Succession*

Thomas Geelen† Jakub Hajda‡

October 20, 2024

Abstract

Managing CEO succession is one of the board's most important tasks. We develop a dynamic model of CEO succession to analyze executive hiring, firing, and entrenchment. The board learns about the CEO's and successor's ability and can decide to replace the executives internally or externally. Our model explains the board's preference towards internal CEO successions, which become more likely with more efficient executive labor markets. We also demonstrate that the CEO's ability to sabotage the successor can make the CEO more entrenched but can also backfire and get the CEO fired.

Keywords: succession, CEO labor markets, CEO turnover, managerial entrenchment, sabotage.

JEL Classifications: G30, G34, M12.

*We would like to thank Andreas Brøgger, Pierre Chaigneau (discussant), Jérôme Detemple, James Dow (discussant), Peter Feldhütter, Stefan Lewellen, Simon Mayer, Kasper Meisner Nielsen, Alejandro Rivera, Enrique Schroth, Jan Starmans, Zhe Wang, and seminar participants at Copenhagen Business School, DFI Research Fellow Retreat, FIRS 2024, Queen's Corporate Finance Theory Workshop, Frankfurt School of Finance & Management, Northern Finance Association 2024 Annual Meeting, Pennsylvania State University, University of Amsterdam, University of Bristol, University of Luxembourg, and University of Warwick for helpful comments.

†Smeal College of Business, Pennsylvania State University. Email: geelen@psu.edu.

‡HEC Montréal. E-mail: jakub.hajda@hec.ca

CEOs have a profound and lasting impact on the companies they lead (Bertrand and Schoar, 2003; Bandiera et al., 2020; Bennedsen et al., 2020; Jenter et al., 2021). Consequently, CEO hiring and succession planning are among the board of directors' most critical responsibilities. Despite this importance, many firms still lack adequate succession plans or have none at all. Furthermore, when successions do occur, the vast majority of successors are promoted from within the firm, even though frictionless labor market models suggest that the new CEO should typically come from outside the firm.[1] Incumbent CEOs also play a significant role in the succession process, often influencing succession planning to further their own interests. This brings up a fundamental question: Why do boards prefer hiring internal candidates and what factors ultimately drive succession planning? To address this question, we develop a dynamic model of CEO succession in which the board learns about the CEO and successor. This allows us to analyze how firms hire and dismiss CEOs, how they establish succession plans, and what the CEO's role is in the succession process.

Our model yields several important insights. First, it provides a theoretical explanation for the high prevalence of internal successions observed in practice (e.g., Parrino, 1997; Huson et al., 2004; Cziraki and Jenter, 2022). Second, it sheds light on why many firms lack a formal succession plan (Cvijanović et al., 2022; Larcker et al., 2022) and why there are often significant delays in appointing new CEOs (Rivolta, 2018; Gabarro et al., 2022). Third, our model reveals that the CEO's actions during the succession process can lead to managerial entrenchment but can also backfire and result in CEO dismissal. Overall, our findings help explain several empirical patterns in CEO succession, generate new testable predictions, and present a novel channel for managerial entrenchment.

In our model, the firm employs both a CEO and a designated successor, such as the current COO or president. Over time, the board learns about the abilities of both the CEO

[1] In frictionless labor market models such as Gabaix and Landier (2008) or Terviö (2008), the most capable CEO available to the firm is typically an external candidate, often the CEO of a slightly smaller firm. Therefore, these models predict that all new CEOs should be hired externally.

and the successor by closely monitoring their performance within the firm (e.g., Cornelli et al., 2013). The CEO's ability is crucial to the board, as it has a direct impact on the firm's cash flows. At any given moment, the board has the option to replace the CEO if they determine that her skills are insufficient; however, this decision comes with a cost. When it becomes necessary to appoint a new CEO, the board faces a choice: promote the successor—resulting in an *internal succession*—or undertake a costly search in the labor market to find an external candidate, leading to an *external succession*.

When deciding on a new CEO appointment, the board evaluates the expected ability of the successor against that of potential external candidates. If the board receives positive information about the successor's capabilities, the likelihood of promoting the successor to CEO increases. Conversely, if the information about the successor's abilities is negative, the board is more inclined to seek an external candidate. This process of learning about the successor's ability drives internal successions and helps explain the empirical trend of firms frequently choosing to hire their CEOs from within (e.g., Cziraki and Jenter, 2022).

Existing literature has often linked internal successions to agency conflicts or managerial biases (e.g., Hermalin and Weisbach, 1998; He and Schroth, 2024). However, our findings suggest that these factors may not be the sole drivers of internal successions. Specifically, we demonstrate that a more efficient labor market for executives actually leads to an increase in internal successions. When labor market frictions are less severe, two key effects emerge. First, it becomes less costly to hire external candidates, which increases the frequency of external successions. Second, replacing the successor also becomes less costly, enabling firms to employ successors with higher expected ability, which in turn leads to more internal successions. Importantly, we find that this second effect outweighs the first as the labor market becomes more efficient. As a result, more efficient labor markets prompt the board to favor internal promotions. This insight has a significant implication: higher rates of internal successions may not necessarily signal inefficiencies in the labor market for CEOs,

as some theories suggest. Instead, they may be indicative of a more efficient labor market for executives. We also show that these findings remain robust even when we extend our framework to include factors such as firm-specific human capital accumulation, internal labor markets, as well as when embedding the model in a labor market equilibrium.

We also show that the lack of succession planning (Cvijanović et al., 2022; Larcker et al., 2022) and the long delays in appointing new CEOs (Rivolta, 2018; Gabarro et al., 2022) can actually be optimal for firms. Our model identifies three key reasons why this might be the case. First, the costs associated with appointing, firing, or replacing CEOs can be high, leading firms to delay the appointment of a new CEO. Second, as the board continues to learn more about the successor's abilities, it may have a strategic incentive to postpone the promotion, as in real options models (see, e.g., Dixit and Pindyck, 1994). Third, a poorly performing CEO is likely to have a short tenure, reducing the value of hiring such a candidate in the first place. Consequently, boards may choose to delay the appointment of a new CEO until a more suitable candidate is found, rather than settling for a less qualified candidate now.

Apart from the board, incumbent CEOs also play a significant role in the succession process. They often do so through mentoring their successors (Bower, 2012; Berns and Klarner, 2017). However, they may not always act in the best interests of shareholders and could actively sabotage the successors to retain their own influence within the firm (Boeker, 1992; Cannella and Shen, 2001; Zhang, 2006). This sabotage could manifest in the CEO's refusal to collaborate with or mentor the successor, thereby leaving the successor less prepared and less capable of effectively leading the firm in the future. To analyze the impact of this behavior on succession planning, we extend our model to include the possibility of the CEO sabotaging the successor, thus proposing a novel channel for CEO entrenchment (e.g., Shleifer and Vishny, 1989; Zwiebel, 1996).

Crucially, while sabotaging the successor may reduce the likelihood of the CEO being

replaced by the board, it also negatively impacts the firm's equity value. Our analysis reveals that compensation structure plays a vital role in shaping the CEO's incentives to sabotage the successor. Specifically, equity-based compensation discourages sabotage because any actions that lower the firm's equity value would directly harm the CEO's own financial interests. In contrast, a fixed wage incentivizes the CEO to engage in sabotage to extend their tenure and maximize their earnings. We demonstrate that the CEO engages in sabotage to weaken the successor, but not so much that the board would consider replacing the weak successor with a stronger external candidate. As a result, increasing the proportion of equity-based compensation effectively *reduces* managerial entrenchment.

The board reacts to the CEO's sabotage of the successor in two key ways.[2] First, the board adjusts its hiring policy by optimally delaying the replacement of any successor, recognizing that the CEO is likely to sabotage future successors as well. This expectation reduces the board's incentive to hire a new successor, which in turn diminishes the successor's expected ability beyond the direct impact of the CEO's sabotage, leading to even greater CEO entrenchment. Second, the board modifies its promotion policy by replacing the CEO with the successor more quickly. This accelerated promotion occurs because the option value of delaying succession is reduced when the CEO actively undermines the successor. In this way, the CEO's attempt to entrench themselves can backfire, as the board anticipates these actions and optimally adjusts its strategy in response. Thus, we demonstrate that while the CEO's sabotage leads to managerial entrenchment, the board's response can either mitigate this entrenchment (through promotions) or intensify it (through hiring). Overall, we present a novel mechanism through which managerial entrenchment can shape corporate policies.

Our paper contributes to several strands of the literature. First, we add to the theoretical literature on the market for CEOs (e.g., Murphy and Zábojník, 2004; Tsoulouhas et al.,

[2]This situation represents a dynamic game between the CEO and the board (similar to DeMarzo and He, 2021), where the board anticipates the CEO's attempts at sabotaging the successor, and the CEO in turn anticipates the board's hiring and promotion strategies.

2007; Gabaix and Landier, 2008; Terviö, 2008; Eisfeldt and Kuhnen, 2013; Nickerson, 2013; Huang, 2016; Anderson et al., 2018; Chaigneau and Sahuguet, 2018, 2023). Most closely related are the articles of Hermalin (2005) and Waldman and Zábojník (2024) and the work by Celentano and Mello (2023), Hamilton et al. (2023), and He and Schroth (2024). In Hermalin (2005), the board chooses whether to appoint an external or internal CEO with uncertain ability after which it can decide to learn about the CEO's ability and possibly replace her with a new CEO. Waldman and Zábojník (2024) focus on costly learning about external candidates via interviews and firm-specific human capital accumulation. In contrast to these papers, we allow for learning about the successor and study the dynamics of the board's succession policy, which allows us to analyze firms' succession planning and highlights the option-like nature of this process. Celentano and Mello (2023), Hamilton et al. (2023), and He and Schroth (2024) use a structural approach to quantify the cost and benefits of succession planning/hiring insiders versus outsiders. Differently from their approach, we allow the board to select and learn about the successor, thereby microfounding the succession planning process. One of the novel predictions of our model is that less severe frictions in the labor market make external successions less likely, because lower frictions alter firms' hiring dynamics, which increases the likelihood of firms already employing a high-expected-ability successor. As a consequence, high levels of internal succession (e.g., Parrino, 1997; Cziraki and Jenter, 2022) may not necessarily be a sign of inefficiencies in the market for CEOs.[3]

Second, our paper contributes to the literature on managerial entrenchment. Existing models show that managerial entrenchment can be driven by investment, financing, boards of directors, compensation, or reputational concerns (e.g., Shleifer and Vishny, 1989; Zwiebel, 1996; Hermalin and Weisbach, 1998; Almazan and Suarez, 2003; Kuhnen and Zwiebel, 2008;

[3]There also exists a related theoretical literature in labor economics that analyzes external hires versus internal promotions (e.g., Chan, 1996; Chen, 2005; Waldman, 2003; DeVaro and Morita, 2013). In contrast to this literature, we study the dynamics of external hires versus internal promotions and how the existing CEO can sabotage internal promotions thereby becoming more entrenched. See Lazear and Oyer (2007), Waldman (2013), or Oyer and Schaefer (2011) for surveys of the personnel economics literature. Additionally, see Berns and Klarner (2017) for a review of the CEO succession literature in management.

Casamatta and Guembel, 2010). However, in our setup the CEO becomes more entrenched by sabotaging the successor. Most closely related to our work is Shleifer and Vishny (1989), who show that CEOs want to undertake actions that make them more valuable to the firm relative to possible successors, which leads to managerial entrenchment. Our model can be considered the flip side of Shleifer and Vishny (1989), in that in our setting the manager undertakes actions which make it harder for the successor to run the firm and increase the opportunity cost of hiring the successor.[4] We also show that the board optimally responds to the CEO's sabotage by delaying hiring a new successor, which fosters managerial entrenchment and speeds up promoting the successor, causing the CEO to get fired more easily.

The remainder of the paper is structured as follows. Section I presents the baseline model. Section II analyses this baseline model and derives the main results. Section III extends the model to allow for sabotage, which leads to managerial entrenchment. Section IV concludes. Appendix A contains additional model analysis, all proofs are in Appendix B, and Appendix C describes the numerical algorithm used to solve the model.

