{**}-M\\ \frac{a_I^{**}}{Q} & \text{if } y>a_I^{**}-M\end{cases},$$

so that

$$\begin{aligned}\mathbb{E}\left(a_O|\text{hired}\right) &= \frac{1}{Q}\left[\int_0^{a_I^{**}-M} y(y+M)dy+a_I^{**}\int_{a_I^{**}-M}^{1} ydy\right]\\ &= \frac{1}{2Q}\left[a_I^{**}-\frac{1}{3}\left(a_I^{**}-M\right)^3\right].\end{aligned}$$

Similarly, for the internal candidate we have

$$\Pr\{\text{promoted}\}=1-Q$$

and

$$\Pr\{\text{promoted}|a_I=y\}=\begin{cases}0 & \text{if } y\leq M\\ \Pr\{a_O\leq y-M\} & \text{if } y\in(M,a_I^{**}]\\ 1 & \text{if } y>a_I^{**}\end{cases},$$

which yields the probability density function of the internal candidate's ability conditional on being promoted as

$$\eta\left(y|\text{promoted}\right)=\begin{cases}0 & \text{if } y\leq M\\ \frac{y-M}{1-Q} & \text{if } y\in(M,a_I^{**}]\\ \frac{1}{1-Q} & \text{if } y>a_I^{**}\end{cases}.$$

Therefore,

$$\begin{aligned}\mathbb{E}\left(a_I|\text{promoted}\right) &= \frac{1}{1-Q}\left[\int_M^{a_I^{**}} y(y-M)dy+\int_{a_I^{**}}^{1} ydy\right]\\ &= \frac{1}{1-Q}\left[a_I^{**2}\left(\frac{a_I^{**}}{3}-\frac{M+1}{2}\right)+\frac{M^3}{6}+\frac{1}{2}\right].\end{aligned}$$

Recalling that $M\equiv -D=\frac{w_I^{**}-w_O^{**}}{k}-s_I$, $w_I^{**}=\gamma\mathbb{E}(a_I|\text{promoted})$, and $w_O^{**}=\gamma\mathbb{E}(a_O|\text{hired})$, any Perfect Bayesian Equilibrium of the model in which $D\leq 0$ is then given by a solution $(a_I^{**},w_O^{**},w_I^{**})$ to the following three conditions:

$$\begin{aligned}M &= \frac{\gamma}{k}\left[\frac{1}{1-Q}\left[a_I^{**2}\left(\frac{a_I^{**}}{3}-\frac{M+1}{2}\right)+\frac{M^3}{6}+\frac{1}{2}\right]-\frac{1}{2Q}\left[a_I^{**}-\frac{1}{3}\left(a_I^{**}-M\right)^3\right]\right]-s_I;\\ Q &= a_I^{**}-\frac{1}{2}\left(a_I^{**}-M\right)^2=B+M-\frac{1}{2}B^2;\\ a_I^{**} &= B+M;\end{aligned}$$

where $B \equiv 1 - \sqrt{\frac{2c}{k}}$. Plugging the last two conditions above into the first one and rearranging, any equilibrium with $M \geq 0$ must solve the following equation:

$$M = \frac{\gamma}{k}\left[\frac{1 + MB^2 + \frac{2}{3}B^3 - (M+B)^2}{2\left[1 + \frac{1}{2}B^2 - (M+B)\right]} - \frac{M + B - \frac{1}{3}B^3}{2\left(M + B - \frac{1}{2}B^2\right)}\right] - s_I.$$

Now, given that $s_I > 0$, $M \geq 0$ requires that the expression in the square brackets is positive. The assumptions $\gamma < 1$ and $k > 1$ then imply that

$$\begin{aligned} M &< \frac{1 + MB^2 + \frac{2}{3}B^3 - (M+B)^2}{2\left[1 + \frac{1}{2}B^2 - (M+B)\right]} - \frac{M + B - \frac{1}{3}B^3}{2\left(M + B - \frac{1}{2}B^2\right)} - s_I, \text{ or} \\ s_I &< g(M,B) - t(M,B) \equiv s_I^*(M,B), \end{aligned} \tag{A12}$$

where

$$\begin{aligned} g(M,B) &\equiv \frac{1 + MB^2 + \frac{2}{3}B^3 - (M+B)^2}{2\left[1 + \frac{1}{2}B^2 - (M+B)\right]} - \frac{M}{2} \quad \text{and} \\ t(M,B) &\equiv \frac{M + B - \frac{1}{3}B^3}{2\left(M + B - \frac{1}{2}B^2\right)} + \frac{M}{2}. \end{aligned}$$

Condition (A12) means that an equilibrium with $M \geq 0$ can exist only if $s_I < s_I^*(M,B)$.

