Board Dynamics: A Structural Investigation

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Abstract

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This paper studies how board structure changes with CEO characteristics. I estimate a structural model that endogenizes board structure, CEO firing, and firm performance to mitigate endogeneity concerns. Adopting such an approach allows for the exploration of some within-firm results that are difficult to document using regressions. I find that CEO ability alone explains less than 50% of the variation in board structure, as measured by the standard deviation of board independence. Also, there is a negative relation between board independence and CEO ability. This relation is strong when CEO ability is low, but it is weak on average. These results explain why this relation becomes insignificant in regression models. Additionally, I find that appointing more outsiders only moderately improves the board's monitoring performance. The directors are unwilling to fire some low-ability CEOs because their personal firing cost can be as large as $116 million on average. An outsider-dominated board reduces such a cost by less than 20%. Some low-ability CEOs are therefore able to keep their jobs even when the board comprises mostly of outsiders and board members hold a significant proportion of equity.

1 Introduction

The corporate board has drawn significant attention lately. Questions such as how CEOs affect corporate boards and how board structure affects directors' performance have been widely discussed since the Enron and Worldcom scandal. Despite all the scholarly and political interests, researchers still cannot confidently confirm or reject some of the hypotheses predicted by extant theoretical work.

A standard framework that explains how CEOs affect board structure is provided by Hermalin and Weisbach (1998). In their model, a high-ability CEO has more bargaining power against the board because she can threaten to leave if the board does not yield. The high-ability CEO can therefore bargain for a less independent board and higher wages. Consequently, the model predicts a negative relation between CEO ability and board independence.

Although an important insight, this bargaining hypothesis is difficult to confirm empirically. As pointed out by Adams and Weisbach (2010), the model of Hermalin and Weisbach (1998) predicts that a successful CEO can bargain for a less independent board within her tenure. However, existing empirical work has been more successful in documenting cross-sectional variation in board structure and is largely silent on within-firm results. Researchers consistently obtain statistically insignificant results after including firm or CEO fixed effects in the regression models. There is still no direct empirical evidence that a high-ability CEO can bargain for a less independent board within the same firm on the time series dimension.

There are several possible reasons why such a result is difficult to verify. First, regression coefficients may be biased since board structure is endogenous, as argued by Hermalin and Weisbach (1998) and Demsetz and Lehn (1985). Second, the CEO's true ability and the directors' perception of their CEO's ability are not directly observable. Researchers therefore have to rely on variables such as tenure or historical firm performance to proxy for CEO ability. But it is not clear whether these variables are ideal proxies for CEO ability. Coles, Lemmon and Meschke (2012) and Coles, Lemmon and Wang (2008) show that this causes measurement error and produces spurious results. Because of these econometric concerns, researchers may obtain statistically insignificant results even if there is a relation between CEO ability and board structure. Alternatively, it is possible that board structure and CEO characteristics are minimally correlated. The relation between CEO ability and board structure is too weak to be detected even if the aforementioned econometric concerns are absent.

Understanding the true relation between board structure and CEO ability requires researchers to disentangle the effects of these possibilities. This is a challenging task under the traditional regression framework. Therefore, I depart from regression analysis and propose the usage of a structural approach. The goal of this paper is to examine how board structure changes both cross-sectionally and dynamically with CEO characteristics. Do CEO characteristics affect board structure at all? If so, why do researchers have problem documenting such results? Does the variation in board structure mainly come from CEO ability? Or is board structure actually more sensitive to other CEO characteristics?

To answer these questions, I build a dynamic model that endogenizes board structure, CEO firing, and firm performance. Model parameters are estimated using the Simulated Method of Moment (SMM), which is also adopted by Hennessy and Whited (2005), Hennessy and Whited (2007), and Taylor (2010). I then generate simulated samples and conduct simulation experiments to infer the relation between board structure and CEO characteristics.

The model features a self-nominating board that determines its own structure (the proportion of outsiders on the board) and makes CEO firing decisions every year. A CEO is characterized by two traits: her ability and the strength of her personal ties to the board. When a CEO leaves a firm, the firm hires the next CEO from the outside labor market. The characteristics of this new CEO are determined exogenously. The directors know how personally connected this new CEO is to the board, but they do not know her true ability. They update their beliefs on the CEO's ability every year using the firm's historical earnings. After updating, the directors then use the perceived CEO ability to determine board structure and make CEO firing decision by maximizing the discounted sum of their per-period utility. Similar to Taylor (2010), the main agency problem in my model is the entrenchment problem that directors are unwilling to fire some low-ability CEOs since they would incur a personal utility loss by doing so. This personal firing cost arises due to the directors' personal ties to the CEO.

The model of this paper is closest to Hermalin and Weisbach (1998) and Taylor (2010). My framework differs from Hermalin and Weisbach's in that my model is fully dynamic. Also, factors other than CEO ability are allowed to affect board composition. Additionally, compared to Taylor's work, this paper endogenizes board structure and focuses on how board structure changes over time, while the main goal of Taylor's work is to explain why CEOs are rarely fired.

There are several reasons why a structural model that uses unobservable CEO characteristics as the state variables can help improve our understanding of corporate boards. First, simulated samples that reasonably resemble the real sample can be used to make inferences. The advantage of using the simulated sample is that researchers can directly observe the latent variables and the underlying data generating process. Second, simulation experiments can be conducted in a controlled manner. That is, researchers can change just one variable at a time while keeping other variables constant, and then observe how the endogenous variables change in response. This helps quantify the relative importance of each factor that affects board structure and firm value. Third, the structural approach takes into account the fact that board structure and firm value are both endogenous, thus alleviating the endogeneity concern that often plagues empirical work in corporate governance.

This paper makes several contributions to the literature. First, it evaluates the relative importance of different CEO characteristics in determining board structure. Hermalin and Weisbach (1998) suggests that CEO ability affects board structure. More recently, Fracassi and Tate (2012) show that CEOs' personal ties to the directors also affect board composition and directors' behavior. However, it is unclear how much variation in board structure can be attributed to CEO ability and CEO-board ties. From simulation experiments, I find that the variation in CEO ability alone explains less than 50% of the variation in board structure. Other CEO characteristics, such as CEO-board ties, are also important in determining board structure. Board structure is sensitive to the strength of the CEO-board ties because these ties drive the variation in the directors' personal firing cost. It follows that the strength of the CEO-board ties also affects the board's firing decisions, and exacerbates the entrenchment problem that some low-ability CEOs are not fired. In a dynamic framework, the impact of keeping a low-ability CEO is nontrivial because the firm's operating profits will remain low for several consecutive years. The un-conflicted directors recognize this problem and attempt to mitigate it by adding more outside directors when the overall personal firing cost is high. Board structure is therefore sensitive to CEO-board ties.

Second, this paper explores how board structure changes dynamically with CEO characteristics. I confirm a negative relation between CEO ability and board independence, but this relation is not uniform across firms. It is stronger when CEO ability is low but weak otherwise. To my knowledge, this is the first paper that documents such an asymmetric relation between CEO ability and board independence. When CEO ability is high, board independence is reduced because there is no need to fire this CEO. The board puts more weight on maximizing its overall productivity rather than mitigating entrenchment. Since my estimates show that inside directors are more productive than outsiders, more insiders are appointed when CEO ability is high. However, when CEO ability is low, the un-conflicted directors (whose personal firing cost is low) prefer to fire this low-ability CEO but are stopped by the conflicted directors. To lower the overall cost of firing, these un-conflicted directors push to add more outsiders or replace the conflicted directors. This effect is particularly strong when CEO ability is low because firing the CEO can potentially increase firm value more, and increasing board independence helps expedite the CEO firing process.

Third, I investigate the monitoring effectiveness of the board. Empirical work finds mixed results on the impact of increasing board independence. For example, Hochberg, Sapienza and Vissing-Jørgensen (2009) show that strong governance improves the stock performance of firms with severe agency problems, while Duchin, Matsusaka and Ozbas (2010) find that outside directors add value only when they can acquire firm-specific information easily. My estimation suggests that an outsider-dominated board only moderately improves the board's monitoring performance. This is because adding outsiders to the board does not significantly reduce the board's personal firing cost. Given an average-ability CEO whose tie with the board is relatively strong (one standard deviation above the mean), increasing board independence from 50% to 100% only reduces the directors' personal firing cost by 16% (from \$189 million to \$159 million). The directors' personal firing cost therefore remains quite large even if the board is mostly comprised of outsiders. This finding implies that the so-called independent directors may still have personal connections with their CEOs, causing these directors to be reluctant to fire low-ability CEOs. Increasing the proportion of outsiders only moderately mitigates entrenchment.

Finally, these findings help explain why existing empirical work fail to verify within-firm results between board structure and CEO ability (Boone et al. (2007) and Ryan and Wiggins (2004)), but is more successful in documenting cross-sectional findings (Coles, Daniel and Naveen (2008) and Linck, Netter and Yang (2008)). First, the link between CEO ability and board independence is not very strong to begin with. Board structure does not change much during a CEO's tenure since the directors' belief about CEO ability does not change drastically. Second, the link between CEO ability and board independence is strongest when CEO ability is low. But low-ability CEOs are more likely to be fired and do not stay in the sample for too long. Econometricians therefore lose the opportunity to examine whether board independence increases when a CEO loses power. Third, CEO ability alone explains less than 50% of total variation in board structure. Other CEO characteristics, such as CEO-board ties, play a more crucial role in affecting the directors' firing decisions and the board structure. Yet existing literature does not always control for other causes of entrenchment.

Properly controlling for those variables may help us obtain cleaner empirical results.

The rest of the paper is structured as follows. Section 2 describes the model. Data are introduced in Section 3, while Section 4 discusses the empirical procedure. The main results are introduced in Section 5. Section 6 describes some robustness checks, and Section 7 concludes.

2 Model Setup

I describe the model setup in this section. A firm's profits are assumed to depend on CEO ability (η), board structure (m, the proportion of outside directors on the board), and whether there is a CEO turnover event. Specifically, a firm's profits in year t are given by

$$Y_t\,(\eta, turnover_t) = \eta \times m_t^{\alpha_0} \times (1 - m_t)^{\alpha_1} \times (1 - C)^{turnover_t} \times \epsilon_t, \tag{1}$$

or, equivalently,

$$log\,(Y_t) = log(\eta) + \alpha_0 log(m_t) + \alpha_1 log(1 - m_t) + turnover_t \times log(1 - C) + log(\epsilon_t), \tag{2}$$

where C is the firm's cost of replacing the CEO, $turnover_t$ is a binary variable indicating whether there is a CEO turnover event, and ϵ_t is an unobservable random shock specific to the firm. $log(\epsilon_t)$ is assumed to be normally distributed with mean 0 and variance σ_ϵ^2. A CEO turnover event occurs for two reasons. First, the CEO may retire for exogenous reasons with probability f at the end of each year. Second, she may be fired by the directors. That is, $turnover_t = fire_t + ret_t$, where $fire_t$ and ret_t are dummies indicating whether the incumbent CEO is fired or retired. Parameters α_0 and α_1 are productivity of the outside and inside directors respectively. I allow insiders and outsiders to have different productivity levels because insiders may possess more firm-specific information than outsiders, as suggested by Adams and Ferreira (2007), Harris and Raviv (2008), and Raheja (2005). This assumption highlights the possibility that insider-dominated boards may be optimal for some firms.