I Model

In this section, we develop a dynamic model of CEO succession. The model is an infinitely repeated real option problem (e.g., Fischer et al., 1989; Mauer and Ott, 1995; Hugonnier et al., 2015). Time t is continuous. There exists an infinitely-lived firm owned by risk-neutral shareholders who discount cash flows at rate $r > 0$. The firm is run by a board so as to maximize shareholders' equity value. The firm can employ a CEO and a successor. The board can decide to replace the CEO by the successor or by an external candidate. This

[4]There also exists a related theoretical literature in economics that studies sabotage (e.g., Salop and Scheffman, 1983; Lazear, 1989; Chen, 2003, 2005). Unlike this literature, we study the CEO's incentives to sabotage their subordinates (the successor) and the corresponding response by the firm. See Chowdhury and Gürtler (2015) for a survey of the literature on sabotage in contests.

process repeats itself over time, which allows us to study the succession of current and future CEOs within the firm.

A CEO

At time zero, the firm employs a CEO with ability θ^c, which can be either low or high $\theta^c \in \{L, H\}$, where $L = 0$ and $H = 1$. The CEO's ability, which can be interpreted as the fit with the firm, is unknown to the board, whose prior about it being high is $c \in [0, 1]$.[5] The firm's cash flows dX_t are influenced by the CEO's ability θ^c

$$dX_t = (\mu + \theta^c)\, dt + \frac{1}{\phi^c} d\tilde{B}_t^c,$$

where $\mu \geq 0$ measures the cash flows unrelated to the CEO's ability, $\phi^c \geq 0$ is the "speed" of learning about the CEO's ability, and $\tilde{B}_t^c$ is a standard Brownian motion. Higher speed of learning ϕ^c implies that cash flows dX_t are less noisy and therefore more informative about the CEO's ability. Higher cash flow level μ implies that the CEO's ability is relatively less important for the firm's cash flows.[6]

The board updates its beliefs about the CEO's ability by observing the cash flows dX_t. Let $C_t = \mathbb{E}_t[\theta^c]$ be the CEO's expected ability given the information acquired by the board up to time t. The CEO's expected ability C_t can also be interpreted as the probability that the CEO's ability is high, as $L = 0$ and $H = 1$. As in Daley et al. (2024), Bayes' rule implies that the dynamics of the CEO's expected ability are

$$dC_t = \phi^c C_t(1 - C_t)\phi^c(dX_t - (\mu + C_t)\, dt) = \phi^c C_t(1 - C_t) dB_t^c, \tag{1}$$

[5] In the baseline model, only the board undertakes actions and therefore it does not matter what the CEO and successor know. In the extension in Section III, the CEO also undertakes actions.

[6] While compensation plays an important role in generating the right incentives for executives (Edmans et al., 2017b), we do not endogenize the CEO's (or successor's) compensation to keep our model tractable and focus on the board's optimal succession policy (similar to, e.g., Taylor, 2010; He and Schroth, 2024).

where B_t^c is a standard Brownian motion given the information available to the board. From this equation it becomes clear that a higher speed of learning ϕ^c (less noisy cash flows) leads to a faster updating of beliefs. Furthermore, when beliefs are close to either zero or one, they move at a slower pace as Bayes' rule implies that more information is required to change beliefs.

Given the boards beliefs, the CEO's expected ability C_t thus directly impacts the firm's performance (Bertrand and Schoar, 2003; Bandiera et al., 2020) as the cash flows are

$$dX_t = (\mu + C_t)\, dt + \frac{1}{\phi^c} dB_t^c.$$

If the firm does not employ a CEO at time zero, then it generates cash flows $\mu dt + \frac{1}{\phi^c} dB_t^c$, which is equivalent to $c = 0$. This situation can also be interpreted as the firm employing an interim CEO with low ability at no cost.

To keep the model parsimonious, we assume that the firm's *current* cash flows only depend on the CEO's ability and not on that of the successor, which we discuss in more detail below. In Subsection II.C, we discuss an extension of the model in which the firm's cash flows also depend on the successor's ability and when there is (firm-specific) human capital accumulation.

B Successor

The firm can also employ a successor. The successor could, for example, be the firm's current COO or CFO.[7] The successor's ability is captured by θ^s, which can be either low or high $\theta^s \in \{0, 1\}$. The successor's ability is unknown to the board, whose prior about it being high is $s \in [0, 1]$. Over time, the board receives news Y_t about the successor's ability by observing the successor's work (Harris and Holmstrom, 1982; Cornelli et al., 2013). The dynamics of

[7] Larcker and Tayan (2022) report that prior to becoming the CEO, the executive was 33% of the time a president/divisional, 27% of the time a COO, and 9% of the time a CFO.

the news are

$$dY_t = \theta^s dt + \frac{1}{\phi^s} d\tilde{B}_t^s,$$

where $\phi^s \geq 0$ is the "speed" of learning about the successor's ability and $\tilde{B}_t^s$ is a standard Brownian motion, which is independent of $\tilde{B}_t^c$. Consistent with our model, Fee and Hadlock (2004) find that "*firms continually update their assessments of their non-CEO senior executive personnel and regularly remove suboptimal managers*".

As in the case of the CEO, this setup implies that the dynamics of the successor's expected ability given the information acquired by the board up to time t, $S_t = \mathbb{E}_t[\theta^s]$, are

$$dS_t = \phi^s S_t(1 - S_t)\phi^s(dY_t - S_t dt) = \phi^s S_t(1 - S_t) dB_t^s, \tag{2}$$

where B_t^s is a standard Brownian motion, which is independent of B_t^c, given the information available to the board. If the firm does not employ a successor at time zero, then $s = 0$. From now on, all dynamics of the state variables (c, s) and expectations are under the board's beliefs.[8]

C Succession

CEOs can depart for exogenous reasons (e.g., related to death as in Nguyen and Nielsen, 2014; Bennedsen et al., 2020) and endogenous reasons (e.g., due to bad performance as in Jenter and Lewellen, 2021). Thus, we assume that the CEO's contract can be terminated either exogenously, which happens with intensity $\lambda \geq 0$, or endogenously, when the board decides to replace the CEO.

[8] We could allow the dynamics of C_t (Equation 1) and S_t (Equation 2) to be correlated. This would allow us to study how the CEO's and the successor's expected abilities relate. Doing so would not fundamentally alter the underlying economic trade-offs highlighted in the paper. However, solving the full filtering problem in case when the signals dX_t and dY_t are correlated is outside the scope of this paper.

If the board decides to replace the CEO with the successor then the firm incurs a replacement cost $K \geq 0$ as in Taylor (2010). The total cost of replacing a CEO includes direct costs such as deferred compensation or golden parachutes and indirect costs, for example stock price pressure or personnel turnover. Taylor (2010) and Nickerson (2013) provide evidence that such costs significant and amounts to $1.33 - 2.18\%$ of firms' assets. Besides costs that are directly born by the firm, K could also incorporate cost incurred or perceived by the board such as board capture (e.g., Page, 2018). Let τ_R be the time at which the board replaces the CEO with the successor whose expected ability is $S_{\tau_R^-}$ where t^- indicates the left limit of t. As soon as this happens, cash flows dX_t become dependent on the successor's ability, which is high with probability $S_{\tau_R^-}$. The board thus performs due diligence on the successor before replacing the CEO, which can be seen as a *real option* (Daley et al., 2024).

The board can also search for external candidates on the executive labor market to replace either the CEO or the successor. However, conducting the search is costly as it requires incurring a fixed cost $\Phi \geq 0$. In practice, such a cost could materialize for firms when they hire an executive search firm (Khurana, 2000) or when offering sign-on bonuses (Xu and Yang, 2016).

The next time the board searches for an external candidate is at the time τ_E. When engaging in the external search, the board meets an external candidate. The external candidate's ability can be low or high, $\theta^e \in \{0, 1\}$ and is unknown to the board. The expected ability of all external candidates is $e \in [0, 1]$, which is also the probability that the candidate has a high ability. To keep the model tractable, we assume that expected ability of all external candidates is known ex ante. In Subsection II.C, we discuss how our results change in a setting in which the expected ability of external candidates is unknown ex ante and when the board learns about the external candidates' ability.

The board has two options when meeting an external candidate. First, it can decide to replace the CEO with the external candidate and bear the cost K. In this case, the firm's

cash flows become dependent on the external candidate's expected ability e. Second, the board can replace the current successor with the external candidate. Following this change, which involves no additional cost, the news about the successor become dependent on the external candidate's ability. Given that the expected ability of the external candidate e is known, the board has no incentives to incur the search cost and not hire the external candidate at the same time. As the firm can replace the CEO and the successor multiple times, the board's problem corresponds to an infinitely repeated real option.

Remark (Internal versus External Wedge): The cost of hiring a new external CEO is $K + \Phi$ while the cost of promoting a successor is K. Φ can thus also be interpreted as the wedge in hiring/promotion cost between internal and external CEOs.

Figure 1 plots all of the possible management reshuffles in the model. When having a CEO with expected ability C_t and a successor with expected ability S_t, the firm generates cash flows $dX_t = (\mu + C_t)\, dt + \frac{1}{\phi^c} dB_t^c$ and news $dY_t = S_t dt + \frac{1}{\phi^s} dB_t^s$. If the CEO leaves for exogenous reasons (at τ_λ) or endogenous reasons (at τ_R) and the board does not search for an external candidate (at $\tau_\lambda \wedge \tau_R < \tau_E$), then the board has two options:

1. *Promote the successor to become the CEO.* In this case, the firm's bears the fixed cost K and the cash flows become $dX_\tau = (\mu + S_{\tau^-})dt + \frac{1}{\phi^c} dB_\tau^c$, where $\tau = \min\{\tau_\lambda, \tau_R, \tau_E\}$ and there is no news $dY_\tau = 0dt$.

2. *Not appoint any CEO.* In this case, the firm generates cash flows $dX_t = \mu dt + \frac{1}{\phi^c} dB_t^c$ and the news remains $dY_\tau = S_\tau dt + \frac{1}{\phi^s} dB_\tau^s$.

When the board searches for an external candidate (at τ_E), which requires incurring the search cost Φ, there are three possible options:

1. *Replace the current CEO by the external candidate.* In this case, the cash flows become $dX_\tau = (\mu + e)dt + \frac{1}{\phi^c} dB_\tau^c$, the news remain $dY_\tau = S_\tau dt + \frac{1}{\phi^s} dB_\tau^s$, and the firm incurs the replacement cost K.

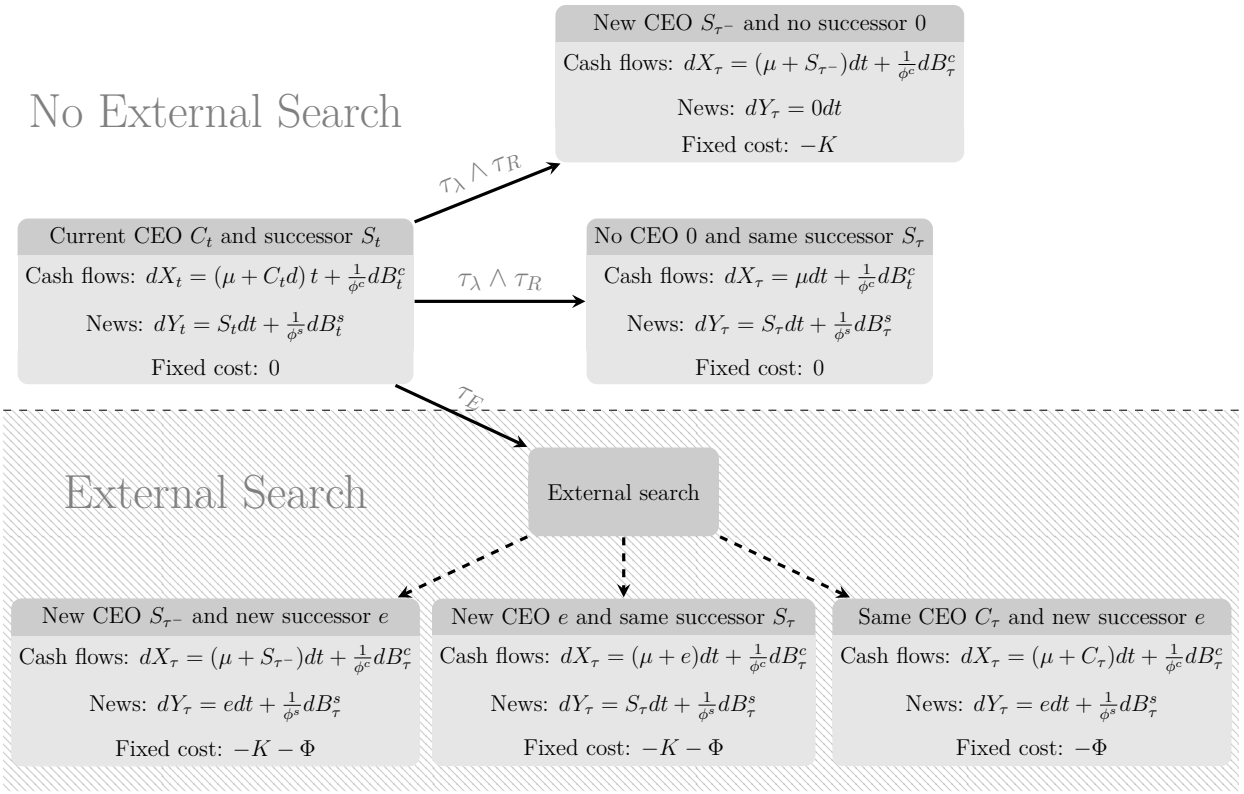

Figure 1: **Management Reshuffles.** The figure describes all possible transition dynamics within the management, including the new cash flows and news that the firm generates given the board's beliefs, and possible fixed costs of hiring and search it incurs. $\tau_\lambda \wedge \tau_R = \min\{\tau_\lambda, \tau_R\}$ and $\tau = \min\{\tau_\lambda, \tau_R, \tau_E\}$.