Now, simple calculations show that $\frac{\partial g}{\partial M} < 0$ if and only if $B^3\left(\frac{1}{4}B - \frac{1}{3}\right) < 0$, which always holds for $B \in (0,1]$. Similarly, $\frac{\partial t}{\partial M} > 0$ if and only if

$$\left(\frac{1}{2}B^2 - \frac{2}{3}B^3 + \frac{1}{4}B^4\right) + \left[M^2 + MB(2-B)\right] > 0.$$

The expression in the square brackets is clearly strictly positive for all $B \in (0,1]$. The expression in the first set of parentheses is equal to zero at $B = 0$ and increasing in B for all $B \in (0,1)$, which implies that the expression is also strictly positive for all $B \in (0,1]$. Hence, $\frac{\partial t}{\partial M} > 0$ for all $B \in (0,1]$.

Combined, $\frac{\partial g}{\partial M} < 0$ and $\frac{\partial t}{\partial M} > 0$ imply that $s_I^*(M,B)$ decreases in M for any $B \in (0,1]$ and for $M \geq 0$ therefore attains a maximum at $M = 0$, i.e., $s_I^*(M,B) \leq s_I^*(0,B)$ for all $M \in [0,1]$. Plugging $M = 0$ into (A12), we get

$$s_I^*(0,B) = \frac{1 - B^2 + \frac{2}{3}B^3}{2 - 2B + B^2} - \frac{B - \frac{1}{3}B^3}{2B - B^2}.$$

This expression is maximized at $\widehat{B} \approx 0.423801$, at which point $s_I^*(0,B) \approx 0.05755$. Q.E.D.

Proof of Proposition 8: (i) We have Pr{ promoted} > Pr{hired} if and only if

$$\begin{aligned} 1+\frac{a_I^{**2}}{2}-a_I^{**}(1-D) &> a_I^{**}(1-D)-\frac{a_I^{**2}}{2}, \text{ or} \\ (1-a_I^{**})^2 &> -2a_I^{**}D. \end{aligned}$$

When $a_I^{**} \neq 0$, this always holds if $D > 0$, which by Lemma 3 is true for all $s_I \geq s_{I1}^*$.

(ii) As shown in the text, for $a_I^{**} \in (0,1)$ the equilibrium is given by the conditions (14) – (16). Start by eliminating (14) by substituting it into (15) and (16). Next, define $z \equiv \frac{w_O^{**}-w_I^{**}}{k}$ and $T \equiv \sqrt{\frac{2c}{k}}$, use w instead of w_I^{**} (to simplify notation), and rewrite (15) and (16) in terms of z and w. This yields

$$(kz+w)(1-z-s_I+T)-m\left(1-\frac{(1-z-s_I-T)^2}{3}-(1-T)(z+s_I)\right)=0 \tag{A13}$$

$$w\left(1+\frac{(1-z-s_I-T)^2}{2}\right)-m\left(\frac{1}{2}+\frac{(1-z-s_I-T)^3}{3}\right) - (1-z-s_I-T)\left(w-m\frac{(1-z-s_I-T)}{2}\right)(1-z-s_I)=0 \tag{A14}$$

Now, solve for w from each of (A13) and (A14) and denote the former solution by w_1 and the latter by w_2:

$$\begin{aligned} w_1(z,s_I) &= \frac{m\left[1-\frac{1}{3}(T+s_I+z-1)^2+(T-1)(s_I+z)\right]-kz(T-s_I-z+1)}{T-s_I-z+1} \\ w_2(z,s_I) &= -\frac{m\left[\frac{1}{3}(T+s_I+z-1)^3-\frac{1}{2}\right]-\frac{1}{2}m(s_I+z-1)(T+s_I+z-1)^2}{\frac{1}{2}(T+s_I+z-1)^2-(s_I+z-1)(T+s_I+z-1)+1}. \end{aligned}$$

As the notation suggests, we will treat w_1 and w_2 as functions of z and s_I.