CEO ability (η) is exogenously given when a CEO is just hired and is constant throughout the CEO's tenure. I assume that $log(\eta)$ follows a normal distribution with mean η_0 and variance σ_η^2. Directors do not know the true value of η and update their estimate of CEO ability every year. The estimated CEO ability is denoted by $\hat{\eta_t}$. When a new CEO is hired, the directors' prior belief on her ability is normally distributed with mean η and variance σ_η^2. At the beginning of each year, the directors use last year's earnings to update their beliefs on η using the Bayes' rule.

After updating their beliefs, the directors simultaneously determine board structure (m_t) and whether or not to fire the current CEO ($fire_t$) by maximizing the discounted sum of their per-period utility. The per-period utility function of the risk-neutral representative director is assumed to depend on both firm performance and the director's personal cost of firing the CEO. Its expression is:

$$u_t = (\rho + \gamma_t)Y_t - personal_t \times (fire_t + ret_t)\,. \tag{3}$$

The representative director cares about firm performance because of her fiduciary duties or reputation concerns. As a result, she puts a weight of ρ on the firm's profit Y_t. She may also be awarded $\gamma_t Y_t$ as incentive pay, where $\gamma_t \in [0, 1]$ is the proportion of equity that the whole board holds. I include the directors' equity holding into the model because Kumar and Sivaramakrishnan (2008) show that directors' equity holdings interact with board structure in determining directors' performance. In this paper, γ is assumed to be given exogenously and is treated as a state variable since I am mainly interested in board structure rather than the optimal design of the compensation contract for directors. Endogenizing γ makes the model too complicated for structural estimation purposes.

Now I discuss the component $personal_t$ in Equation (3). $personal_t$ represents the director's personal utility loss from firing the incumbent CEO. Directors may be unwilling to fire the CEO because they have private ties to her, they are afraid that firing the CEO will put their own jobs at risk or deter other firms from hiring them, or they simply do not enjoy firing anyone. The existence of such a personal firing cost creates the entrenchment problem that some low-ability CEOs are not fired by the board. I assume that the directors' personal firing cost takes the following functional form:

$$personal_t = (1 + m_t)^{\alpha_2} \times B \times Y_t. \tag{4}$$

This expression is admittedly ad-hoc and requires justification. First, the directors are assumed to feel as if they lose a proportion of the firm's operating profit when the CEO leaves the firm. This assumption is similar to those of Nikolov and Schmid (2012) and Nikolov and Whited (2009). Since the firm's operating profits depend mainly on CEO ability in my setup, this assumption allows CEO ability to affect the directors' personal firing cost. CEO ability may affect the directors' willingness to fire a CEO because firing a good CEO may jeopardize the directors' reputation. Or perhaps defying a high-ability CEO requires the directors to exhort more effort. This costs them time and energy and causes disutility.

Second, I assume that the directors' personal firing cost depends on B, which measures the strength of the personal ties between the directors and the CEO. It is worth pointing out that B may also come from factors other than the CEO-board ties. As mentioned previously, directors may be reluctant to fire their CEOs because they have private connections with the CEO, because they have career concerns, or simply because they do not enjoy firing anyone. I do not attempt to distinguish between these alternative interpretations of B since the main goal of this paper is to evaluate the impact of CEO ability rather than identifying the source of entrenchment. In the text below, I still refer to B as the strength of the CEO-board tie, although B includes the impact of all the factors that (1) affect the directors' personal firing cost and (2) do not covary directly with firm performance.

When a new CEO is hired, B is drawn randomly from the normal distribution with mean B_0 and variance σ_B^2. The randomness of B does not mean that the directors do not know how much it cost them to fire a CEO. Instead, such an assumption captures the possibility that when the directors determine board structure this year, they do not know for sure who the next CEO will be next year should there be a CEO turnover event.

Third, I assume that the directors' personal firing cost depends on board structure m, and α_2 is a parameter measuring the sensitivity of the directors' personal firing cost to board structure. If higher board independence reduces the directors' personal firing cost, α_2 would be negative, and vice versa. The magnitude of α_2 allows me to examine the extent to which board structure mitigates entrenchment.

To ensure that my results are not entirely driven by the functional form of (4), I discuss alternative specifications for the directors' personal firing cost in the robustness check section below.

Should the current CEO retire or be fired, a new CEO is hired from the managerial labor market. A CEO is characterized by two traits: her ability (η) and the strength of her personal ties to the board (B). As mentioned above, $log(\eta)$ follows a normal distribution with mean η_0 and variance σ_η^2, and B is a random draw from a normal distribution with mean B_0 and variance σ_B^2. Both η and B are exogenously given when a new CEO is hired and are constant throughout her tenure. But the directors' knowledge on the true values of η and B differs. Once a new CEO is hired, directors know the true value of B immediately, but they do not observe the true value of η. They update their belief on η every year using historical earnings of the firm.

Next, I write down the expression for the director's per-period expected utility. If the directors decide not to fire the CEO, the current CEO retires with probability f. So the directors' expected per-period utility for not firing the CEO can be written as

$$\begin{aligned} E(u^{keep}) =& \big(1-f\big) \times E(u^{no\,turn}) + f \times E(u^{turn}), \\ & where\ E(u^{no\,turn}) = (\rho+\gamma)E\left[Y\left(\hat{\eta},0\right)\right] \\ & \qquad E(u^{turn}) = (\rho+\gamma)E\left[Y\left(\eta_0,1\right)\right] - B \times (1+m)^{\alpha_2} \times Y\left(\hat{\eta},0\right). \end{aligned} \tag{5}$$

And if the directors decide to fire the CEO, their expected per-period utility is simply $E(u^{turn})$.

Each year, directors make decisions on board structure and CEO firing by maximizing the discounted sum of their per-period utility. The Bellman equation can be written as

$$\begin{aligned} U(\hat{\eta}, \gamma, B, \tau) = \sup_{fire, m} \Bigg\{ & E(u^{keep}) \times (1 - fire) + E\left(u^{fire}\right) \times fire \\ & + \beta \Bigg(\Big\{ \big(1 - f\big) \times E\left[U(\hat{\eta}', \gamma, B, \tau + 1)\right] + f \times E[U(\eta_0, \gamma, B_0, 0)] \Big\} \\ & \times (1 - fire) + E[U(\eta_0, \gamma, B_0, 0)] \times fire \Bigg) \Bigg\}, \end{aligned} \tag{6}$$

where β is the discount factor and the primes represent variables in the next period. I solve this dynamic programming problem using value function iteration. Appendix B contains more details on solving the model numerically.

3 Data

I start building my sample from the RiskMetrics database, which provides information on boards of directors of S&P 1500 firms from 1998 to 2006. For each firm-year observation, I obtain the number of directors, the number of independent directors, and the number of shares held by directors from RiskMetrics. Following the literature, regulated (SIC 4900-4999) and financial (SIC 6000-6999) firms are removed. I then merge the sample with ExecuComp, which provides information on CEO compensation, tenure and turnover. However, ExecuComp does not provide enough information on why CEO turnovers occur. To determine whether a CEO is forced to leave the post, I read through news from Factiva and use the algorithm proposed by Huson, Parrino and Starks (2001). Lastly, I collect financial statement data from Compustat and stock price data from CRSP. Firm-year observations with negative equity, negative assets, or return on assets greater than 100% or less than -100%

Table 1: Data and Variable Definitions

This table summarizes the definitions of the variables used in this paper. The first column lists the names of the variables and their notations in the model. The second column explains how they are computed or derived. The third column lists the data source.

Variable	Variable Definition	Source
Industry-adjusted Operating Profits (Y)	Operating income before depreciation / Total assets - Industry mean	Compustat
Stock Return	Industry-adjusted return	CRSP
Board Independence (m)	Number of independent directors / Number of directors	RiskMetrics
Directors' Equity Holding (γ)	Number of shares held by all directors / Number of shares outstanding	RiskMetrics, Compustat
CEO Tenure (τ)	Current year - Year the CEO is hired	ExecuComp
CEO turnover Dummy ($turn$)	$turn = 1$ in the CEO turnover year and 0 otherwise.	ExecuComp
CEO Firing Dummy ($fire$)	$fire = 1$ if a CEO is fired and 0 otherwise	Hand collected

are excluded from the sample. Firms with stock prices less than $1 are also removed as their financial data are highly volatile, which may bias the SMM estimator. Table 1 summarizes the variables I use and their definitions, and Table 2 gives summary statistics.

The empirical proxy for Y is the industry-adjusted operating profits normalized by total assets. Yearly industry means are then subtracted to remove industry heterogeneity in the data. To allow the model to work smoothly, I rescale this measure such that its smallest value is zero (i.e., it becomes a non-negative variable). Such rescaling does not affect solution behavior or estimation results.

Summary statistics of the main variables are listed in Panel A of Table 2. Since the model suggests that the board self-corrects its structure when facing different CEOs, it is informative to learn from the real data if firms do adjust board structure from time to time. Panel B provides such information. The two rows of Panel B contain the number and the

Table 2: Summary Statistics

The sample consists of 9,573 firm-year observations of S&P 1500 firms from 1998 to 2006. Variable definitions are described in Table 1. Panel A of this table contains summary statistics on the main variables used in this paper. Panel B provides information on the number and the proportion of observations that change their board structures.