2. *Replace the CEO by the successor and appoint the external candidate as the new successor.* Under this scenario, the cash flows become $dX_\tau = (\mu + S_{\tau^-})\, dt + \frac{1}{\phi^c}dB^c_\tau$, the news become $dY_\tau = edt + \frac{1}{\phi^s}dB^s_\tau$, and the firm incurs the replacement cost K.

3. *Replaces the successor by the external candidate.* If this happens, the cash flows remain at $dX_\tau = (\mu + C_\tau)\, dt + \frac{1}{\phi^c}dB^c_\tau$ but the successor now has expected ability e instead of S_{τ^-} and therefore the news become $dY_\tau = edt + \frac{1}{\phi^s}dB^s_\tau$.

The board can also replace both the CEO and successor with external candidates at once. This would be equivalent to performing an external search twice, as in Figure 1, with one

search resulting in replacing the CEO and the other search in replacing the successor.

D Equity Value

Our setup implies that the equity value $V(c,s)$ depends on the expected abilities of both the CEO (c) and the successor (s). If at time zero the firm employs no CEO, then $c=0$ and if at time zero the firm employs no successor, then $s=0$. Let $\tau=\min\{\tau_\lambda,\tau_R,\tau_E\}$ be the time when there is a management reshuffle, then the equity value is

$$
\begin{aligned}
V(c,s)=\sup_{\tau_R,\tau_E}\Bigg\{ & \underbrace{\mathbb{E}_{c,s}\left[\int_0^\tau e^{-rt}dX_t\right]}_{\substack{\textit{Cash flows under}\\ \textit{current CEO}}} \\
& +\underbrace{\mathbb{E}_{c,s}\left[\mathbb{I}_{\{\tau<\tau_E\}}e^{-r\tau}\max\{V(S_{\tau^-},0)-K,V(0,S_\tau)\}\right]}_{\textit{CEO leaves but no external search}} \\
& +\underbrace{\mathbb{E}_{c,s}\left[\mathbb{I}_{\{\tau=\tau_E\}}e^{-r\tau}\left(\max\{V(e,S_\tau)-K,V(S_{\tau^-},e)-K,V(C_\tau,e)\}-\Phi\right)\right]}_{\textit{External search}}\Bigg\},
\end{aligned}
\tag{3}
$$

where the operator $\mathbb{E}_{c,s}[\cdot]$ denotes an expectation given the board's beliefs conditional on employing a CEO and a successor with initial expected abilities c and s, respectively. The board selects the CEO replacement strategy τ_R and the external search strategy τ_E to maximize the equity value. The first term in Equation (3) corresponds to cash flows generated by the current CEO, dX_t, up until the time when management changes, τ. The second term reflects what happens when the CEO leaves and the firm has no external candidate, $\tau<\tau_E$. In this case, the board either replaces the CEO by the successor $V(S_{\tau^-},0)-K$ or appoints no new CEO and keeps on employing the successor $V(0,S_\tau)$. The third term captures the effect of searching for an external candidate $\tau=\tau_E$. In that case, the external candidate can either *i*) replace the CEO $V(e,S_\tau)-K$, *ii*) replace the successor and the successor becomes the CEO $V(S_{\tau^-},e)-K$, or *iii*) replace the successor $V(C_\tau,e)$. These three different scenar-

ios are also summarized in the external search part of Figure 1. In Appendix A we study how executives' expected abilities affect the firm's equity value and analyze their departure policies.

From the equity value and the cash flows dX_t it also follows that the firm always generates cash flows μdt, which is independent of the ability of the CEO. As we show in Corollary 1, since these cash flows are unrelated to the CEO's ability, the board does not take them into account when determining the optimal succession policy.

Corollary 1 (Non-CEO Cash Flows μdt and Optimal Policies)**.** *The firm value* $V(c,s)$ *satisfies*

$$V(c,s) = V(c,s|\mu=0) + \frac{\mu}{r},$$

and therefore the board's optimal policies do not depend on the cash flows unrelated to the CEO's ability μ*.*

E Succession Policies and Ability Dynamics

In Figure 2, we illustrate all the different actions taken by the board depending on the state variables (c,s). Specifically, there are five different regions of the state space. In the white region, the board does not undertake any action and the current management continues running the firm. The CEO and successor are of sufficient expected ability and thus the board has no incentive to replace either of them. In the blue region, the successor is promoted and a new successor is appointed. The successor is significantly better than the current CEO and therefore the board decides to replace the CEO with the successor and then fill the vacant successor position with an external candidate. In the light red region, a new external CEO is appointed. The outside candidates dominate both the current CEO and the successor. Therefore, the board replaces the CEO with an external candidate. In the

dark red region, both the CEO and the successor are replaced by external candidates, since the board believes that their expected ability is insufficient. In the gray region, only a new successor gets appointed. The successor is sufficiently worse than the external candidates and therefore is replaced by the board.

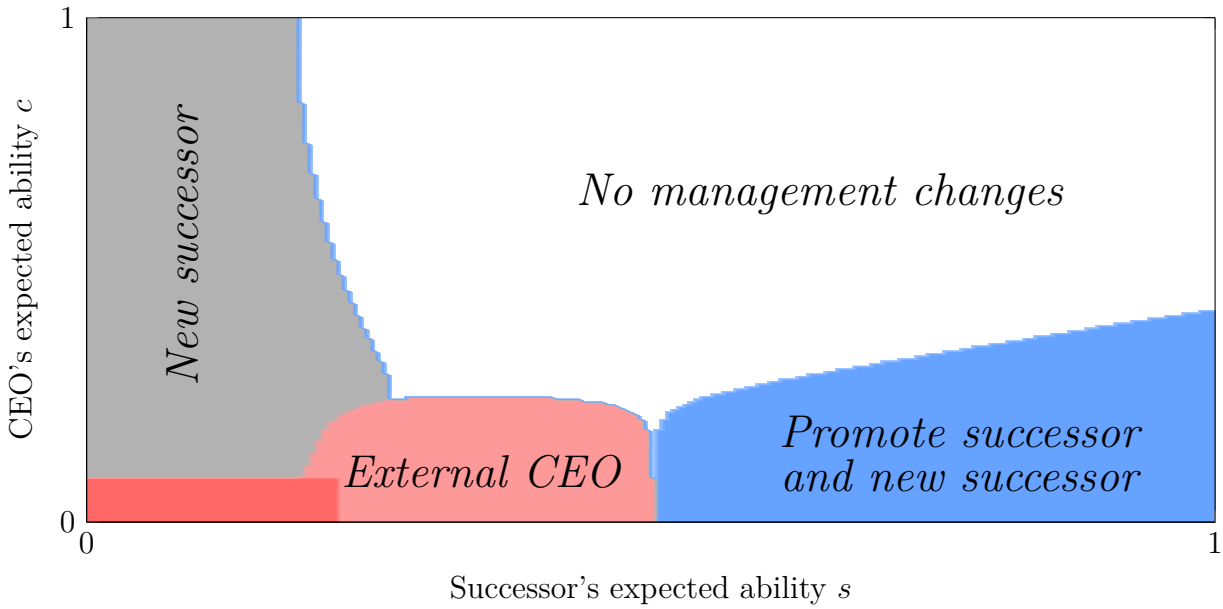

Figure 2: **Optimal Succession Policy**. The figure shows the solution of the model given the parameters $(r, \lambda, \phi^c, \phi^s, K, e, \Phi) = (4\%, 10\%, 0.5, 0.5, 0.4, 0.5, 0.5)$. Appendix C describes the numerical algorithm used to solve the model.

We provide further intuition about the optimal policies by illustrating the dynamics of CEO and successor expected abilities (c, s) in Figure 3, which shows three possible sample paths of the state variables (c, s).

1. (c_1, s_1): The CEO's and successor's expected abilities are (c_1, s_1). The board receives negative news about the successor and positive news about the CEO, which moves the expected abilities to (c_1', s_1'). This makes it optimal for the board to replace the successor since the likelihood of the successor becoming a suitable CEO in the future is too low. As a consequence, (c, s) jumps to (c_1', e).

2. (c_2, s_2): The CEO's and successor's expected abilities are (c_2, s_2). The CEO is of high expected ability, and so is the successor, but then the CEO leaves for exogenous reasons at τ_λ and the expected abilities move to $(0, s_2)$. The board decides to act by promoting the successor and hiring a new successor, and the expected abilities end up at (s_2, e).

3. (c_3, s_3): The CEO's and successor's expected abilities are (c_3, s_3). The board receives negative news about the successor and CEO, which drives down the expected abilities to (c_3', s_3'). At this point, the CEO is no longer sufficiently able and the board replaces the CEO with an external candidate, which moves the expected abilities to (e, s_3').

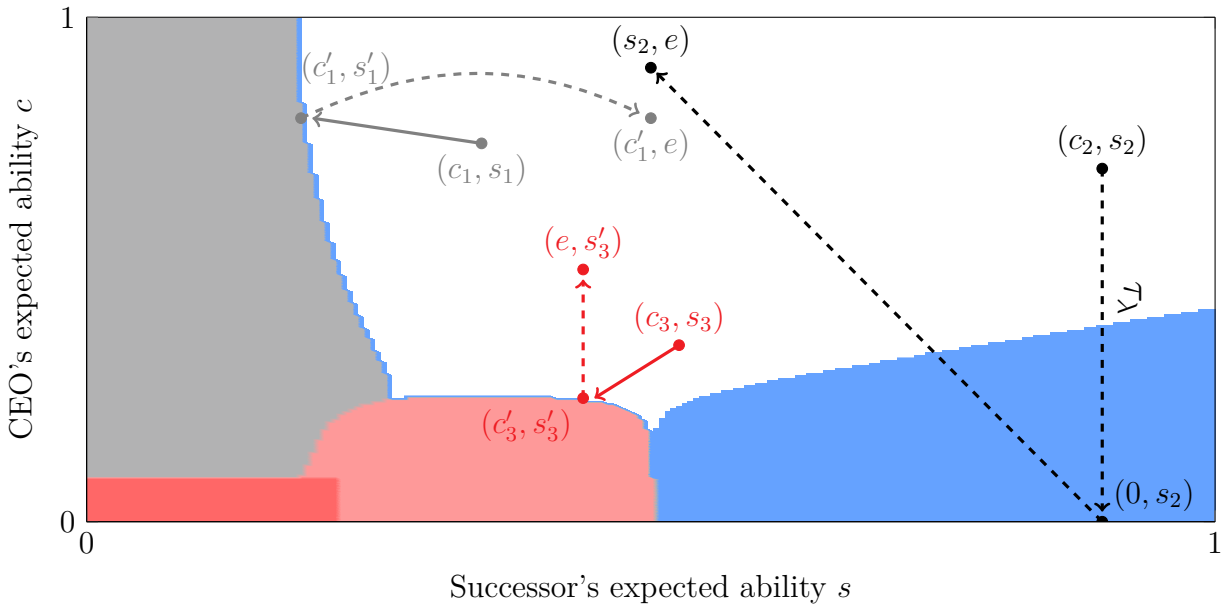

Figure 3: **Different Sample Paths**. The figure shows the solution of the model and state variables (c, s) dynamics given the parameters $(r, \lambda, \phi^c, \phi^s, K, e, \Phi) = (4\%, 10\%, 0.5, 0.5, 0.4, 0.5, 0.5)$. Appendix C describes the numerical algorithm used to solve the model.