Step 1: There exists an $s_I^* \in (0,1)$ s.t. $w_1(0,s_I) > w_2(0,s_I)$ for all $s_I > s_I^*$. To see this, evaluate w_1 and w_2 at $z=0$ to get

$$w_1(0,s_I) = m\left(\frac{s_I(T-1)-\frac{1}{3}(T+s_I-1)^2+1}{T-s_I+1}\right),$$

$$w_2(0,s_I) = m\left(\frac{2+3T^2-2T^3-3s_I^2+s_I^3+3s_I-3T^2s_I}{6s_I+3T^2-3s_I^2+3}\right),$$

and

$$\begin{aligned}\frac{dw_1(0,s_I)}{ds_I} &= \frac{m}{3}\frac{(1-s_I)}{(T-s_I+1)^2}(2T+1-s_I) > 0,\\ \frac{dw_2(0,s_I)}{ds_I} &= -\frac{m\left[3T^4+6T^2-4T^3(1-s_I)+s_I^4-4s_I^3+2s_I+1\right]}{3\left(T^2-s_I^2+2s_I+1\right)^2} < 0.\end{aligned}$$

The inequality sign for $\frac{dw_1(0,s_I)}{ds_I}$ is immediate because $s_I < 1$. The sign for $\frac{dw_2(0,s_I)}{ds_I}$ follows from $T < 1$, $s_I < 1$, and $s_I^4 - 4s_I^3 + 2s_I + 1 \geq 0$ for all $s_I \in [0,1]$.

Now, let $s_I = 1$. Then

$$w_1(0,1) = m\left(1-\frac{1}{3}T\right) \text{ and } w_2(0,1) = m\frac{3-2T^3}{6+3T^2},$$

which implies that $w_1(0,1) > w_2(0,1)$ if and only if

$$1-\frac{1}{3}T-\frac{3-2T^3}{6+3T^2} > 0.$$

Since $3-2T^3 > 0$, this holds if $1-\frac{1}{3}T-\frac{3-2T^3}{6} > 0$, or $3-2T+2T^3 > 0$, which is always true given that $T \leq 1$. The fact that $w_1(0,1) > w_2(0,1)$ combined with $\frac{dw_1(0,s_I)}{ds_I} > 0$ and $\frac{dw_2(0,s_I)}{ds_I} < 0$ implies that there exists an $s_I^* \in (0,1)$ s.t. $w_1(0,s_I) > w_2(0,s_I)$ for all $s_I > s_I^*$.

Step 2: $s_I^* \leq 0.08$. This follows from the arguments in Step 1 if $w_1(0,0.08) > w_2(0,0.08)$, that is, if

$$L(T) \equiv \frac{0.69333T-\frac{1}{3}T^2+0.63787}{T+0.92}-\frac{2.76T^2-2T^3+2.2213}{3.4608+3T^2} > 0.$$

The equation $L(T) = 0$ has two real roots, both of them strictly negative ($T_1 = -0.245\,03$ and $T_2 = -2.0509$). Furthermore, $L(0) > 0$. Hence, $L(T) > 0$ for all $T \in [0,1]$.

Step 3: Suppose $s_I < (1-T)\left(1-\frac{m}{2k}\right)$ and let $\widehat{z} = 1-s_I-T$. Then $w_1(\widehat{z},s_I) < w_2(\widehat{z},s_I)$.

Plugging $\widehat{z} = 1-s_I-T$ into the expressions for $w_1(z,s_I)$ and $w_2(z,s_I)$ yields $w_1(\widehat{z},s_I) < w_2(\widehat{z},s_I)$ if and only if

$$\frac{m(2-T)-2k(1-s_I-T)}{2} < \frac{1}{2}m,$$

which holds if and only if $s_I < (1-T)\left(1-\frac{m}{2k}\right)$.

Step 4: Continuity of $w_1(z,s_I)$ and $w_2(z,s_I)$ in z, along with the facts that $w_1(0,s_I) > w_2(0,s_I)$ for all $s_I \geq 0.08$ and $w_1(\widehat{z},s_I) < w_2(\widehat{z},s_I)$ for $z = 1-s_I-T$, implies that for any $s_I \geq 0.08$ there must exist a $z^{**} \in (0, \widehat{z})$ such that $w_1(z^{**}, s_I) = w_2(z^{**}, s_I)$. That is, z^{**}, $w^{**} \equiv w_1(z^{**}, s_I) = w_2(z^{**}, s_I)$, and $a_I^{**} = 1 - z^{**} - s_I - T$ solve the system of equations (14) - (16). Moreover, $z^{**} > 0$ implies $w_O^{**} > w_I^{**}$, and $z^{**} < \widehat{z}$ implies $a_I^{**} \in (0, 1)$. Q.E.D.

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