Panel A

Variable	Mean	Standard Deviation	First Quartile	Median	Third Quartile
Board Independence	66.06%	16.85%	55.56%	66.67%	80%
ROA (Industry-Adjusted)	6.28%	10.40%	0.05%	4.45%	10.93%
Stock Return (Industry-Adjusted)	8.19%	68.57%	-19.01%	0.76%	23.91%
Directors' Equity Holdings	8.84%	12.56%	1.52%	3.87%	10.60%
Assets (in million)	11,686.34	65,551.00	588.06	1,516.50	5,196.00

Panel B

	Entire Sample (9,573 obs.)			Turnover (880 obs.)			No Turnover (8,693 obs.)		
	Board ind. changes	Board ind. rises	Board ind. drops	Board ind. changes	Board ind. rises	Board ind. drops	Board ind. changes	Board ind. rises	Board ind. drops
Number of Obs.	5,215	3,187	2,028	546	289	257	4,669	2,898	1,771
% of Total Sample	54.48%	33.29%	21.18%	62.04%	32.84%	29.20%	53.71%	33.34%	20.37%

proportion of firm-year observations that change board structure during the sample period. When there is no CEO turnover event, about 50% of firm-year observations change their board structures. And in the year of CEO turnover, this ratio jumps up to 62%. These results provide preliminary evidence that corporate boards do adjust their structures, and such adjustments are more likely to occur when new CEOs are just hired.

4 Empirical Strategy

I use simulated method of moments (SMM) to estimate the structural parameters. This approach involves matching a set of simulated moments to the actual ones. I first simulate data according to the model described in section 2 at a given set of structural parameters. Important moments are then computed using both the actual and the simulated data to obtain empirical and simulated moments. Finally, the optimal parameters are selected by minimizing the distance between the empirical and the simulated moments.

For SMM to identify model parameters successfully, the moments that researchers choose to match should be sensitive to changes in parameter values. Panel A of Table 3 summarizes the moments I choose to fit. The table also contains the empirical and the simulated values of these moments. As in traditional moment-matching exercises, I match the means and variances of interesting variables. But the first two moments do not adequately capture the correlations between variables and the full information contained in the entire data set. Therefore, I also match regression coefficients from several auxiliary models to help identify parameters that measure correlations or sensitivities. Note that the auxiliary models used in this section are not derived from the structural model introduced in Section 2. Use of auxiliary model is common in SMM because they generate interesting moments that help identify structural parameters.

I start the discussion of identification with parameters α_0 (productivity of outside directors), α_1 (productivity of inside directors), and α_2 (the sensitivity of the board's personal firing cost to board independence). The average board independence is mainly determined by these three parameters. But one moment is not enough to pin down three parameters. I need two other moments that are sensitive to changes in α_0, α_1, and α_2. The first such moment is the regression coefficient β_1 from auxiliary model 1 listed in Table 3. β_1 measures the correlation between board structure and operating profits. It is mainly determined by α_0 and α_1. Determining α_2 is trickier, as the directors' personal firing cost is unobservable. But recall that the directors' personal firing cost affects their firing decisions. Thus,

Table 3: A List of Moments and Parameters

Panel A of this table lists the moments being matched for the Simulated Method of Moments (SMM) described in Section 4. The moments are listed in the first column. The second and the third columns contain the empirical and simulated values of these moments. Panel B of the table contains results of the overidentification test.

Auxiliary model 1: $log(Y_{it}) = \beta_1 log(m_{it}) + \beta_2 log(\gamma_{it}) + \beta_3 turnover_{it} + year\ FE + firm\ FE + \epsilon_{1,it}$
Auxiliary model 2:

$$turnover_{it} = \beta_4 \mathbf{1}_{low\,return} + \beta_5 \gamma_{it} + \beta_6 \mathbf{1}_{low\,return} m_{it} + year\ FE + industry\ FE + \epsilon_{2,it},\ where\ \mathbf{1}_{low\,return}\ is\ a\ dummy\ indicating\ returns\ in\ the\ past\ 3\ years\ are\ below\ the\ 1st\ quartile$$

Auxiliary model 3: $\epsilon^j_{1,it} = \alpha^j + \epsilon^j_{3,it}$ for each CEO j (i.e., j regressions in total)

Panel A: Moments from SMM Estimation

Moment	Empirical Value	Simulated Value
Average board independence	0.6606	0.6633
Regression coefficient β_1	-0.0789	-0.0644
Regression coefficient β_6	0.0891	0.1061
Average ROA	1.0493	1.0494
Variance of α^j	0.0023	0.0037
Variance of ROA	0.0108	0.0115
Average firing rate	0.0230	0.0271
Variance of board independence when tenure = 0 and 1	0.0278	0.0315
Variance of board independence when tenure = 2, 3, and 4	0.0266	0.0284
Variance of board independence when tenure > 4	0.0291	0.0273
regression coefficient β_3	-0.0131	-0.0141
ρ is fixed at 1		
β is fixed at 0.9		
f is fixed at 0.0689		

Panel B: Overidentification Test

$\chi^2 = 10.4550$	p-Value = 0.0054

the relation between directors' firing decisions and board independence reveals information on α_2. In particular, the turnover-board structure sensitivity is more informative about α_2 when CEO ability is low and the need to fire the CEO is more urgent. I therefore match the regression coefficient β_6 from auxiliary model 2. Auxiliary model 2 regresses the CEO turnover dummy on board structure interacted with a dummy variable indicating whether the average industry-adjusted stock return of a firm in the past three years is below the first quartile. β_6 measures the sensitivity of the directors' firing decision to board structure when CEO ability is low. It therefore helps determine α_2.

Auxiliary model 1 listed in Table 3 also helps identify the parameter C, the firm's cost of firing the CEO. C is identified by the regression coefficient β_3, which measures the reduction in operating profits when CEO firing occurs.

Next, I discuss how to identify the average CEO ability η_0, its standard deviation σ_η, and the standard deviation of earnings surprise σ_ϵ. Since operating profits depend on CEO ability in the model, I use the average ROA to help identify η_0. As to σ_η and σ_ϵ, I use the residuals from auxiliary model 1 ($\epsilon_{1,it}$). $\epsilon_{1,it}$ contains information on both CEO ability (η) and earnings surprise (ϵ). I first group $\epsilon_{1,it}$ by CEO. For each CEO j, I then compute the mean of $\epsilon_{1,it}$ and call it α^j. α^j should be mainly influenced by η rather than ϵ because it is a time-series average by construction, so the effect of ϵ is averaged out. Thus, the variance of α^j across CEOs helps determine σ_η. I then compute the variance of operating income (Y) to determine σ_ϵ.

The average strength of the CEO-board tie (B_0) determines how often CEO firing occurs. I therefore use the overall probability that CEOs are fired to identify B_0. σ_B (the standard deviation of B) mainly affects the variance of board independence. I compute the variance of board independence during three different periods during a CEO's tenure: when a CEO is just hired ($tenure$= 0 or 1), when the board gradually learns about CEO ability ($tenure$= 2, 3, or 4), and when the CEO has been working for a while ($tenure > 4$). These three moments not only help determine σ_B, but also provide information on the distance between α_2 and α_1

Table 4: Parameter Estimates

This table contains the optimal estimates of parameters from the model in Section 2. The data consists of 9,573 firm-year observations from S&P 1500 firms during 1998 and 2006. Parameters are estimated using Simulated Method of Moments (SMM) described in Section 4. The estimated values are listed in the second row. The third and the fourth row list the standard errors and the z-statistics of the estimated parameters.

Parameter	α_0	α_1	α_2	η_0	σ_η^2	σ_ϵ^2	B_0	σ_B^2	C
Value	0.0006	0.0024	-0.2188	0.0261	0.0010	0.0097	0.1921	0.0139	0.0072
Standard Error	0.0171	0.0072	0.0153	0.0078	0.0085	0.0034	0.292	0.0028	0.0173
z-stat	0.0361	0.3311	-14.2975	3.3671	0.1195	2.8580	6.5731	5.0422	0.4158

(productivity of inside directors). If α_1 is large relative to $|\alpha_2|$, variation in board structure decreases very quickly over time. This is because CEOs who can survive the first several years are more likely to have high ability. Increasing board productivity to increase firm value becomes more important when α_1 is large enough relative to $|\alpha_2|$. Thus, all corporate boards reduce independence after their CEOs survive the first several years. This causes the variance of board structure to drop quickly with tenure. I therefore choose to match variation in board structure during different periods of a CEO's tenure to obtain further information on the magnitudes of α_1 and α_2.

Result of the overidentification test is reported in Panel B of Table 3. This is a formal test of model fit to see if the data support the model. This model is rejected at the 1% significance level. This rejection is not surprising because I am fitting the same stylized model to over 2,000 CEOs. I therefore do not consider this rejection particularly damaging.

Appendix C contains more details on the estimation procedure. The values of the estimated parameters are listed in Table 4. Section 5 below discusses how these parameters affect model solution.

5 Main Results

I solve the model numerically since closed-form solutions are not available. In general, increasing board independence mitigates entrenchment but reduces the overall productivity of the board. The optimal board structure is obtained by balancing these two forces. In the first-best case that CEO firing does not cause any personal utility loss for the directors ($B = 0$), board structure is determined simply by balancing the productivity of the outside directors and insiders. Since the estimates in Table 4 indicate that insiders are more productive ($\alpha_1 > \alpha_0$), the board consists of more insiders to achieve higher overall productivity in an entrenchment-free firm.

But when some of the directors are reluctant to fire the CEO ($B > 0$), the board takes into account the need to mitigate potential entrenchment when determining board structure. In this case, increasing board independence has two opposing effects on the directors' utility. First, it reduces the directors' personal firing cost since Table 4 shows that the estimated value for α_2 is negative. This increases the directors' utility level. Second, it lowers the overall productivity of the board and firm value because inside directors are more productive than outsiders. This in turn lowers the directors' utility level. Since α_2 is much larger in absolute magnitude than α_0 and α_1, increasing board independence reduces the directors' personal firing cost by a larger dollar amount than it hurts board productivity. Therefore, whenever the directors have to choose between mitigating entrenchment and enhancing board productivity, the former is of first priority. This causes board structure to be sensitive to the CEO-board ties (B).

The rest of this section demonstrates model solution behavior by conducting simulation experiments that involve assigning different CEOs to an average firm. Recall that a CEO is characterized by two traits: her ability (η) and her personal ties to the board (B). In each experiment, I keep one of the two traits fixed and allow the other one to vary. Board structure and equity value predicted by the model are then examined.

5.1 The Effect of CEO Ability

This subsection discusses how CEO ability affects board structure. In 5.1.1, I first document that CEO ability does affect board structure, although CEO ability alone fail to generate enough variation in board structure. In 5.1.2 and 5.1.3, I assign CEOs with different abilities to an average firm and examine how board structure and firm value change in response.

5.1.1 Board Structure Variation and CEO Ability

Researchers have been interested in the effect of CEO ability on board structure since Hermalin and Weisbach (1998). But how much variation in board structure comes from CEO ability alone? To answer this question, I conduct counterfactual experiments by setting $\sigma_B^2 = 0$ while keeping all the other parameter values to be the same as those listed in Table 4. By setting $\sigma_B^2 = 0$, the strength of the CEO-board tie is forced to be the same for all CEOs across all firms. Thus, the only variable that can cause board structure to vary is CEO ability. I then generate simulated data (assuming $\sigma_B^2 = 0$) and compute the standard deviation of board independence using the simulated sample. Table 5 summarizes the results.