II Model Analysis

In this section, we analyse the model's predictions about the firm's succession planning.

A Succession Planning

We first analyze the issue related to the *lack* of succession planning. In our model, firms can be optimally run without a CEO, $V(0, S_\tau)$, or without a successor, $V(S_\tau, 0)$ as shown by Figure 1 and Equation (3). Both succession strategies are optimal since they result from the board's maximizing the equity value. Therefore, having no successor in place and the apparent absence of succession planning—no direct replacement of a departing CEO—may not necessarily indicate that the firm is badly run, as suggested by prior empirical work (Charan, 2005; Fernández-Aráoz et al., 2021).

In particular, our model suggests that there are three reasons why the board might not appoint a new CEO. First, appointing a new CEO is costly to the firm, as the fixed replacement cost is K. Notably, this effect would even be present in a static version of the model. Second, the option value of delaying management reshuffle due to learning about the successor's ability plays an important role as well, as in standard real options models (see e.g., Dixit and Pindyck, 1994). Third, the board might be reluctant to act as hiring a subpar CEO today makes it highly likely that it will be necessary to replace this CEO in the near future, which decreases the benefits of hiring such a CEO today. This effect arises due to the fact that the real option embedded in the CEO hiring decision repeats over time.[9]

In Proposition 1, we show that the replacement cost K of appointing a new CEO plays an important role in delaying management reshuffles. When this cost is too high, the board strategically delays appointing a new CEO. Furthermore, the more able the successor, the higher the cost needs to be to induce the board to forgo appointing a new CEO.

[9]It is possible that hiring a subpar CEO in a static model would be positive NPV, but the firm still would still abstain from hiring a new CEO due to the second and third effect.

Proposition 1 (Delayed Succession)**.** *For any successor of expected ability s, there exists a replacement cost $\bar{K}(s) \leq \frac{\max\{s,e\}}{r+\lambda}$ with $\bar{K}'(s) \geq 0$ such that for $K > \bar{K}(s)$ the board prefers to not directly appoint a new CEO*

$$\max\{V(s,0) - K, V(e,s) - K - \Phi\} < V(0,s).$$

We further illustrate the mechanism in Figure 4, which shows the board's optimal actions when the replacement cost K is high. If the CEO leaves for an exogenous reason and the successor is currently of low expected ability, then the board will not appoint a new CEO until it is sure that the successor's expected ability is high enough, which happens when it reaches the blue region. The board thus optimally delays succession.

These results justify the existence of the empirically documented lack of succession planning in many corporations (Cvijanović et al., 2022; Larcker et al., 2022) and of the long delays in appointing a new CEO (Rivolta, 2018; Gabarro et al., 2022).[10] Moreover, Proposition 1 implies that if smaller firms bear relatively larger CEO replacement costs, then succession planning—a direct replacement of a departing CEO—is value destroying for *smaller* firms while it is value-enhancing for *larger* firms. This result is consistent with the evidence of McConnell and Qi (2022) who show that succession planning disclosure destroys value for smaller firms and increases the value of larger firms, Cvijanović et al. (2022) who find that larger firms are more likely to have a succession plans, and Gabarro et al. (2022) who document that smaller firms are more likely to have protracted successions.

[10] Cvijanović et al. (2022) report that although the prevalence of succession plan disclosures reached 36% in 2010, on average, only 16.4% of firms have ever disclosed their succession plans. Rivolta (2018) finds that when there is a delay in CEO appointment following an unplanned CEO departure then this delay is, on average, 112 days.

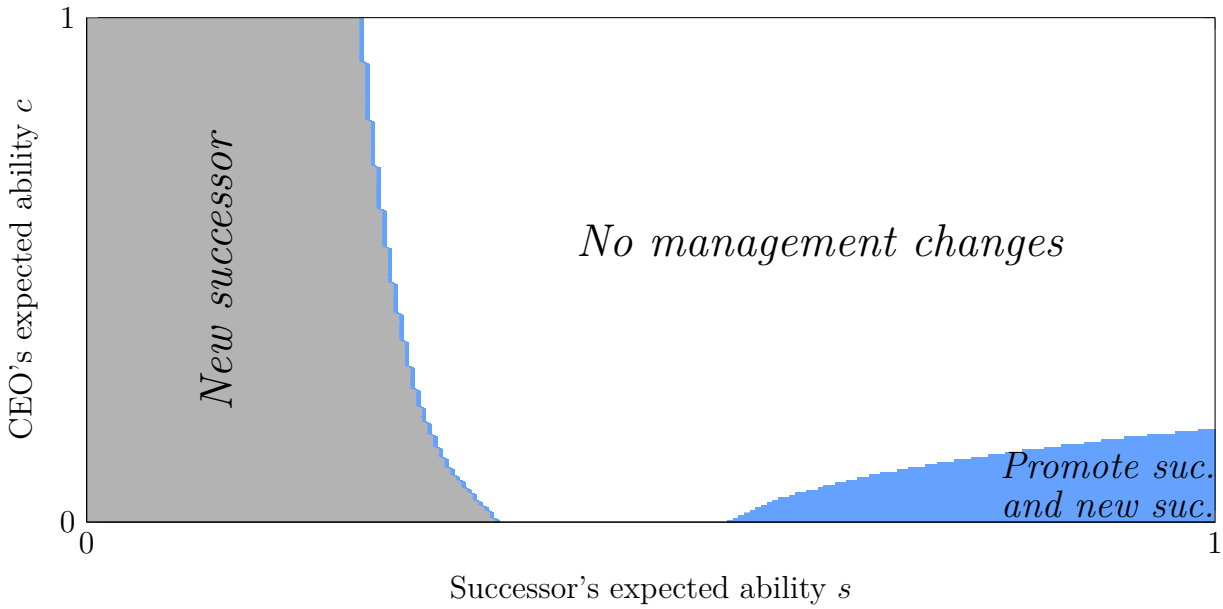

Figure 4: **Delayed Succession**. The figure shows the solution of the model given the parameters $(r, \lambda, \phi^c, \phi^s, K, e, \Phi) = (4\%, 10\%, 0.5, 0.5, 2.5, 0.5, 0.35)$. Appendix C describes the numerical algorithm used to solve the model.

B Who Becomes the New CEO?

We next focus on who becomes the new CEO following a management reshuffle. In particular, we want to understand when an external candidate is more likely to replace the CEO than an internal one. We define an *external succession* as the scenario in which the board appoints an external candidate to directly replace the firm's CEO, $c = e$.[11] If the board promotes an internal successor, then we call this an *internal succession*, $c = s$. We show that the incidence of internal and external successions crucially depends on *learning about the successor's ability* by the board. As we demonstrate in Proposition 2, without this channel ($\phi^s = 0$), and when no current successor is in place ($s = 0$), there is no difference between hiring a new CEO internally or externally in terms of the expected cash flows they would generate as CEO. In this case, to delay incurring the search cost, the board optimally hires external candidates

[11] By this we mean that the external candidate is hired at time t and becomes the CEO at time t.

to directly become the CEO instead of hiring an internal successor early on.

Proposition 2 (No Learning)**.** *Assume that the board does not learn about the successor ($\phi^s = 0$), there are costs of searching for an external candidate ($\Phi > 0$), and there is no current successor ($s = 0$). Then in the future there are only external successions.*

In Figure 5, we illustrate the succession dynamics in this case. Because there is no successor at the firm, the firm remains at $s = 0$. The CEO leaves for exogenous reasons at τ_λ or is fired when the CEO's expected ability drops sufficiently, that is to $\underline{c}(0)$. In either case, the board hires an external candidate to become the new CEO. The figure also indicates that the board never hires a successor and provides an example of the succession dynamics in the model. The firm starts at $(e, 0)$, receives positive news about the CEO and moves to $(c', 0)$, after which the CEO leaves for exogenous reasons and gets replaced, so that the firm ends up again at $(e, 0)$. In this case, there are only external succession, which highlights that learning about the successor gives the board an incentive to promote internal candidates.

On the other hand, when there are no search costs, $\Phi = 0$, and when the board learns about the successor, $\phi^s > 0$, then the firm's successor is almost surely better than any external candidate. When the firm does not have to incur the search cost, a subpar successor $S_t < e$ would be directly replaced at no cost by an external candidate. Consequently, the successor's expected ability S_t is higher than the external candidates' expected ability e, giving the board an incentive to promote the successor. Notably, this result still holds when the cost of appointing a new CEO is zero, $K = 0$.

Proposition 3 (No Search Cost)**.** *Assume that there is learning about the successor ($\phi^s > 0$), there are no costs of searching for an external candidate ($\Phi = 0$), the CEO contributes more to the equity value than the successor ($c_1 \geq c_2 \Rightarrow V(c_1, c_2) \geq V(c_2, c_1)$), and the firm employs a successor of ability $s \geq e$. Then in the future there will only internal successions.*[12]

[12]We assume that if the board is indifferent between appointing the successor or an external candidate to

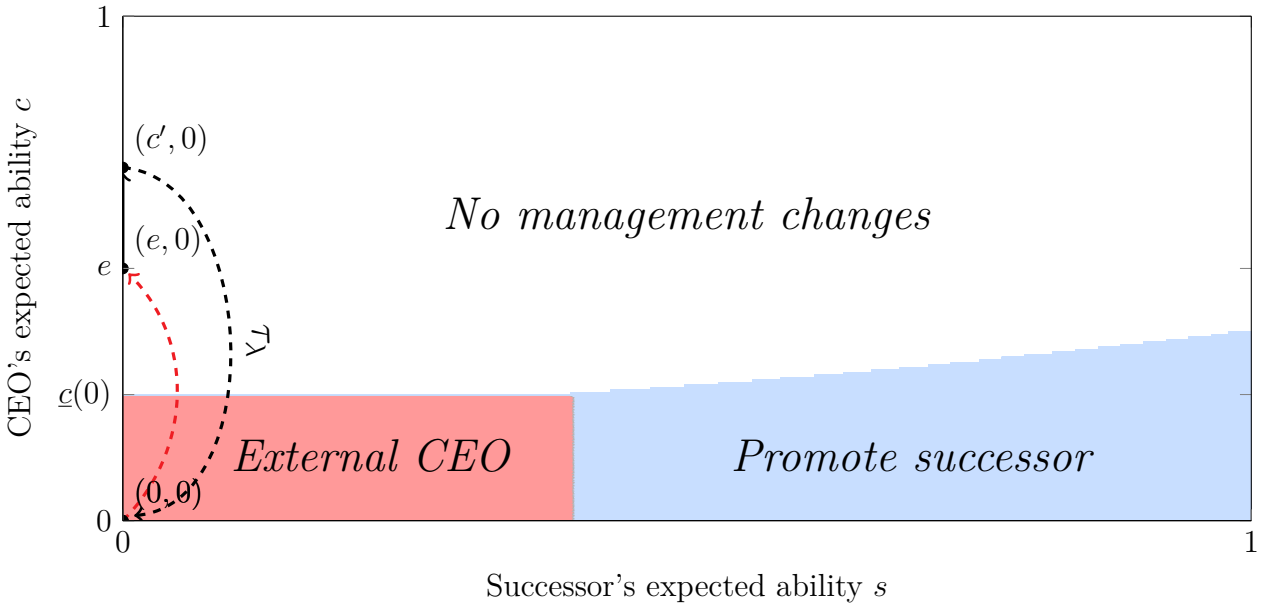

Figure 5: **No Learning Leads to External Successions**. The figure shows the solution of the model given the parameters $(r, \lambda, \phi^c, \phi^s, K, e, \Phi) = (4\%, 10\%, 0.5, 0, 0.4, 0.5, 0.5)$. Appendix C describes the numerical algorithm used to solve the model.

In Figure 6, we illustrate the succession dynamics in this case. The gray area acts as a reflective boundary due to the fact that the board replaces a successor as soon as the successor's expected ability is lower than that of an external candidate, $S_t < e$. Therefore, the board only replaces the CEO if the successor's expected ability ends up in the blue region, in which case the successor is promoted to CEO and a new successor is hired. Consequently, in this case there are only internal successions.

Propositions 2 and 3 together provide the main insight of our analysis. First, we theoretically justify why firms appear to prefer hiring internal successors, as documented by Parrino (1997), Huson et al. (2004) or Cziraki and Jenter (2022).[13] In particular, we argue that the

CEO then it appoints the successor, and if the board is indifferent between hiring a new successor or not, then it hires a new successor. Furthermore, we assume that the timing of information arrival and actions at time t is as follows: *i*) τ_λ arrives or not, *ii*) the board decides who to appoint as CEO, *iii*) news about the CEO and the successor arrives, and *iv*) the board decides who becomes the successor.