When σ_B^2 takes its estimated value of 0.0139 (as listed in Table 4), the standard deviation of board independence predicted by the model is 0.1690. This is quite close to its empirical counterpart of 0.1685, indicating that the model does a reasonable job generating variation in board structure. But when I restrict σ_B^2 to be zero, the standard deviation of board independence drops significantly to 0.0806, which is less than 50% of its empirical counterpart. That is, although CEO ability does affect board structure, it alone accounts for less than 50% of the variation in board structure. This is provides one explanation as to why researchers fail to find robust relations between board structure and CEO ability using regression analysis: a significant proportion of variation in board structure comes from factors other than CEO ability.

Now that I have established that CEO ability does cause board structure to vary, the next step is to examine how CEO ability associates with board structure and firm value.

Table 5: Counterfactual Experiment ($\sigma_B^2 = 0$)

This table compares the empirical and the simulated standard deviation of board independence given different parameter values. Board independence is the ratio of the number of outside directors to the total number of directors. The first row lists the standard deviation of board independence calculated from the empirical sample. The second row lists the standard deviation of board independence computed using the simulated sample generated by the the optimal parameters listed in Table 4. In the third row, the simulated sample is generated under the assumption that $\sigma_B^2 = 0$ while other parameters still take the values listed in Table 4.

	σ(board independence)
Empirical	0.1685
$\sigma_B^2 = 0.0139$	0.1690
$\sigma_B^2 = 0$	0.0806

Sections 5.1.2 and 5.1.3 discuss these topics. Figure 1 and Figure 2 demonstrate the results graphically. In both figures, each of the four plots represents a different time point during a CEO's tenure. The horizontal axes for both figures are CEO ability (η). The vertical axis is board independence (m) in Figure 1 and market value of equity scaled by total assets in Figure 2. In each plot, the black solid line represents the case $B = B_0$. The red dotted line and the blue dashed line represent the cases that $B = B_0 + \sigma_B$ and $B = B_0 - \sigma_B$ respectively. Table 6 contains summary information on the simulated data used to produce Figure 1 and 2. The data are generated using parameter values listed in Table 4, with directors' equity holdings fixed at 3.87% (the sample median). I simulate 1,000 CEO spells for each (η, B) pair, record the average board independence and equity value, and then plot them in Figure 1 and Figure 2. The purpose of taking the average is to remove the randomness that results from earnings surprise, CEOs' retirement decision, and the difference in the directors' initial perception of CEO ability.

5.1.2 CEO Ability and Board Structure

This subsection discusses the relation between board independence and CEO ability. Main results are presented in Figure 1 and Table 6. Figure 1 shows that there is a negative relation between CEO ability and board independence. In all the four plots, the black, red, and blue lines all have negative slopes, indicating that such a negative relation holds for any given level of B in any year during a CEO's tenure. Panel A of Table 6 demonstrates the same result numerically. As mentioned before, the model predicts a negative relation between CEO ability and board independence for two reasons. First, increasing board independence lowers the directors personal firing cost. When CEO ability is low, the board hires more outsiders to mitigate possible entrenchment caused by the CEO-board ties. Second, the insiders are more productive than outsiders. When CEO ability is high, more insiders are appointed so as to maximize the board's productivity.

Although Figure 1 and Table 6 illustrate the relation between board independence and CEO ability clearly, they do not provide enough information on how board structure changes dynamically within a CEO's tenure. To fill this gap, Table 7 documents simulation results in a different way. For each CEO characteristics pair $(\eta,\ B)$, the table lists the simulated board independence when this CEO is just hired, when the CEO leaves the job, and also the average board independence over her tenure. This allows researchers to observe how the board adjusts its structure when facing various CEOs. To facilitate comparison, the simulated data used in this table are generated under the assumption that the directors' initial perceived CEO ability is the average value (i.e., $\hat{\eta} = \eta_0$) for all new CEOs. Consistent with the results from Figure 1, Table 7 shows that board independence decreases (increases) as the board learns that the CEO has high (low) ability.

The second important finding from Figure 1 and Table 6 is that the strength of the relation between board structure and CEO ability is asymmetric. It is stronger when the CEO has low ability. As can be seen from Table 7, given a CEO with low ability ($\eta = \eta_0 - \sigma_\eta$) and average CEO-board tie ($B = B_0$), board independence rises from 70% when the CEO is just hired to 77% when she retires. But when CEO ability is relatively high ($\eta = \eta_0 + \sigma_\eta$), board independence drops less significantly from 70% to only 67%.

The relation between CEO ability and board independence is stronger when CEO ability is low because replacing the CEO can potentially increase firm performance more. Firm value is more sensitive to board structure in this case because a board that comprises of

Table 6: Simulated Data Summary (Board Independence and Equity Value)

This table summarizes how board independence and equity value change given CEOs with different characteristics. Simulated data are generated by the model described in Section 2 and parameter values listed in Table 4, with directors' equity holdings fixed at 3.87% (the sample median). I simulate 1,000 CEO spells for each (η, B) pair and record the average outcome in this table.

Panel A: Board Independence

		CEO Ability		
		$\eta_0 - \sigma_\eta$	η_0	$\eta_0 + \sigma_\eta$
Personal Firing Cost Measure	$B_0 - \sigma_B$	67%	53%	48%
	B_0	77%	70%	67%
	$B_0 + \sigma_B$	84%	77%	76%

Panel B: Equity Value

		CEO Ability		
		$\eta_0 - \sigma_\eta$	η_0	$\eta_0 + \sigma_\eta$
Personal Firing Cost Measure	$B_0 - \sigma_B$	0.49	0.57	0.82
	B_0	0.45	0.52	0.81
	$B_0 + \sigma_B$	0.36	0.51	0.81

Table 7: Simulated Data Summary (Board Independence and Equity Value)

This table summarizes how board independence changes given CEOs with different characteristics. Simulated data are generated by the model described in Section 2 and parameter values listed in Table 4, with directors' equity holdings fixed at 3.87% (the sample median). Earnings surprise (ϵ) and the probability that CEOs resign voluntarily (f) are set to be 0. Data are simulated under the extra assumption that the board's initial guess on new CEO's ability is η_0. Each column contains board independence when the CEO is just hired (tenure=1) and when she is retired or fired (tenure=15) as well as the average board independence over her tenure.

		CEO Ability								
		$\eta_0 - \sigma_\eta$			η_0			$\eta_0 + \sigma_\eta$		
	tenure	1	15	average	1	15	average	1	15	average
Personal	$B_0 - \sigma_B$	50%	66%	59%	50%	50%	50%	50%	46%	47%
Firing Cost	B_0	68%	74%	72%	68%	68%	68%	68%	66%	67%
Measure	$B_0 + \sigma_B$	76%	80%	79%	76%	76%	76%	76%	74%	75%

more outsiders is more likely to fire the CEO quickly. Since the directors' utility level also depends on firm performance, it follows that directors' utility is more sensitive to board structure when CEO ability is low. The un-conflicted directors therefore push harder to increase board independence. As to the case that CEO ability is high, board independence does not drop as much because the productivities of insiders and outsiders are both quite small. Their interactions with CEO ability are therefore limited when determining the firm's operating profits. Additionally, the productivity of outside directors is not zero. To utilize the expertise of the outside directors, the board still maintain a certain degree of independence even if their CEO has high ability.

5.1.3 CEO ability And Firm Value

The market value of equity is computed as the discounted sum of operating profits (Y). Since Y is scaled by total assets, the market value of equity is also scaled by total assets. Figure 2 and Panel B of Table 6 show that, in general, there is a positive relation between equity value and CEO ability. This is straightforward because a high ability CEO is able to generate higher operating profits by model construction. The only exception is the V-shaped red dotted line in the left-upper plot of Figure 2. When the board's personal firing cost is high ($B = B_0 + \sigma_B$, as represented by the red dotted line), equity value is slightly higher for firms with the worst CEO compared to firms with relatively bad CEOs. This is because the market believes that the worst CEOs will be fired quickly, so the future earnings of the firm do not depend much on this low-ability CEO. But when CEO ability is only moderately low, the CEO may not be fired because of the board's high personal firing cost. Although this CEO is not the worst, her low-ability has a lasting impact on the firm's future. Firms with relatively bad CEOs therefore have lower market value than firms with the most value-destroying CEOs.

5.2 The Effect of the Directors' Personal Firing Cost

In this subsection, I conduct a different set of experiment. I allow the strength of the CEO-board tie (B) to differ but keep CEO ability (η) constant to isolate the effect of B. Results on board structure and equity value are plotted in Figure 3 and 4 respectively. As in Figure 1 and 2, each plot in Figure 3 and 4 represents a different time point during the CEO's tenure. The black solid line, the red dotted line, and the blue dashed line represent the case of average CEO ability ($\eta = \eta_0$), CEO ability one standard deviation above the mean ($\eta = \eta_0 + \sigma_\eta$), and CEO ability one standard deviation below the mean ($\eta = \eta_0 - \sigma_\eta$) respectively. The vertical axis is board independence (m) for plots in Figure 3 and equity value scaled by assets for plots in Figure 4. The horizontal axis is the strength of the CEO-board tie (B) for both figures. Summary statistics of the simulated data used to generate Figure 3 and 4 are listed in Table 6.

5.2.1 The Directors' Personal Firing Cost and Board Structure

As can be seen from Figure 3, the model predicts a positive relation between B and board independence. More outsiders are appointed to the board when B is large because the directors wish to reduce the overall personal utility loss from CEO firing. But why do the directors self-correct board structure and attempt to reduce their personal firing cost? Recall that firm performance also enters into the directors' utility function. In a dynamic framework, failing to fire a low-ability means that the firm's operating profits will remain low for several consecutive years. The impact of entrenchment is nontrivial. Therefore, entrenchment hurts not only the shareholders, but also the directors. When a new CEO is hired and the directors find out that firing her will cause substantial utility loss, they can mitigate the potential entrenchment problem by either firing this new CEO immediately or changing board structure. Firing this new CEO is not optimal because they are not sure about her ability yet, and CEO firing is costly to the firm too. Therefore, they adjust board structure instead. This explains why board structure is sensitive to the CEO-board tie (B).