[13] Cziraki and Jenter (2022) document that 80% of new CEOs are insiders and the board is familiar with more than 90% of new CEOs.

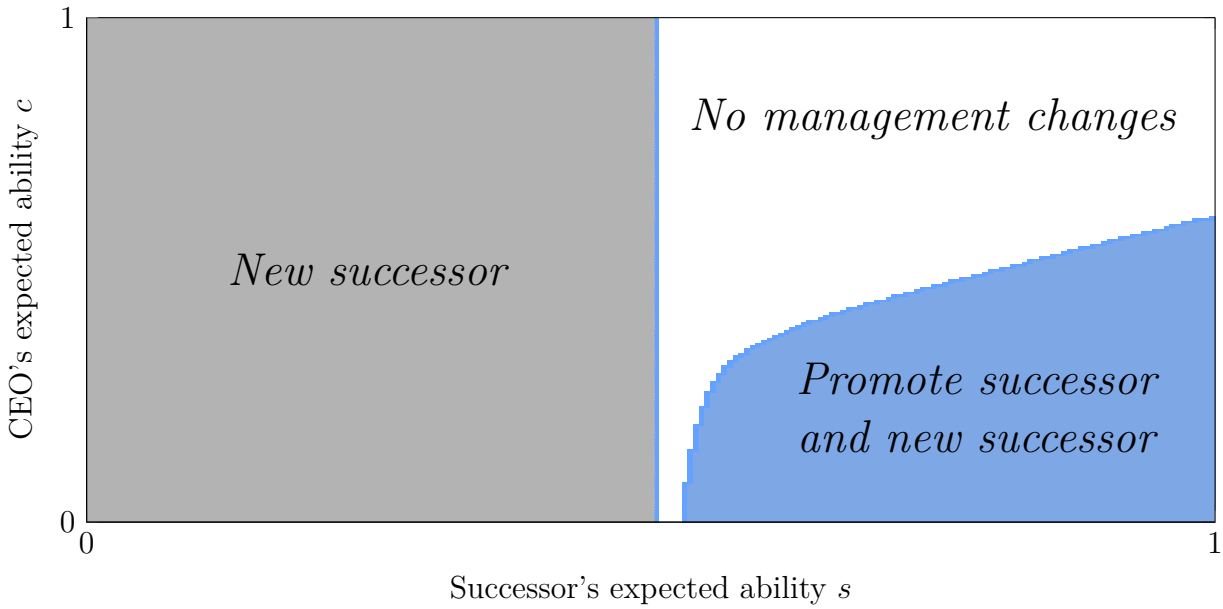

Figure 6: **No Search Cost Leads to Internal Successions**. The figure shows the solution of the model given the parameters $(r, \lambda, \phi^c, \phi^s, K, e, \Phi) = (4\%, 10\%, 0.5, 0.5, 0.4, 0.5, 0)$. Appendix C describes the numerical algorithm used to solve the model.

internal successions are driven by the board learning about the successor, because employing the successor is akin to having a real option. Second, Propositions 2 and 3 demonstrate (in limiting cases) that firms allow for more internal successions when they have to incur lower search costs ($\Phi \downarrow$) or when they learn more about the successor ($\phi^s \uparrow$). [14]

Additionally, our results imply that higher levels of internal successions do not necessarily mean that the market for CEOs is inefficient. In our model, a lower search cost ($\Phi \downarrow$) has two effects. First, it makes hiring external candidates less expensive, so that external succession is more likely. Second, a lower search cost is associated with a less costly replacement of the successor, which results in the firm employing successors of higher expected ability and

[14] Gompers et al. (2023) find that PE-backed have more external successors. One can argue that the difference in succession policies between public firms (Cziraki and Jenter, 2022) and private firms (Gompers et al., 2023) is driven by the fact that PE-backed firms have access to higher ability external candidates ($e \uparrow$), for example due to having a larger network of potential successors. These better external candidates decrease the benefits of having an internal successor as there is less potential upside to learning about the successor's ability. Therefore they are more likely to hire externally.

therefore increases the incidence of internal successions. In Proposition 3, we show that this second effect dominates as the labor market becomes frictionless. Therefore, the large extent of internal successions observed empirically is also consistent with a more efficient labor market instead of other explanations such as agency conflicts or behavioral biases (e.g., Hermalin and Weisbach, 1998; He and Schroth, 2024).

C Robustness and Extensions

We now discuss several extensions of the model and analyze their impact on the results in Proposition 2 and Proposition 3.

Labor Market Equilibrium

Our framework could be embedded into a labor market equilibrium. In this case, the external candidates ability becomes a function of the model and labor market parameters L: $e^*(r, \lambda, \phi^c, \phi^s, K, \Phi, L) \in [0, 1]$. Propositions 2 and 3 hold true even in a labor market equilibrium in which the ability of the external candidates is endogenous $e^*(r, \lambda, \phi^c, \phi^s, K, \Phi, L) \in [0, 1]$. The reason is that both propositions do not depend on a specific value of the expected ability of external candidates e and therefore also hold for $e^*(r, \lambda, \phi^c, \phi^s = 0, K, \Phi > 0)$ in Proposition 2 and for $e^*(r, \lambda, \phi^c, \phi^s > 0, K, \Phi = 0, L)$ in Proposition 3.

Unknown Ability of External Candidates

We could allow for external candidates with different, ex ante unknown, expected abilities. Instead of a constant expected ability e, we could assume that the expected ability of external candidates is independently and identically distributed according to a probability density function $f(\cdot) > 0$ on the domain $[\underline{e}, \bar{e}]$, where $\bar{e} < 1$. Propositions 2 and 3 would still hold true in such a setting. In particular, with no learning about the successor, the firm would still have no incentives to hire a successor leading to only external successions. In the absence of

labor market frictions, the board would repeatedly search for new external candidates until it finds one of the type $\bar{e}$, which would then be hired. The same arguments as before would then imply that the expected ability of the successor is better than the external candidate, $S_t \geq \bar{e}$, leading to only internal successions.

Learning About External Candidates

We could extend our model so that the board learns about the external candidates. The expected ability of external candidates could be time-varying e_t and follow a learning process similar to that of the CEO's and successor's expected ability, see Equation (1) and (2). When the board does not learn about the successor, $\phi^s = 0$, but does learn about the external candidates e_t, then the board might have an incentive to hire an external candidate with a high expected ability e_t as the successor and continue to learn about other external candidates. Doing so is costly, as it requires the firm to pay K today instead of in the future. This successor can then be promoted to CEO. Internal successions could thus also arise when the board learns about external candidates but not about the internal successor. In Proposition 3, the board compares the successor to the best external candidates and replaces the successor as soon as it finds a better external candidate. As a consequence, the successor in place always dominates any external candidate, $S_t \geq e_t$, and there are only internal successions.[15]

Cash Flows Affected by Successor

We also analyze what happens if the successor affects the firm's cash flows, for example, if the firm's cash flows are given by $dX_t + \beta dY_t$ with $\beta \geq 0$. We assume that dX_t and

[15]The key assumption is that hiring on the executive labor market does not affect e_t. If it did, then the firm could have an incentive to delay hiring a successor to keep the current successor and the high ability external candidate and as a consequence $e_t > S_t$. When there is a chance that this external candidate gets poached by another firm then the firm might have incentives to employ two successors.

dY_t are individually observable by the board so as not to complicate the learning problem. Proposition 3 is unaffected by this change as the expected ability of the successor S_t still dominates the expected ability of any external candidate e, $S_t \geq e$, which drives the internal successions. Proposition 2 remains valid as long as β is sufficiently small. A larger β increases the board's incentives to employ a successor since by not doing so the firm has to forgo expected cash flows $\mathbb{E}_t[\beta dY_t] \geq 0$. For low values of β, these forgone cash flows are small relative to the labor market search cost Φ and the board does not hire any successor and therefore all successions are external successions. For high values of β, the forgone cash flows dominate and the firm starts hiring successors, who might be promoted.

Human Capital

We could incorporate the notion of firm-specific human capital accumulation into the model by having low-ability CEOs and successors become high-ability with an exogenous intensity. This would make their expected ability drift upwards over time. Human capital accumulation would incentivize the board to hire a successor in Proposition 2, as it would generate benefits of having a successor and therefore would lead to internal successions. The result in Proposition 3 is not be affected by human capital accumulation, as the expected ability of the successor S_t still dominates the expected ability of any external candidate e, $S_t \geq e$, which drives internal successions.

Strategic Change

Our framework could be extended to include the notion of strategic change, for instance by allowing the firm to be hit by an exogenous shock, which would require the board to change the firm's strategy and thus lower the CEO's and successor's fit with the company—their respective abilities. Such a strategic change would not affect the result in Proposition 2 as it would not generate any benefits to hiring a successor. However, external succession would

become possible in Proposition 3, because a strategic change incentivizes the board to hire executives from the outside. Internal succession would still take place in case no strategic change happens.

Internal and External Labor Market

We can allow the board to search for executives on an internal labor market. That is, the board can look for a new candidate within the organization to become the new CEO or successor. These candidates would have an expected ability e^{int} and come at a cost Φ^{int}. Proposition 3 remains valid in the presence of the internal labor market (assuming $\Phi = \Phi^{int} = 0$), as the successor still dominates any internal or external candidate ($S_t \geq \max\{e, e^{int}\}$). However, internal successions can happen in Proposition 2, because the board could now prefer internal labor market candidates over external labor market ones. This happens, for example, if internal labor market candidates have a higher expected ability ($e^{int} > e$) while also being cheaper to hire ($\Phi^{int} < \Phi$).

III The CEO's Role in the Succession Process

Incumbent CEOs have been shown to play an important role in the succession process (Bower, 2012; Berns and Klarner, 2017). However, when engaging in this process, CEOs may not always have the shareholders' best interest in mind, but rather do so to preserve their influence on the firm by *sabotaging the successor* (Boeker, 1992; Cannella and Shen, 2001; Zhang, 2006). For example, it has been reported that Disney's CEO Bob Iger undermined his hand-picked successor, Bob Chapek.[16] In this section, we extend the baseline model from Section I by allowing the CEO to sabotage the successor appointed by the board (Salop and Scheffman, 1983; Lazear, 1989). By doing so, the CEO makes the successor appear worse off

[16] See "The Palace Coup at the Magic Kingdom" New York Times, 8 September 2024 and "Bob's Your Uncle at Disney", Wall Street Journal, 26 December 2022.

to lower the likelihood of being replaced by the board and thus becomes more entrenched. We show that compensation plays a crucial role in determining the CEO's incentives to sabotage the successor and become entrenched and that the CEO's attempts to become entrenched can sometimes backfire and result in the CEO getting fired.

In the extended model, the CEO can engage in sabotage to aggravate the successor's ability. In practice, the CEO could, for example, not collaborate with the successor or not engage in mentoring, which would effectively make the successor less prepared and thus less capable of running the firm in the future. We assume that: *i*) the CEO cannot sabotage external candidates due to limited direct interactions, *ii*) the CEO has the same information as the board and thus does not know her own ability, *iii*) the level of sabotage f_t is observable by the board, *iv*) the CEO is risk-neutral and discounts cash flows at the rate $r > 0$, and *v*) if the CEO is indifferent between sabotaging or not sabotaging the successor, then the CEO does not sabotage the successor.[17] At each time t, the CEO selects the level of sabotage $f_t \in [0, \bar{f}]$ to maximize compensation, where $f_t = 0$ means that the CEO does not engage in sabotage. Choosing a level of sabotage f_t implies that a high-ability successor becomes a low-ability successor with intensity $f_t dt$. Therefore, this level of sabotage lowers the expected ability of the successor by $-f_t S_t dt$. The dynamics of the successor's expected ability given the CEO's choice of sabotage f_t are

$$dS_t = -f_t S_t dt + \phi^s S_t (1 - S_t) dB_t^s.$$

Crucially, the CEO's incentives to sabotage the successor depend on the CEO's compensation, which consists of two parts: a fixed wage and an equity stake, similar to Nikolov and Whited (2014). The CEO receives a fixed wage α when being in office, which amounts to $\alpha W(c, s)$, where $W(c, s)$ is the present value of receiving a cash flow of one during the CEO's

[17] The last assumption is needed to avoid having to separately treat indifference cases in the results below.

tenure. Consequently, this form of compensation increases with CEO tenure.[18] The CEO is also granted a fraction $\beta \geq 0$ of the firm's equity $\beta V(c,s)$. We assume that the CEO cannot sell its equity stake until it leaves the firm (Edmans et al., 2017a). This implies that the CEO's total expected discounted compensation is

$$\alpha W(c,s) + \beta V(c,s). \tag{4}$$

At any time, the CEO's expected future compensation is also given by Equation (4). We normalize the CEO's outside option to zero.