Again, the strength of the link between B and board structure is not symmetric. Board independence increases more drastically with B when B is relatively low. Given average CEO ability ($\eta = \eta_0$), Table 6 shows that when $B = B_0 - \sigma_B$, the average board independence over the CEO's tenure is 53%. But if B jumps up to its mean B_0, the average board independence increases significantly to 70% to reflect the directors' concern over potential entrenchment. If B increases further to one standard deviation above the mean ($B_0 + \sigma_B$), the average board independence rises less dramatically to 77%. This asymmetry is obtained because the average CEO-board tie B_0 is already strong enough to prevent the board from firing some bad CEOs. Board independence increases a lot as B rises from $B_0 - \sigma_B$ to B_0 because of this potential entrenchment problem. But when B goes up from B_0 to $B_0 + \sigma_B$, the problem that bad CEOs can keep their jobs does not change substantially. The increase in board independence is therefore less drastic.

5.2.2 The Directors' Personal Firing Cost and Their Firing Decisions

This subsection investigates how the directors' personal firing cost affects their monitoring performance. In the model, directors are considered vigilant monitors if they quickly fire CEOs whose ability is below average. Table 8 provides predictions on the average number of years a CEO with certain characteristics can serve in office.

Table 8 shows that although the directors' personal firing cost makes them reluctant to fire their CEOs, entrenchment is not so severe that even the most value-destroying CEOs can keep their jobs. For example, a CEO with ability three standard deviations below the mean is fired within 4 years even when the CEO-board tie is strong ($B = B_0 + 2\sigma_B$). On the other hand, Table 8 also highlights the problem that some low-ability CEOs are not fired even when the board is dominated by outside directors. For example, when $B \geq B_0 + \sigma_B$ and the CEO has ability one standard deviation below the mean ($\eta = \eta_0 - \sigma_\eta$), Table 6 shows that board independence goes up to 84% in this case. But this low-ability CEO can still serve in office for as long as 10 years on average.

Table 8: Simulated Data Summary(Tenure)

This table summarizes how many years CEOs with different characteristics can keep their job. Simulated data are generated by the model described in Section 2 and parameter values listed in Table 4, with directors' equity holdings fixed at 3.87% (the sample median). I simulate 1,000 CEO spells for each (η, B) pair and record the average outcome in this table.

		CEO ability		
		$\eta_0 - 3\sigma_\eta$	$\eta_0 - 2\sigma_\eta$	$\eta_0 - \sigma_\eta$
Personal Firing Cost Measure	$B_0 - 3\sigma_B$	2	2	2
	$B_0 - 2\sigma_B$	2	2	2
	$B_0 - \sigma_B$	2	2	4
	B_0	2	2	8
	$B_0 + \sigma_B$	2	5	10
	$B_0 + 2\sigma_B$	4	10	10
	$B_0 + 3\sigma_B$	8	10	10

An outsider-dominated board still fails to fire some low-ability CEOs because, according to my estimates, bringing in outsiders reduces the board's personal firing cost only moderately. Table 9 summarizes how the directors' personal firing cost changes with CEO characteristics and board structure. The directors' personal firing cost is computed using equation (4) in Section 2. As can be seen from Table 9, the directors' personal firing cost is decreasing in board independence, but the magnitude of reduction is not large. Consider an average board with 5 outsiders and 3 insiders. When CEO ability (η) and the CEO-board tie (B) are both around the average, increasing the number of outsiders from 5 to 6 lowers the directors' personal firing cost by only \$3 million dollars (from \$117 million to \$114 million). In the more extreme case that board independence increases from 50% to 100%, the board's personal firing cost reduces by only 21% (from \$120 million to \$95 million).

There are several reasons why the impact of bringing in more outside directors is limited. First, it is possible that the CEO's personal ties to the insiders are not the main cause of entrenchment. Since recent governance reforms significantly increased the directors' duties, chances are that even the insiders care more about firm performance than their ties to the CEOs now. Second, Fracassi and Tate (2012) show that a powerful CEO is able to bring in new outside directors who have private ties to her. Thus, the outsiders still have high

Table 9: Directors' Personal Firing Cost

This table summarizes how the directors' personal firing cost changes with CEO characteristics (η, B) and board independence. The directors' personal firing cost is computed using Equation 4 in Section 2 and is expressed in millions of dollars. The table considers the case of an average board with 8 directors. Board independence is defined as the number of outside directors to the total number of directors.

	Board Independence				
	4/8	5/8	6/8	7/8	8/8
$\eta_0 - \sigma_\eta$, $B_0 - \sigma_B$	\$21	\$20	\$19	\$18	\$13
$\eta_0 - \sigma_\eta$, B_0	\$47	\$45	\$44	\$42	\$37
$\eta_0 - \sigma_\eta$, $B_0 + \sigma_B$	\$73	\$71	\$69	\$67	\$62
η_0, $B_0 - \sigma_B$	\$54	\$52	\$49	\$46	\$33
η_0, B_0	\$120	\$117	\$114	\$109	\$95
η_0, $B_0 + \sigma_B$	\$189	\$185	\$180	\$174	\$159
$\eta_0 + \sigma_\eta$, $B_0 - \sigma_B$	\$87	\$84	\$80	\$73	\$54
$\eta_0 + \sigma_\eta$, B_0	\$194	\$189	\$183	\$175	\$154
$\eta_0 + \sigma_\eta$, $B_0 + \sigma_B$	\$305	\$298	\$290	\$281	\$257

personal firing cost and are unwilling to fire the CEO. Third, entrenchment may also arise from the directors' concern that firing CEOs may deter other firms from hiring them in the future. Since outsiders may still have such a concern, their personal cost of firing may not be lower than insiders'.

In short, I find evidence consistent with the view that recent reforms do not change directors' behavior substantially in firms with severe entrenchment. What is more surprising is that even when the board's personal firing cost is just around the average ($B = B_0$), appointing outsiders to the board is still insufficient. Some bad CEOs can still keep their jobs because of the board's high personal firing cost.

5.2.3 The Directors' Personal Firing Cost and Firm Value

Section 5.2.2 shows that some bad, but not the worst, CEOs are not fired because of the board's high personal firing cost. A natural question that follows is how much equity value is destroyed because of such an entrenchment problem. This subsection explores that question.

Figure 4 and Panel B of Table 6 report a negative relation between B and equity value.

But this relation is not obvious when CEO ability is above or around the average ($\eta \geq \eta_0$). This is because when a CEO has high or average ability, the shareholders do not wish to fire her anyway. The directors' personal firing cost therefore does not affect firm performance much.

The influence of B is more obvious when CEO ability is low. Given a CEO with ability one standard deviation below the mean, increasing B from B_0 to $B_0 + \sigma_B$ can reduce equity value from 0.45 to 0.36 (a 20% reduction) on average over a CEO's tenure. The effect of entrenchment is therefore nontrivial. As mentioned previously, this is because the market expects this low-ability CEO to stay in the firm for a long time due to the board's high personal firing cost. The expected operating profits of the firm will remain low for several consecutive years, which drives down equity value considerably. Therefore, the directors' personal firing cost causes agency problem only when CEOs have relatively low ability.

To sum up, results from sections 5.2.1 through 5.2.3 suggest that the effectiveness of governance is not universal across firms. When CEO ability is above average, the board's high personal firing cost does not hurt firm value. When a CEO has really low ability (e.g., $\eta = \eta_0 - 3\sigma_\eta$), she is fired despite the board's personal utility loss from firing. Board monitoring is most important when CEO ability is relatively low ($\eta \in (\eta_0 - 2\sigma_\eta,\ \eta_0)$) and the directors' personal firing cost is not too high ($B \leq B_0$). However, simulation experiments show that within these ranges, some low-ability CEOs are still not fired. Appointing outside directors to the board does mitigate entrenchment but does not completely eliminate the directors' personal utility loss from firing the CEO.

5.3 The Effect of Directors' Equity Holdings

Board structure is not the only element that affects the directors' behavior. For example, Kumar and Sivaramakrishnan (2008) show that board structure and directors' incentive pays interact with each other in determining directors' performances. This section therefore explores how directors' equity holdings affect board structure and their behavior. I focus on the cases that CEO ability is below average since entrenchment hurts firm value more under such a circumstance, and it is useful to examine whether other governance mechanisms help mitigate entrenchment.

Table 10 provides summary information on the simulated data to illustrate how board structure, directors' firing decision, and equity value change with the proportion of equity held by the board. In each panel, each row represents a situation that a CEO with characteristics (η, B) is assigned to a board that holds a certain proportion of equity. Panel A, B, and C contain information on the average board independence, CEO tenure, and average equity value respectively.

As can be seen from Panel A of Table 10, there is a negative relation between board independence and directors' equity holding, suggesting that governance mechanisms are substitutes. But the magnitude of change is of little economic significance. The model predicts a negative relation between board independence and directors' equity holding because directors care more about firm performance when they hold more equity. The agency problem that bad CEOs are not fired is less severe. Board independence therefore does not need to be as high to mitigate entrenchment. More insiders serve on the board to increase the overall productivity of the board.

Next I discuss if the directors' monitoring performance improves as they hold more equity. Panel B of Table 10 contains information on the average number of years that a CEO with certain characteristics serves in office. When CEO ability is low enough ($\eta \leq \eta_0 - 2\sigma_\eta$) , directors fire the CEO as long as their personal firing cost is not too high ($B \leq B_0$). But when $B \geq B_0$, bad CEOs can keep their jobs for as long as 7 years on average. As to the case of less value-destroying CEOs ($\eta = \eta_0 - \sigma_\eta$), increasing directors' equity holding does not seem to speed up CEO firing when B is around its mean value B_0. CEOs can keep their jobs even though board independence rises to as high as 84% and the directors hold as much as 10% of equity. These results echo the previous findings that governance mechanisms are not always effective. The directors' average personal firing cost is so high that awarding more

Table 10: Simulated Data Summary (Directors Equity Holdings Vary)

This table contains summary information on the average board independence (Panel A), CEO tenure (Panel B), and equity value (Panel C) when CEO characteristics (η, B) and directors' equity holdings (γ) change. Simulated data are generated by the model described in Section 2 and parameter values listed in Table 4. I simulate 1,000 CEO spells for each (η, B) pair and record the average outcome in this table.