The present value of receiving a cash flow of one during the CEO's tenure is

$$W(c,s) = \underbrace{\mathbb{E}_{c,s}\left[\int_0^\tau e^{-rt}dt\right]}_{\textit{Fixed wage until change}} + \underbrace{\mathbb{E}_{c,s}\left[\mathbb{I}_{\{\tau=\tau_E\}}e^{-r\tau}\mathbb{I}_{\{V(C_\tau,e)>\max(V(e,S_\tau)-K,V(S_\tau,e)-K)\}}W(C_\tau,e)\right]}_{\textit{Future fixed wage by current CEO}}.$$

The first term represents the fixed wage of one from now until the moment when either the CEO or the successor are replaced. The second term reflects the value of this compensation when only the successor gets replaced at τ.

The board chooses the optimal succession policy by maximizing firm value and the CEO selects the sabotage strategy to maximize compensation. This problem corresponds to a dynamic game between the board and the current (and future) CEOs, because the CEO's optimal sabotage of the successor depends on the firm's succession policy, and vice versa. We study Markov Perfect Equilibria in (c,s) in this game (Maskin and Tirole, 2001). This means that *i*) the optimal sabotage and succession policies are a function of (c,s), *ii*) the CEO's sabotage policy is optimal given the firm's succession policy, and *iii*) the firm's succession

[18] The results presented later would also hold if instead of a fixed wage the CEO receives a utility flow from being the CEO or a fraction of the profits.

policy is optimal given the CEO's sabotage policy.[19]

In equilibrium, the CEO picks the level of sabotage $\{f_t\}_{t\geq 0}$ to maximize the expected discounted compensation. The impact of the CEO's sabotage f_t on the compensation received is

$$-\left(\alpha W_s(c,s)+\beta V_s(c,s)\right) f_t S_t dt. \tag{5}$$

Therefore, the optimal level of sabotage is

$$f_t = \begin{cases} \bar{f} & \frac{\alpha}{\beta} < -\frac{V_s(c,s)}{W_s(c,s)} \\ 0 & \frac{\alpha}{\beta} \geq -\frac{V_s(c,s)}{W_s(c,s)} \end{cases}. \tag{6}$$

From Equation (6) it becomes clear that the CEO's compensation, as summarized by the fraction of the fixed wage over the equity stake $\frac{\alpha}{\beta}$, is an important determinant of the level of sabotage. To this end, in Proposition 4 we show that, when offered only equity-based compensation, the CEO maximizes the firm's equity value and therefore does not sabotage the successor since it negatively impacts the equity value. As a consequence, the CEO does not become entrenched.

Proposition 4 (Equity Compensation and No Sabotage)**.** *When the CEO only receives equity compensation ($\alpha = 0$ and $\beta > 0$). In any equilibrium, the CEO does not sabotage the successor $f_t = 0$ and therefore does not become entrenched.*

On the other hand, when only receiving a fixed wage, the CEO is incentivized to prolong her tenure and, as a consequence, the CEO sabotages any sufficiently-abled successor to prevent getting replaced.

[19] It is important to realize that there is no commitment on the side of the CEO or the board with regards to the future actions (as in DeMarzo and He, 2021).

Proposition 5 (Fixed Wage and Sabotage)**.** *Assume that the CEO only receives a fixed wage ($\alpha > 0$ and $\beta = 0$) and that there is only learning about the successor ($\phi^s > 0$ and $\phi^c = 0$). Given an equilibrium and a CEO and a successor (c, s), this CEO sabotages this successor if and only if $S_t > \hat{s}(C_t|c, s)$.*[20]

The results in Propositions 4 and 5 show that CEO compensation plays a crucial role in determining sabotage and entrenchment in equilibrium. CEOs whose compensation is more equity-based should have less incentives to sabotage their successors and are therefore less entrenched. The same holds true for CEOs facing weaker successors.

How should the board optimally respond to a CEO who sabotages the successor? In Figure 7, we take the baseline parameter values from Figure 2 and assume that the firm is run by a CEO (and future CEOs) who always sabotages the successor(s). Figure 7 shows that the board responds in two distinct ways to the CEO's actions. First, the board alters the hiring policy by delaying replacing the successor (as compared to Figure 2). This happens because the CEO will also sabotage future successors, which results in the board being less likely to hire one today. Such a change in the board's hiring policy negatively impacts the successor's expected ability above and beyond the direct effect of the CEO's sabotage, thereby further increasing managerial entrenchment. Second, the board alters the promotion policy and replaces the CEO sooner. Knowing that the CEO sabotages the successor lowers the option value of delaying succession. In response, the board changes the promotion policy and replaces the CEO with the successor earlier. Trying to become entrenched can thus backfire for the CEO, since the board anticipates her actions and acts accordingly.[21]

[20] The result also holds true if there is learning about the CEO ($\phi^c > 0$) and the following two conditions are satisfied: $W_{cc}(c, s) \geq 0$ and if for any $c \in [0, 1]$ the region in which there are no management reshuffles $\mathcal{R}(c) \in [0, 1]$ is convex with respect to s.

[21] Solving for the full equilibrium is numerically challenging due to the two-dimensional nature of the problem. This is why we only show the board's response in the case when the CEO always sabotages. This figure also shows that it is not always optimal for the CEO to sabotage the successor. In the region just to the right of the red-colored area, sabotage hurts the CEO's compensation because it lowers both the firm's equity value and the CEO's expected tenure.

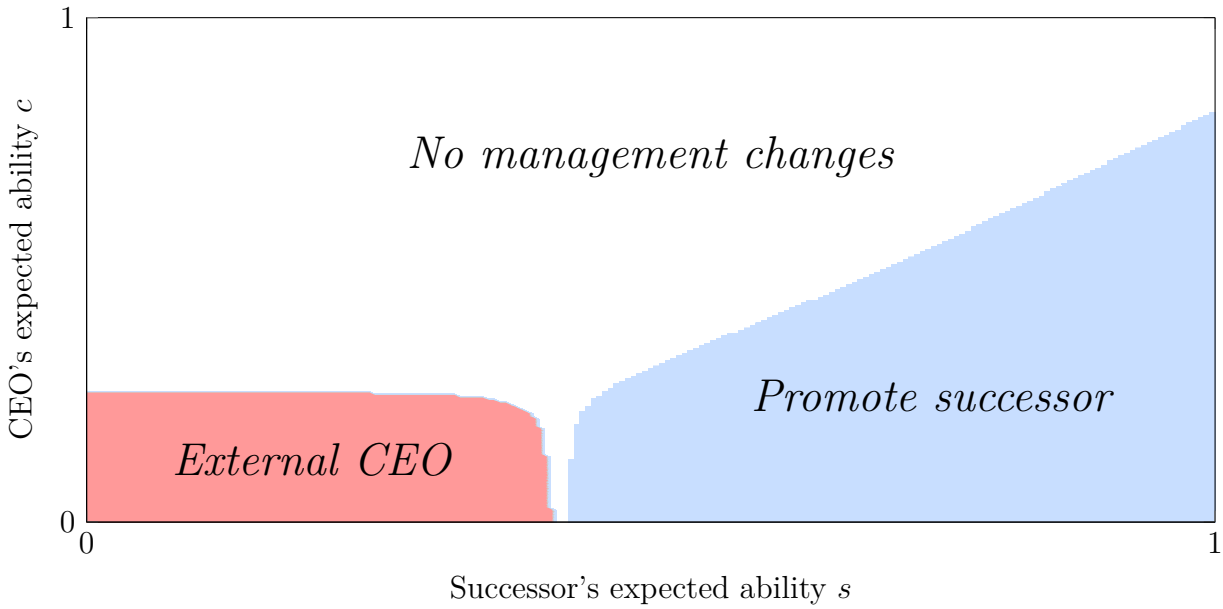

Figure 7: **The Firm's Response to Sabotage**. The figure shows the solution of the model in which the CEO always sabotages the successor given the parameters $(r, \lambda, \phi^c, \phi^s, K, e, \Phi, \bar{f}) = (4\%, 10\%, 0.5, 0.5, 0.4, 0.5, 0.5, 15\%)$. Appendix C describes the numerical algorithm used to solve the model.

A Mentoring

In practice, the CEO can also help foster executive talent within the firm. This mentoring by the CEO is an important part of the succession process and helps the successor develop into a future CEO (Moats and DeNicola, 2021). We could extend our model by allowing the CEO to mentor the successor. The CEO would select a level of mentoring $m_t \in [0, \bar{m}]$ to maximize her payoff and the dynamics of the successor's expected ability given the choice of mentoring m_t would be $dS_t = m_t(1 - S_t)dt + \phi^s S_t(1 - S_t)dB_t^s$.

In a setup with mentoring, we can derive several results. First, we can demonstrate that equity compensation would incentivize the CEO to mentor the successor as it increases the firm's equity value. Second, we can prove that a fixed wage would make it more likely for the CEO to mentor the successor if and only if the successor is sufficiently weak. The reason is

that mentoring a too able successor would increase the likelihood of the CEO being replaced while mentoring a less able successor would decrease the likelihood of this successor being replaced by a more able one. Third, the board would respond to the CEO mentoring the successor by lowering the chances of replacing the successor, which would prolong the CEO's tenure.

IV Conclusion

We develop a dynamic model of CEO succession. In the model, the board learns about the ability of the CEO and successor and can replace the CEO by the successor or search for an external candidate. As a consequence, the presence of a successor within the firm is akin to a real option.

We use our model to rationalize the prevalence of internal CEO successions, the apparent absence of succession planning, and the delays in appointing new CEOs. Our results also demonstrate that more efficient labor markets are associated with a higher incidence of internal successions, which indicates that internal successions may not necessarily be a sign of labor market inefficiencies.

Finally, we study the CEO's role in the succession process and find that the CEO might have an incentive to sabotage her successor. This sabotage fosters managerial entrenchment but can also result in the CEO getting fired. Overall, our analysis highlights the importance of succession planning in shaping corporate decisions and outcomes.

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Appendix

In Appendix A, we provide additional analysis regarding the impact of the CEO and the successor on the firm's equity value as well as analyze their optimal departure policies. In Appendix B, we present all the proofs. Appendix C contains the numerical implementation of the baseline model.

A Model Analysis

I CEO Ability and Equity Value

We first study how the CEO and the successor's expected abilities affect equity value. Proposition 6 shows that the firm's equity value is always higher when having a CEO or a successor with a higher expected ability.

Proposition 6 (Equity Value and CEO and Successor Expected Ability)**.** *The equity value $V(c, s)$ is (weakly) increasing in the CEO's expected ability c and in the successor's expected ability s.*

In our model, more able CEOs and successors allow the firm to generate higher cash flows, which increases the equity value. This result is consistent with existing empirical evidence documenting that CEO ability is positively related to equity value (Bertrand and Schoar, 2003; Bandiera et al., 2020; Bennedsen et al., 2020; Jenter et al., 2021). An additional prediction of our model is that equity value should also increase in the successor's expected ability. In our setup this happens even though successor does not influence today's cash flows, but because the successor's ability can affect them in the future.

II Departures

We next focus on analyzing when executives depart from the firm. We establish that the CEO's departure policy has a threshold form. Proposition 7 shows that if the board wants to replace the CEO due to insufficient ability, then it will also replace any worse CEO.

Proposition 7 (CEO Departures)**.** *There exists a threshold $\underline{c}(s)$ such that the board (weakly) wants the CEO to leave if and only if $c \leq \underline{c}(s)$.*

$$V(c, s) = \max\{V(e, s) - K - \Phi, V(s, 0) - K\} \quad \Leftrightarrow \quad \forall c \leq \underline{c}(s).$$

The successor's departure policy also has a threshold form. Similarly, Proposition 8 shows that if the board wants to replace the successor due to insufficient ability, then it will also replace any worse successor.