	Panel A: Board Independence						Panel B: Tenure					
	γ						γ					
	0%	2%	4%	6%	8%	10%	0%	2%	4%	6%	8%	10%
$\eta_0 - 2\sigma_\eta$, $B_0 - \sigma_B$	88%	88%	88%	88%	86%	86%	2	2	2	2	2	2
$\eta_0 - 2\sigma_\eta$, B_0	82%	82%	81%	81%	81%	81%	3	3	3	3	3	3
$\eta_0 - 2\sigma_\eta$, $B_0 + \sigma_B$	90%	90%	90%	90%	90%	90%	8	8	8	7	7	7
$\eta_0 - \sigma_\eta$, $B_0 - \sigma_B$	68%	68%	68%	67%	67%	66%	10	10	10	10	10	9
$\eta_0 - \sigma_\eta$, B_0	78%	77%	77%	77%	76%	76%	11	11	11	11	11	11
$\eta_0 - \sigma_\eta$, $B_0 + \sigma_B$	85%	84%	84%	84%	84%	84%	11	11	11	11	11	11
η_0, $B_0 - \sigma_B$	54%	54%	53%	52%	52%	52%	11	11	11	11	11	11
η_0, B_0	70%	70%	69%	69%	69%	69%	11	11	11	11	11	11
η_0, $B_0 + \sigma_B$	78%	78%	77%	77%	76%	76%	11	11	11	11	11	11

Panel C: Equity Value						
	γ					
	0%	2%	4%	6%	8%	10%
$\eta_0 - 2\sigma_\eta$, $B_0 - \sigma_B$	0.49	0.49	0.51	0.51	0.51	0.51
$\eta_0 - 2\sigma_\eta$, B_0	0.42	0.45	0.46	0.46	0.46	0.46
$\eta_0 - 2\sigma_\eta$, $B_0 + \sigma_B$	0.31	0.34	0.36	0.36	0.36	0.36
$\eta_0 - \sigma_\eta$, $B_0 - \sigma_B$	0.48	0.48	0.49	0.49	0.50	0.50
$\eta_0 - \sigma_\eta$, B_0	0.42	0.44	0.45	0.45	0.45	0.45
$\eta_0 - \sigma_\eta$, $B_0 + \sigma_B$	0.33	0.35	0.36	0.36	0.36	0.36
η_0, $B_0 - \sigma_B$	0.55	0.56	0.56	0.57	0.57	0.57
η_0, B_0	0.52	0.52	0.53	0.53	0.53	0.53
η_0, $B_0 + \sigma_B$	0.50	0.50	0.51	0.51	0.51	0.51

equity to them still does not improve their monitoring performance much.

As to results on equity value, Panel C of Table 10 shows that there is a positive relation between directors' equity holding and equity value. This is because the directors are more likely to fire bad CEOs when they hold more equity.

5.4 Notes on Current Empirical Work

It is worth mentioning that the results in Section 5.1 and 5.2 provide explanations as to why researchers find it difficult to verify any within-firm results between board structure and CEO ability. First, CEO ability does not generate enough variation in board structure. The strength of the CEO-board tie (B) also contributes to differences in board structure. Section 5.1.1 shows that when σ_B is artificially set to be zero, the standard deviation of board structure in the simulated sample is 0.0806, while its empirical counterpart is 0.1685. That is, CEO ability alone explains only about 48% of variation in board structure. A significant portion of variation in board structure comes from differences in the strength of the CEO-board ties.

Second, the directors' perceived CEO ability does not change much within a CEO's tenure. Even though the directors update their beliefs on CEO ability every year and there is a relation between CEO ability and board independence, the directors' perceived CEO ability seldom changes drastic enough to trigger an adjustment in board structure. In the simulated sample, it is often the case that the optimal board structure changes only slightly from, say, 62.5% to 63%. In an average board with 5 outsiders and 3 insiders, the board's natural response is to keep board independence constant at 62.5% rather than hiring 100 directors so as to achieve a board independence of 63%. Thus, the observed board structure does not change every year even though the directors' perceived CEO ability does. This creates a mismatch between the observed board structure and CEO ability. Since researchers observe neither the directors' perceived CEO ability nor the optimal board structure in the directors' minds, it is not surprising that regression analysis fails to capture the association between CEO ability and board independence.

Third, section 5.1.2 shows that the link between CEO ability and board independence is weak on average and strong when CEO ability is low. But low-ability CEOs are more likely to be fired and do not stay in the sample for too long. Researchers therefore miss the opportunity to test whether board independence increases when a CEO loses power. These results explain why it is difficult to document time series properties of board structure using regression analysis.

6 Robustness Check

This section describes some potential concerns that may affect my estimation results. I address each of them by modifying some parts of the model but do not find any significant changes in qualitative predictions of the model.

One of the most important concern is that my results are not robust under different model specifications. In particular, the functional form for the directors' personal firing cost, as specified by Equation (4), is admittedly ad-hoc. Also, both the inside and outside directors of a given board are forced to have the same B. To address such a concern, I allow inside and outside directors to have different magnitudes of personal ties to the CEO. The inside directors' personal ties to the CEO is represented by B_{ins}, which is drawn from a normal distribution with mean B_0 and variance σ_B^2. And the outside directors' personal ties to the CEO is represented by B_{out}, which is drawn from a normal distribution with mean B_1 and variance σ_B^2. The personal firing cost of the average director is then assumed to be $personal = [B_{ins} \times (1-m) + B_{out} \times m] \times \eta$, where m is board independence and η is CEO ability. My results from Section 5 remain similar under this specification: CEO ability still does not generate enough variation in board structure, and the negative relation between CEO ability and board independence is still weak on average and stronger when CEO ability is low. More detailed estimation results can be found in Appendix D.

Second, identifying voluntary and forced CEO turnovers is difficult and remains controversial. Most empirical work follows the algorithm proposed by Huson, Parrino and Starks (2001). But recently, Jenter and Lewellen (2010) find that there may be more performance-induced CEO turnovers than previously found. The existing classification method is likely to underestimate the number of forced CEO firings. To avoid the classification of forced versus voluntary CEO turnover in my framework, I no longer fix the parameter f (the probability that CEOs leave exogenously) and estimate it along with other parameters. Such a parameter can be identified by the performance-turnover sensitivity (regression coefficient β_4 in auxiliary model 2 from Table 3). Estimation results show that the optimal estimate for f is quite close to the one used in the main results. The values of other parameters are also almost the same as before. Model solution behavior does not change much because of such adjustment either.

Third, my model treats CEO ability as exogenously given. But Acharya, Gabarro and Volpin (2011) suggest that the matching between CEO and firm may be endogenous, with good CEOs matched with weakly governed firms and vice versa. To allow for such a possibility, I allow future CEO ability to be a function of board structure. But it turns out that the correlation between these two variables is very close to zero. Therefore, endogenizing CEO ability has little effect on my results. Note that this does not necessarily imply that the data do not support the prediction of Acharya, Gabarro and Volpin (2011), whose argument depends on the firm's overall governance strength, not just board independence. Since Morellec, Nikolov and Schürhoff (2012) also demonstrate that the magnitude of agency conflict depends significantly on governance mechanisms such as institutional ownership and pay-performance sensitivity of the executives, it follows that a careful test of Acharya, Gabarro and Volpin (2011) should include governance mechanisms other than board monitoring.

The fourth concern is that, in my setup, CEO ability (η) and the CEO-board tie (B) are independent of each other. But it is possible that low-ability CEOs have stronger incentives to develop stronger ties with their directors. To account for such a scenario, I allow η and B

to be drawn from a bivariate normal distribution. But in the end, the correlation between these two CEO characteristics has to be almost zero to match the empirical correlation coefficient between average board independence and average operating income. My results largely remain the same after such adjustment.

Since all of the modifications mentioned above do not significantly change my estimates or the model predictions, I keep the model as it is for simplicity. However, it is worth pointing out that this paper does not solve all the endogeneity problems. Like most other structural estimation work, this paper assumes that variation in endogenous variable is attributable to the forces that I choose to include in the model. Other governance mechanisms, such as monitoring by institutional investors, are silent in my setup. Such simplification is necessary for me to estimate model parameters successfully. But, as noted by Welch (2013), doing so certainly creates the concern that my results are biased because the impact of any left-out elements may be absorbed by my state variables.

7 Conclusion

Endogeneity is a pervasive problem that plagues empirical work in corporate governance. This paper adopts a structural approach to mitigate that concern. The goal of this paper is three-fold. First, it quantifies the importance of CEO ability in determining board structure. Second, it examines how CEO characteristics affect corporate boards and equity value on the time-series dimension. Third, it explains why regression analysis fails to document time series properties of board structure. A dynamic model that endogenizes board structure, CEO firing, and firm value is developed. Model parameters are estimated using Simulated Method of Moments. I then generate data using these estimated parameters to conduct simulation experiments, which involves assigning a CEO with certain characteristics to an average firm. Such an approach allows me to observe how much the endogenous variables change in response to the unobservable CEO characteristics.

This paper is among the first to empirically document the within-firm result that board independence is negatively related to CEO ability. More strikingly, I find that such a relation is stronger when CEO ability is low but weak otherwise. Second, using a structural approach gives me the unique advantage of quantifying the relative impact of different latent variables on corporate boards. I find that CEO ability alone explains only 48% of variation in board structure, as measured by the standard deviation of board independence. Other factors that may result in entrenchment, such as CEO-board ties, are also important determinants of board structure.

Researchers suspect that the insignificant regression coefficients found in extant empirical work result from endogeneity. This paper shows that after endogenizing board structure, there is indeed a negative relation between CEO ability and board independence, although this relation is quite weak on average. My results also suggest that researchers lose the opportunity to verify the relation between CEO ability and board structure when it is the strongest. This is because such a relation is strong when CEO ability is low, but low-ability CEOs are more likely to be fired and do not stay in the sample for too long. These results help explain why researchers struggle to document board structure dynamics within a CEO's tenure using regression analysis.