Proposition 8 (Successor Departures)**.** *There exists a threshold* $\underline{s}(c)$ *such that the board (weakly) wants the successor to leave if and only if* $s \leq \underline{s}(c)$*.*

$$V(c,s) = V(c,e) - \Phi \quad \Leftrightarrow \quad s \leq \underline{s}(c).$$

Figure A.1 presents these departure thresholds (for the parameter values as in Figure 2) and documents that the two departure thresholds—$\underline{s}(c)$ and $\underline{c}(s)$—effectively split the parameter space. In the upper part, above $\underline{s}(c)$ and $\underline{c}(s)$, the board does not reshuffle the management, while below it the board changes the firm's management either by replacing the CEO or the successor.

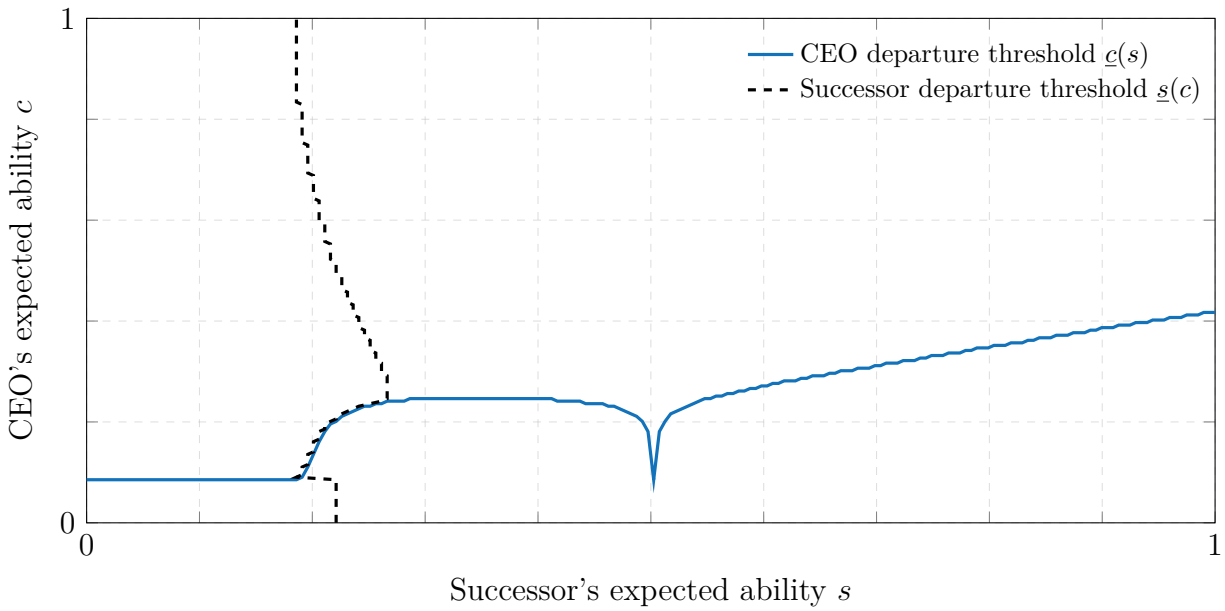

Figure A.1: **CEO and Successor Departure Thresholds**. The figure shows the CEO departure threshold $\underline{c}(s)$ and the successor departure threshold $\underline{s}(c)$ of the model given the parameters $(r, \lambda, \phi^c, \phi^s, K, e, \Phi) = (4\%, 10\%, 0.5, 0.5, 0.4, 0.5, 0.5)$. Appendix C describes the numerical algorithm used to solve the model.

B Proofs

Given the result in Corollary 1, all proofs are carried out for the case $\mu = 0$ without loss of generality, except for the proof of Proposition 5.

Proof of Proposition 6. Given the board's beliefs, we have that $dX_t = C_t dt + \frac{1}{\phi^c} dB_t^c$. Assume that $c' > c$. Given a sample path of $B_t^c(\omega)$, we have that for the current CEO $C_t'(\omega) > C_t(\omega)$.

Let $\tilde{V}(c', s)$ be the equity value when the board acts as if the current CEO only has prior expected ability c instead of c'. Under this policy, the cash flows of $\tilde{V}(c', s)$ and $V(c, s)$ are the same except for the ones generated by the current CEO, which are strictly higher since $C'_t(\omega) > C_t(\omega)$. As a consequence,

$$V(c, s) \leq \tilde{V}(c', s) \leq V(c', s),$$

where the first inequality follows from the fact that all future expected cash flows are weakly larger if the current CEO has expected ability $c' > c$, and the second inequality is due the fact that the board's optimal policies maximize the equity value.

Similar arguments as above imply that when $s' > s$, then $V(c, s) \leq V(c, s')$. □

Proof of Proposition 7. Given s, if the CEO does not depart for any $c \in [0, 1]$, then $\underline{c}(s) < 0$ and we are done. Otherwise, let $\underline{c}(s) \geq 0$ be the largest value of c such that the CEO departs. We know that $V(c, s) \geq \max\{V(e, s) - \Phi - K, V(s, 0) - K\}$ because the board maximizes the equity value.

Assume the result is not true. In this case there would exist a $c < \underline{c}(s)$ such that $V(c, s) > \max\{V(e, s) - \Phi - K, V(s, 0) - K\} = V(\underline{c}(s), s)$, which contradicts the fact that the equity value is weakly increasing in c (Proposition 6).[22] □

Proof of Proposition 8. Given c, if the successor does not depart for any $s \in [0, 1]$, then $\underline{s}(c) < 0$ and we are done. Otherwise, let $\underline{s}(c) \geq 0$ be the largest value of s such that the successor departs. We know that $V(c, s) \geq V(c, e) - \Phi$ because the board maximizes the equity value.

Assume the result is not true. In this case, there would exist an $s < \underline{s}(c)$ such that $V(c, s) > V(c, e) - \Phi = V(c, \underline{s}(c))$, which contradicts the fact that the equity value is weakly increasing in s (Proposition 6). □

Proof of Proposition 1. Let $\tilde{V}(0, s)$ be the equity value when the board acts as if the current CEO is of expected ability c instead of 0. The difference in cash flows between $V(c, s)$ and $\tilde{V}(0, s)$ is

$$\left(C_t dt + \frac{1}{\phi^c} dB_t^c\right) - \left(0 + \frac{1}{\phi^c} dB_t^c\right) = C_t dt \geq 0$$

for as long as the current CEO is employed. Therefore,

$$\frac{c}{r + \lambda} = \mathbb{E}_{c,s}\left[\int_0^{\tau_\lambda} e^{-rt} c dt\right] = \mathbb{E}_{c,s}\left[\int_0^{\tau_\lambda} e^{-rt} C_t dt\right] \geq V(c, s) - \tilde{V}(0, s) \geq V(c, s) - V(0, s). \quad \text{(A.1)}$$

[22] Observe that the board would never strictly prefer to dismiss the CEO without replacement, as the expected cash flows the CEO generates are non-negative $C_t dt \geq 0$.

The second equality follows from the fact that C_t is a martingale. The first inequality results from the difference in cash flows between $V(c,s)$ and $\tilde{V}(0,s)$ and the fact that the current CEO is employed for at most τ_λ. The second inequality is due the fact that the firm's optimal policies maximize the equity value

Assume $K > \tilde{K}(s) = \frac{\max\{e,s\}}{r+\lambda}$. Then, from equation (A.1), Proposition 6, and the fact that $\Phi \geq 0$, it follows that

$$\begin{aligned} V(s,0) - K \leq V(s,s) - K < V(0,s), \\ V(e,s) - K - \Phi \leq V(e,s) - K < V(0,s). \end{aligned}$$

Therefore, the board has no incentive to either promote the current successor or hire an external candidate to become the CEO when $K > \tilde{K}(s)$ and $\tilde{K}'(s) \geq 0$. Thus, it directly follows that the function $\bar{K}(s)$ exists. □

Proof of Proposition 2. We want to show that it is suboptimal for the board to hire a successor given that the firm has no successor today, which guarantees that all successions are external successions.

Given that $\phi_s = 0$, there is no learning about the successor's ability and therefore the successor's expected ability remains at s.

Assume the firm has no current successor $s = 0$ and the current CEO is of expected ability $c \geq 0$. The equity value is $V(c,0)$. Suppose that it is optimal for the board to hire an external candidate today to become the successor. This implies that $V(c,0) = V(c,e) - \Phi$.

Proposition 7 implies that the CEO gets replaced as soon as $C_t \leq \underline{c}(e)$. There are two cases.

1. $c \leq \underline{c}(e)$. In this case, the board (weakly) prefers to replace the CEO and therefore $V(c,e) = \max\{V(e,0) - K, V(e,e) - \Phi - K\}$. There are now two situations.

   (a) $V(c,e) = V(e,0) - K$ and therefore $V(c,0) = V(e,0) - K - \Phi$, which implies that the board directly hires the external candidate to become CEO and therefore does not actually employ a successor.

   (b) $V(c,e) = V(e,e) - \Phi - K$ and therefore $V(c,0) = V(e,e) - 2\Phi - K$, which implies that the board directly hires two external candidates, one to become the CEO and the other to become the successor. Given that the ordering of hiring the external candidates is irrelevant,

   $$V(e,e) - \Phi = V(e,0).$$

   Suppose that $e \leq \underline{c}(e)$, then it would be (weakly) optimal for the board to replace the CEO

   $$V(e,e) = \max\{V(e,0) - K, V(e,e) - K - \Phi\} = V(e,e) - K - \Phi,$$

which cannot be true as $K \geq 0$ and $\Phi > 0$. Therefore, $e > \underline{c}(e)$.
Let $\tau_C = \inf\{t > 0 | C_t \leq \underline{c}(e)\}$ be the time at which the CEO gets replaced for endogenous reasons. The CEO can also leave for exogenous reasons at τ_λ. After the CEO departs (at either τ_C or τ_λ), but before any other actions are taken, the equity value is $V(0, e)$. The following inequalities then hold true

$$\begin{aligned} V(e,0) &= V(e,e) - \Phi \\ &= \mathbb{E}_{e,e}\left[\int_0^{\min\{\tau_C,\tau_\lambda\}} e^{-rt} dX_t + e^{-r\min\{\tau_C,\tau_\lambda\}} V(0,e)\right] - \Phi \\ &< \mathbb{E}_{e,e}\left[\int_0^{\min\{\tau_C,\tau_\lambda\}} e^{-rt} dX_t + e^{-r\min\{\tau_C,\tau_\lambda\}} (V(0,e) - \Phi)\right]. \end{aligned}$$

The first equality follows from the fact that hiring a successor today is optimal and the second equality results from the expected cash flows the firm receives until $\min\{\tau_C, \tau_\lambda\}$. The inequality is due to the fact that $\Phi > 0$, $r > 0$, and $\min\{\tau_C, \tau_\lambda\} > 0$. But this inequality implies that delaying hiring the successor until $\min\{\tau_C, \tau_\lambda\}$ increases the equity value, which contradicts the optimality of hiring a successor today.

2. $c > \underline{c}(e)$. Let $\tau_C = \inf\{t > 0 | C_t \leq \underline{c}(e)\}$ be the time at which the CEO gets replaced for endogenous reasons. The CEO can also leave for exogenous reasons at τ_λ. After the CEO departs (at either τ_C or τ_λ), but before any other actions are taken, the equity value is $V(0, e)$. The following inequalities then hold true

$$\begin{aligned} V(c,0) &= V(c,e) - \Phi \\ &= \mathbb{E}_{c,e}\left[\int_0^{\min\{\tau_C,\tau_\lambda\}} e^{-rt} dX_t + e^{-r\min\{\tau_C,\tau_\lambda\}} V(0,e)\right] - \Phi \\ &< \mathbb{E}_{c,e}\left[\int_0^{\min\{\tau_C,\tau_\lambda\}} e^{-rt} dX_t + e^{-r\min\{\tau_C,\tau_\lambda\}} (V(0,e) - \Phi)\right]. \end{aligned}$$

The first equality follows from the fact that hiring a successor today is optimal and the second equality follows from the expected cash flows the firm receives until $\min\{\tau_C, \tau_\lambda\}$. The inequality is due to from the fact that $\Phi > 0$, $r > 0$, and $\min\{\tau_C, \tau_\lambda\} > 0$. But this inequality implies that delaying hiring the successor until $\min\{\tau_C, \tau_\lambda\}$ increases the equity value, which contradicts the optimality of hiring a successor today.

The board will thus optimally never hire (and therefore promote) a successor and as a consequence all successions are external. □

Proof of Proposition 3. See footnote 12 for additional assumptions. From Proposition 6 it follows that $V_s(c, s) \geq 0$. As a consequence, for any $s \leq e$, $V(c, s) - \Phi = V(c, s) \leq V(c, e)$

and therefore the board replaces the successor as soon as $s \leq e$. As a result, the successor is of expected ability $s \geq e$.