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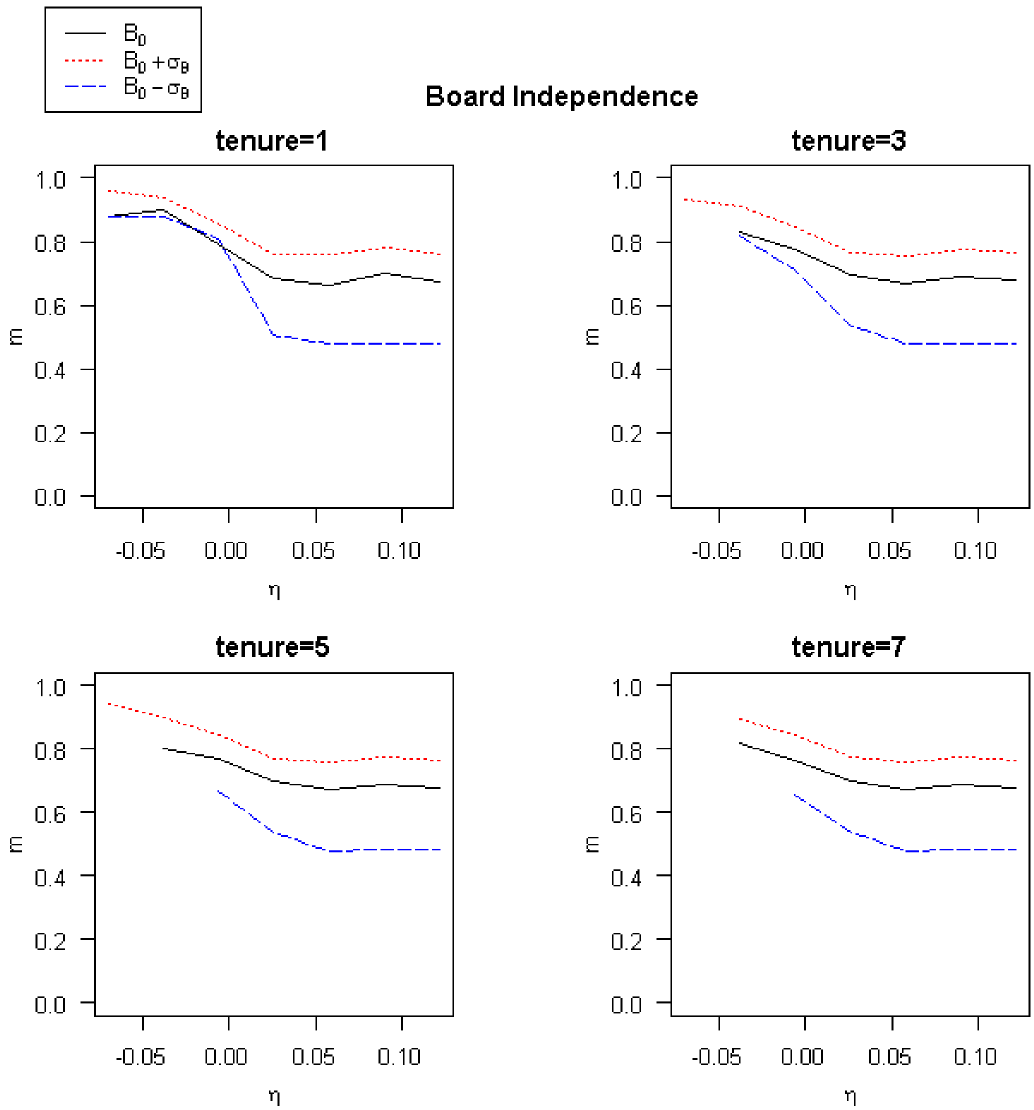

Figure 1: This figure contains four plots that illustrate how board independence changes during a CEO's tenure. Each plot represents a different year, with tenure=1 representing the year that a new CEO is just hired. The horizontal axis of each plot is CEO ability (η) and the vertical axis is board independence (m). The black solid lines represent the case that $B = B_0$, while the cases for $B = B_0 + \sigma_B$ and $B = B_0 - \sigma_B$ are represented by the red dotted lines and blue dashed lines respectively.

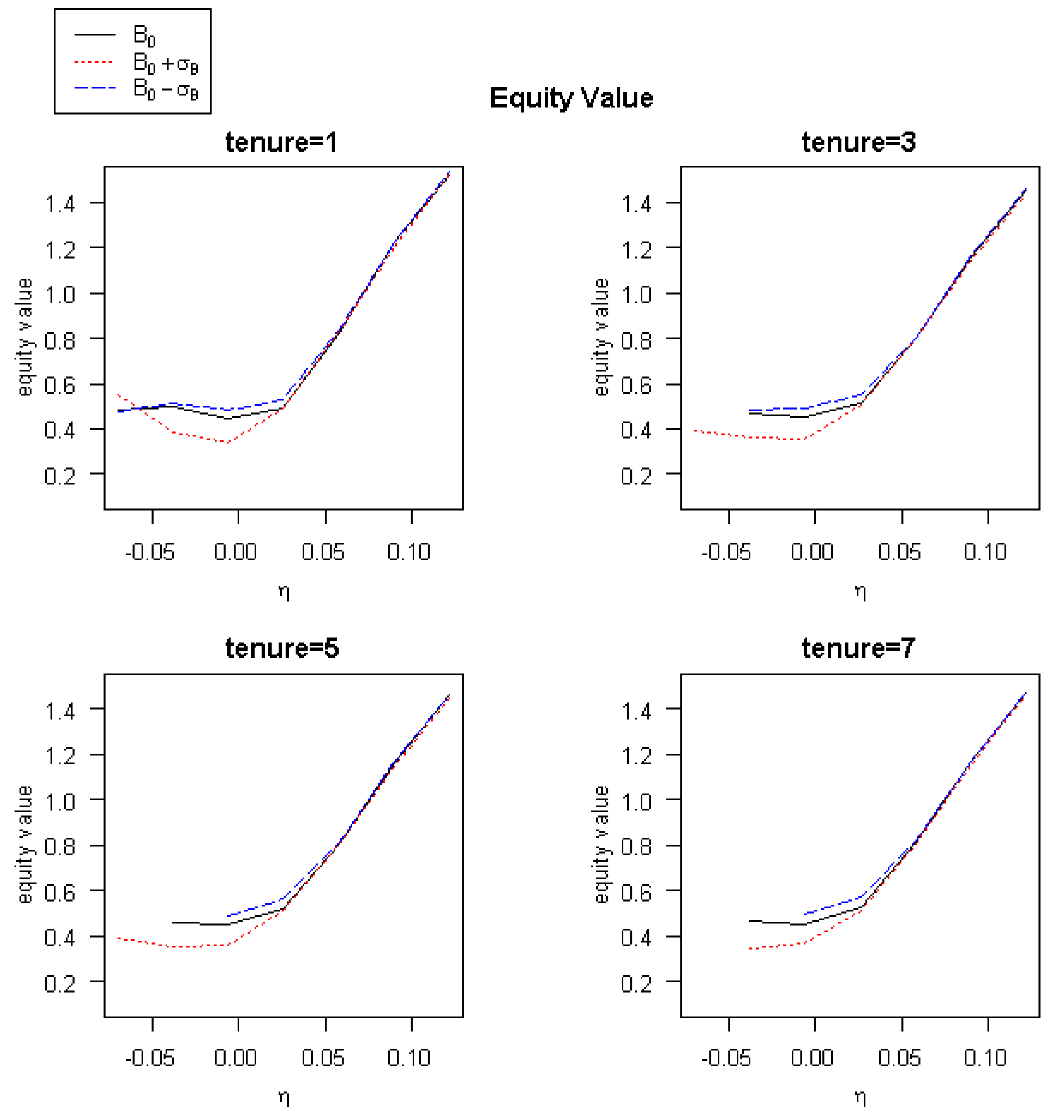

Figure 2: This figure contains four plots that illustrate how equity value (scaled by total assets) changes during a CEO's tenure. Each plot represents a different year, with tenure=1 representing the year that a new CEO is just hired. The horizontal axis of each plot is CEO ability (η) and the vertical axis is equity value. The black solid lines represent the case that $B = B_0$, while the cases for $B = B_0 + \sigma_B$ and $B = B_0 - \sigma_B$ are represented by the red dotted lines and blue dashed lines respectively.

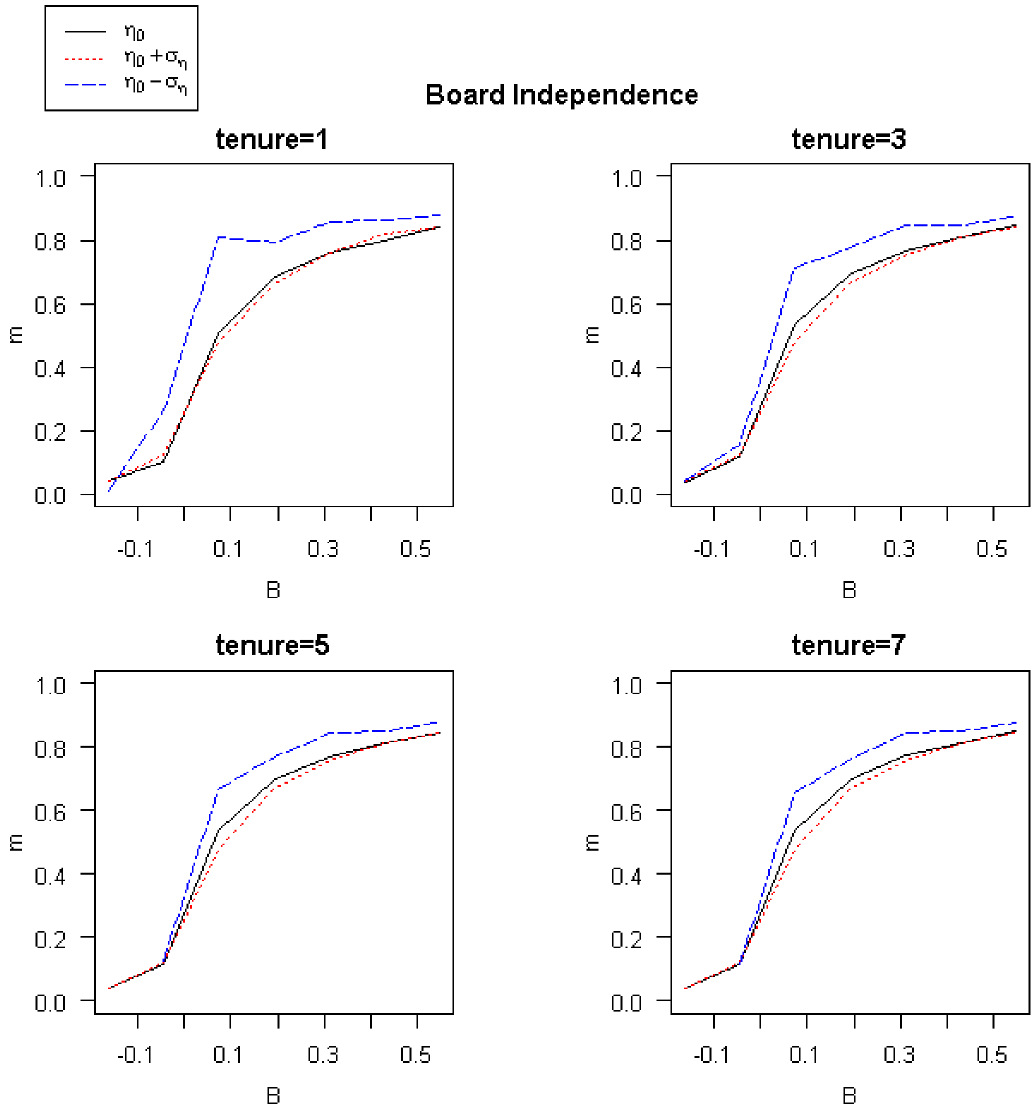

Figure 3: This figure contains four plots that illustrate how board independence changes during a CEO's tenure. Each plot represents a different year, with tenure=1 representing the year that a new CEO is just hired. The horizontal axis of each plot is the strength of the CEO-board tie (B) and the vertical axis is board independence (m). The black solid lines represent the case of an average-ability CEO ($\eta = \eta_0$), while the cases for CEO ability one standard deviation above and below the mean are represented by the red dotted lines and blue dashed lines respectively.