For $s > e$, if it is ever (strictly) optimal to hire an external successor, then it must be that $V(s,e) < V(e,s)$, but since $s > e$ and $c_1 \geq c_2 \Rightarrow V(c_1,c_2) \geq V(c_2,c_1)$, then it cannot be true. Therefore, there are only internal successions for $s > e$.

At $s = e$, the board replaces the CEO with the successor who is of type $s = e$ as no news has arrived yet about the successor before the CEO replacement decision is made, see the assumption about timing at each time t in footnote 12. Therefore, at $s = e$ only internal successions take place. □

Proof of Proposition 4. Given a Markovian sabotaging strategy $f(c,s)$ and $c' = c$, if $s' > s$ for any sample path $(B_t^c(\omega), B_t^s(\omega))$, then for the current successors s' and s it holds that $S'_t(\omega) \geq S_t(\omega)$.[23] If the successors s' and s are promoted at the same time, then this result implies that $C'_t(\omega) \geq C_t(\omega)$ when they are CEOs.

Let $\tilde{V}(c,s')$ be the equity value assuming that the board acts as if the current successor is of expected ability s instead of s'. In that case

$$V(c,s) \leq \tilde{V}(c,s') \leq V(c,s').$$

The first inequality follows from the fact that the cash flows are at least as large for $\tilde{V}(c,s')$ as for $V(c,s)$, given that when the current successors s' and s become CEOs (at the same time), then $C'_t(\omega) \geq C_t(\omega)$. The second inequality is due the fact that $V(c,s)$ maximizes the equity value. Therefore, $V_s(c,s) \geq 0$.

The CEO's compensation is $\beta V(c,s)$. The impact of the CEO's sabotage at time t on compensation is

$$\max_{f_t \in [0,\bar{f}]} -f_t \beta V_s(c,S_t) S_t dt \leq 0,$$

which is maximized when $f_t = 0$ as $\beta > 0$ and $V_s(c,s) \geq 0$. Thus, the CEO does not sabotage the successor and therefore does not become entrenched. □

Proof of Proposition 5. We know that

$$W(c,s) \leq \mathbb{E}_{c,s}\left[\int_0^{\tau_\lambda} e^{-rt} dt\right] = \frac{1}{r+\lambda}.$$

Given that the sample paths of S_t and C_t are continuous as long as the current CEO and successor are in place, in any equilibrium there exists a region $\mathcal{R} \subseteq [0,1]^2$ in which

[23] The sample paths of $(C'_{\tilde{t}}(\omega), S'_{\tilde{t}}((\omega))$ and $(C_{\tilde{t}}((\omega), S_{\tilde{t}}((\omega))$ are continuous. Observe that $C'_t(\omega) = C_t(\omega)$ for any t. If for some t $S'_t(\omega) = S_t(\omega)$, then for any $\tilde{t} > t$ $(C'_{\tilde{t}}(\omega), S'_{\tilde{t}}((\omega)) = (C_{\tilde{t}}((\omega), S_{\tilde{t}}((\omega))$, as the sabotage and shocks they face are the same. Therefore, $S'_t(\omega) \geq S_t(\omega)$.

the firm remains until either the CEO or successor are replaced. Therefore, we can restrict our attention to $\mathcal{R}$. Furthermore, we assume that for a given c this region is convex. This assumption is satisfied when $\phi^c = 0$, as the firm learns about the current successor until the successor's ability hits an upper or a lower bound at which a management reshuffle takes place.

For $(c, s) \in \mathcal{R}$, we know that $W(c, s)$ solves the differential equation

$$(r+\lambda)W(c,s) = 1+\max_{f\in[0,\bar{f}]}\{-fsW_s(c,s)\}+\frac{1}{2}\left(\phi^c\right)^2 c^2(1-c)^2W_{cc}(c,s)+\frac{1}{2}\left(\phi^s\right)^2 s^2(1-s)^2W_{ss}(c,s),$$

where the maximum operator follows from Equation (5) and the fact that $\alpha > 0$ and $\beta = 0$.

Since $W(c, s) \leq \frac{1}{r+\lambda}$, $\phi^s > 0$, and $\left(\phi^c\right)^2 W_{cc}(c, s) \geq 0$, we have that for $s \in (0, 1)$

$$\begin{aligned}
1 &\geq (r+\lambda)W(c,s) \\
&= 1 + \max_{f\in[0,\bar{f}]}\{-fsW_s(c,s)\} + \frac{1}{2}\left(\phi^c\right)^2 c^2(1-c)^2W_{cc}(c,s) + \frac{1}{2}\left(\phi^s\right)^2 s^2(1-s)^2W_{ss}(c,s) \\
&\geq 1 + \frac{1}{2}\left(\phi^s\right)^2 s^2(1-s)^2W_{ss}(c,s), \\
0 &\geq W_{ss}(c,s).
\end{aligned}$$

As a consequence, $W(c, s)$ is concave in s for $(c, s) \in \mathcal{R}$ and therefore $W_s(c, s)$ can cross zero at most once from above. Therefore, a threshold sabotaging strategy $\hat{s}(C_t|c, s)$, in which this CEO sabotages this successor if and only if $S_t \geq \hat{s}(C_t|c, s)$, maximizes the CEO's compensation. □

C Numerical Procedure

This appendix describes the numerical procedure used to calculate the equity value function for the baseline model (Section I).

The equity value function $V(c,s)$ satisfies the following Hamilton-Jacobi-Bellman (HJB) equation

$$\begin{aligned}0 = \max\Bigg\{ & -(r+\lambda)V(c,s) + c + \lambda V(0,s) + \frac{1}{2}(\phi^c)^2 c^2(1-c)^2\frac{\partial^2 V(c,s)}{\partial^2 c} \\ & + \frac{1}{2}(\phi^s)^2 s^2(1-s)^2\frac{\partial^2 V(c,s)}{\partial^2 s}, V(s,0) - K - V(c,s), \\ & V(s,e) - K - \Phi - V(c,s), V(c,e) - \Phi - V(c,s), \\ & V(e,s) - K - \Phi - V(c,s), V(e,e) - K - 2\Phi - V(c,s)\Bigg\}.\end{aligned}$$

We try to find a solution for this HJB equation iteratively.

We first discretize the state space $(s,c) \in [0,1]^2$. We use n equally-spaced discrete points along each dimension so our discretized state space has n^2 points: $\{s_1, ..., s_n\}$ and $\{c_1, ..., c_n\}$ with $s_1 = c_1 = 0$ and $s_n = c_n = 1$.

Start with an initial guess $V_0(c,s)$. Given $V_t(c,s)$, we then want to determine the next iteration $V_{t+\Delta_t}(c,s)$. If we keep on iterating then $\lim_{t\to\infty} V_t(c,s)$ should solve the HJB equation.

First, we loop over $c \in \{c_1, ..., c_n\}$. For each c, we solve the differential equation that is part of the HJB equation treating the term containing the second-order derivative with respect to c as given. More precisely, we use a finite difference scheme that is implicit in the s-dimension and explicit in the c-dimension with a false transient (an artificial time-derivative) (Hansen et al., 2018; Kaplan et al., 2020). Our updating equation looks as follows

$$\begin{aligned}V_{t+\Delta_t}(c,s) \approx V_t(c,s) + \Delta_t\Bigg\{ & -(r+\lambda)V_{t+\Delta_t}(c,s) + c + \lambda V_t(0,s) \\ & + \frac{1}{2}(\phi^c)^2 c^2(1-c)^2\frac{\partial^2 V_t(c,s)}{\partial^2 c} + \frac{1}{2}(\phi^s)^2 s^2(1-s)^2\frac{\partial^2 V_{t+\Delta_t}(c,s)}{\partial^2 s}\Bigg\},\end{aligned}$$

where Δ_t is set sufficiently small to ensure convergence.

Given the discretized state space, we can write this updating equation as

$$
\begin{aligned}
&A^c V_{t+\Delta_t}(c,:) = B_t^c, \qquad \text{(A.2)}\\
&B_t^c = V_t(c,:) + \Delta_t \left(c + \lambda V_t(0,:) + \frac{1}{2} \left(\phi^c\right)^2 c^2 (1-c)^2 \frac{\partial^2 V_t(c,:)}{\partial^2 c} \right),\\
&A^c = I\left(1 + \Delta_t \left(r + \lambda\right)\right) - \Delta_t M,\\
&M_{i,i} = -\frac{\left(\phi^s\right)^2 s_i^2 (1-s_i)^2}{\Delta_s^2},\\
&M_{i,i\pm 1} = \frac{\left(\phi^s\right)^2 s_i^2 (1-s_i)^2}{2\Delta_s^2},
\end{aligned}
$$

where I is the identity matrix and $\Delta_s = s_2 - s_1$ is the step size of the grid of s. The other elements of M are zero. We calculate the second-order derivative with respect to c using neighboring grid points

$$
\frac{\partial^2 V_t(c,s)}{\partial^2 c} = \frac{V_t(c_{j-1},s) - 2V_t(c_j,s) + V_t(c_{j+1},s)}{\Delta_c^2},
$$

where $\Delta_c = c_2 - c_1$ is the step size of the grid of c. At the boundaries of the state space, we don't need to calculate the second-order derivatives since $\frac{1}{2}\left(\phi^s\right)^2 s^2 (1-s)^2 = 0$ for $s \in \{0,1\}$ and $\frac{1}{2}\left(\phi^c\right)^2 c^2 (1-c)^2 = 0$ for $c \in \{0,1\}$.[24] Equation (A.2) is a system of n linear equations with n unknowns, which we can solve and has as solution $\hat{V}_{t+\Delta_t}(c,:)$.

Given this solution, we determine for every $s \in \{s_1, ..., s_n\}$ if the firm is better off changing management or delaying this change

$$
\begin{aligned}
V_{t+\Delta_t}(c,s) = \max \Big\{ &\hat{V}_{t+\Delta_t}(c,s), V_t(s,0) - K, V_t(s,e) - K - \Phi,\\
&V_t(c,e) - \Phi, V_t(e,s) - K - \Phi, V_t(e,e) - K - 2\Phi \Big\}.
\end{aligned}
$$

We repeat this procedure for every c after which we set $t = t + \Delta_t$. We keep on repeating this procedure until the average change in the equity value function,

$$
\frac{\sum_{c,s} \left| V_{t+\Delta_t}(c,s) - V_t(c,s) \right|}{n^2},
$$

is sufficiently small. The algorithm is summarized in the figure below.

[24] For the model with sabotage (Section III), we also need to calculate the first-order derivative $\frac{\partial V(c,s)}{\partial s}$. We do this by using backward differences. We don't need to calculate the derivative at the boundary $s = 0$ since $-f(c,s)sdt = 0$.

Algorithm 1: Equity Value Function

`// Initialize`
$V_0(c, s)$
$t = 0$
$error > value\_function\_error\_bound$

`// Loop to update the value function`
while $error > value\_function\_error\_bound$ **do**

`// Loop over CEO's expected ability` c
for $c \in \{c_1, ..., c_n\}$ **do**

`// Determine updating equation`
Calculate M
$A^c = [(1 + \Delta_t (r + \lambda)) I - \Delta_t M]$
$B_t^c = V_t(c, :) + \Delta_t \left(c + \lambda V_t(0, :) + \frac{1}{2} (\phi^c)^2 c^2 (1 - c)^2 \frac{\partial^2 V_t(c,:)}{\partial^2 c} \right)$

`// Solve for` $\hat{V}_{t+\Delta_t}(c, :)$
Solve $A^c \hat{V}_{t+\Delta_t}(c, :) = B_t^c$

`// Loop over successor's expected ability` s
for $s \in \{s_1, ..., s_n\}$ **do**

`// Management change`
$$V_{t+\Delta_t}(c, s) = \max \Big\{ \hat{V}_{t+\Delta_t}(c, s), V_t(s, 0) - K, V_t(s, e) - K - \Phi, V_t(c, e) - \Phi, V_t(e, s) - K - \Phi, V_t(e, e) - K - 2\Phi \Big\}.$$

end
end

`// Update error and time`
$error = \frac{\sum_{c,s} |V_{t+\Delta_t}(c,s) - V_t(c,s)|}{n^2}$
$t = t + \Delta_t$

end

`// Return results`
return $V_t(c, s)$ and $error$