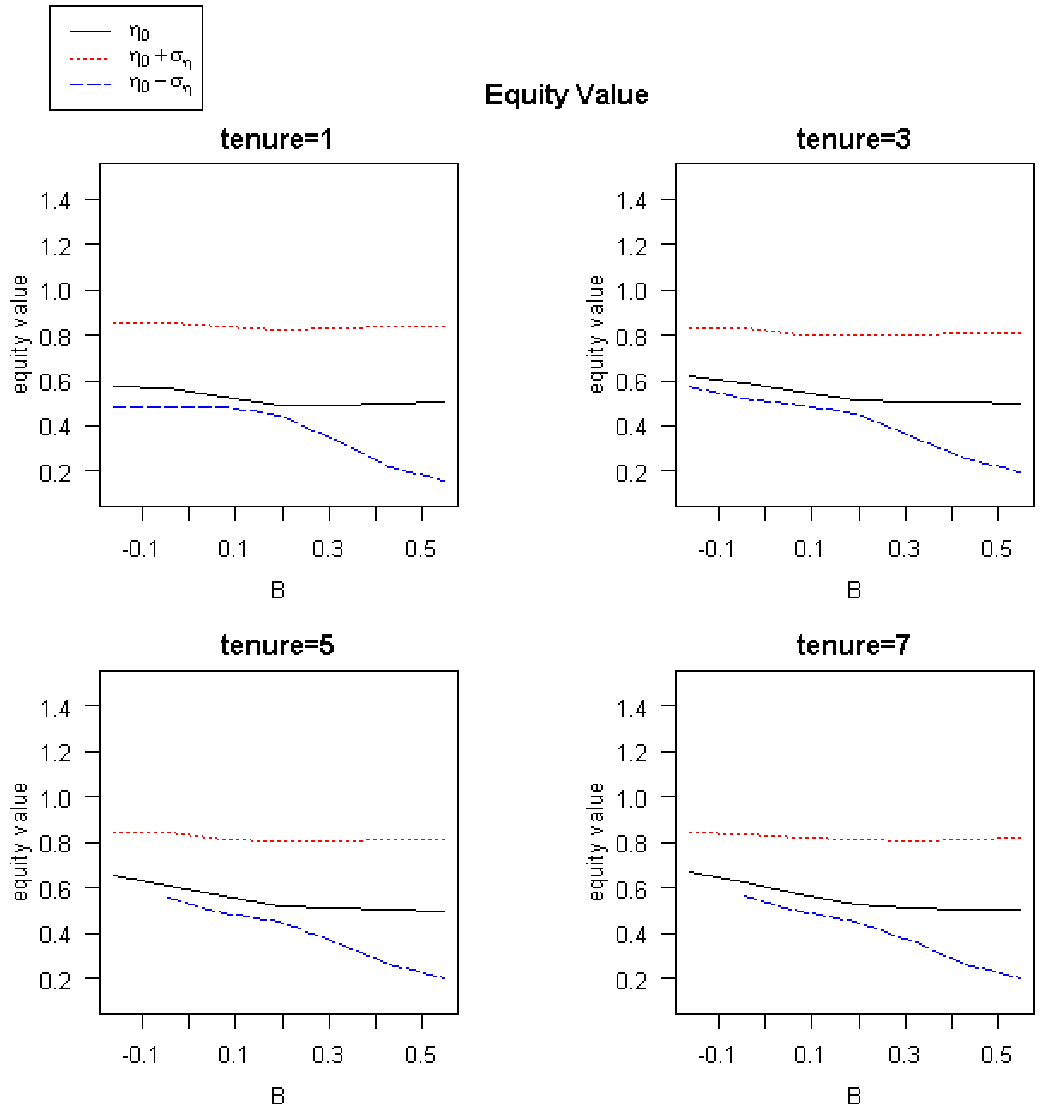

Figure 4: This figure contains four plots that illustrate how equity value (scaled by total assets) changes during a CEO's tenure. Each plot represents a different year, with tenure=1 representing the year that a new CEO is just hired. The horizontal axis of each plot is the the strength of the CEO-board tie (B) and the vertical axis is equity value. The black solid lines represent the case of an average-ability CEO ($\eta = \eta_0$), while the cases for CEO ability one standard deviation above and below the mean are represented by the red dotted lines and blue dashed lines respectively.

Appendix A: Details on Data Simulation

This appendix gives more details on simulation of data. To be consistent with the data described in Section 3 (referred to as the empirical dataset thereafter), I simulate 2,528 CEO spells to generate one simulated sample. A CEO spell is defined as all the years a CEO serves in office. To generate a single spell, I first need the relative rankings of the CEO's true ability and directors' personal cost of firing and the average proportion of equity held by the directors.

To obtain the relative ranking of CEO ability (η), I regress the industry-adjusted ROA on board independence, a dummy variable indicating CEO turnover events, and year fixed effect and keep the residuals. The residuals from this regression should contain information on both CEO ability (η) and earnings surprise (ϵ). For each CEO, I then compute the average residuals during her tenure to remove the effect of ϵ and use such average as the proxy for her ability. The empirical distribution of CEO ability is then established after computing the average residual for each CEO. I then map this empirical distribution to the assumed distribution of CEO ability $N(\eta_0, \sigma_\eta^2)$ to obtain the true ability of each CEO.

The proxy for B is obtained similarly. In the model, board independence contains information on the directors' personal firing cost. I therefore regress board independence on directors' equity holdings, the proxy for CEO ability mentioned in the above paragraph, and firm and year fixed effects. The average residual over a CEO's tenure is then computed to be the proxy for B. The empirical distribution for B is established by computing the average residual for each CEO. I then map the empirical distribution to the assumed distribution of entrenchment $N(B_0, \sigma_B^2)$ to obtain the true value of B.

The above procedures produce all the inputs needed to simulate one CEO spell: the CEO's true ability η, the directors' personal firing cost measure (B), and the average proportion of equity held by all he directors (γ). The earnings path of this CEO during her tenure is generated by these inputs and earnings surprises ϵ that are randomly drawn from $N(0, \sigma_\epsilon^2)$. The model described in Section 2 is solved to obtain the optimal board structure

(m) and firing decision ($fire$).

To take into consideration the fact that the number of independent directors has to be an integer, I make one minor adjustment to the model-predicted board independence. I take the board size of a firm as given, multiply it by m, and then round the product to the nearest integer to obtain the number of independent director for this firm-year observation. Board independence in the simulated sample is calculated as the number of independent directors thus obtained divided by board size. The simulated firms change their board structures less frequently because of such rounding procedure.

This completes the simulation of one CEO spell. The procedure is then repeated for all simulated CEOs to generate a simulated sample.

Appendix B: Details on Model Solving

I solve the model numerically by value function iteration. Since there are continuous state variables in the model, I first have to discretize the state space. I discretize CEO ability (η) into 10 points evenly spaced between $\eta_0 - 3\sigma_\eta$ and $\eta_0 + 3\sigma_\eta$. B is discretized into 10 points even spaced between $B_0 - 3\sigma_B$ and $B_0 + 3\sigma_B$. And directors' equity holding (γ) is discretized into 7 points between 0 and 20%. Following Taylor (2010), I assume that all CEOs retire after year 15 to reduce computation load. Cubic spline quadrature is used for interpolation or extrapolation whenever needed.

Solving the model requires computation of the expected value of future utility. The expected value is approximated by cubic spline quadrature. Finally, I use value function iteration method to solve the dynamic model.

Appendix C: Details on Simulated Method of Moment

The SMM estimator is

$$\hat{\theta} = arg\,\min_{\theta} \left(\hat{M} - \frac{1}{S}\sum_{s=1}^{S} \hat{m}^s(\theta) \right)^T \hat{W} \left(\hat{M} - \frac{1}{S}\sum_{s=1}^{S} \hat{m}^s(\theta) \right)$$

, where $\hat{M}$ is the vector of empirical moments, $\hat{m}^s(\theta)$ is the vector of simulated moments calculated from the sth simulated sample using parameter θ, and $\hat{W}$ is the weighting matrix. The moments I choose to match are listed in Table 3. Details on data simulation are described in Appendix A. I choose $S = 10$ as Michaelides and Ng (2000) find that using a simulated sample 10 times as large as the empirical sample generates good small-sample performance.

The efficient weighting matrix is $\hat{W} = \left[N \times Cov\left(\hat{M}\right) \right]^{-1}$, where N is the size of the empirical sample. I compute the covariance matrix of $\hat{M}$ using the seemingly unrelated regression approach. The moments can be written as the coefficients from the following system:

$$\begin{cases} log(Y_{it}) & = \beta_1 log(m_{it}) + \beta_2 log(\gamma_{it}) + \beta_3 turnover_{it} + year\ FE + firm\ FE + \epsilon_{1,it} \\ turnover_{it} & = \beta_4 \mathbf{1}_{low\,return} + \beta_5 \gamma_{it} + \beta_6 \mathbf{1}_{low\,return} m_{it} + year\ FE + industry\ FE + \epsilon_{2,it} \\ \alpha^j & = \beta_7 \mathbf{1} + \epsilon_{3,it} \\ m_{it}^2 & = \beta_8 \mathbf{1}_{tenure=0,1} + \beta_9 \mathbf{1}_{tenure=2,3,4} + \beta_{10} \mathbf{1}_{tenure\geqslant 5} + \epsilon_{4,it} \\ m_{it} & = \beta_{11} \mathbf{1} + \epsilon_{5,it} \\ ROA_{it}^2 & = \beta_{12} \mathbf{1} + \epsilon_{6,it} \\ fire_{it} & = \beta_{13} \mathbf{1} + \epsilon_{7,it} \\ ROA_{it} & = \beta_{14} \mathbf{1} + \epsilon_{8,it} \end{cases} .$$

The definitions of the notations are in Table 3. $Cov(\hat{M})$ is obtained by estimating the above system using the seemingly unrelated regression approach.

The asymptotic distribution of the optimal SMM estimator is

$$\sqrt{N}\left(\hat{\theta}-\theta_0\right) \xrightarrow{d} N\left(0,\Omega\right)$$
$$\Omega=\left(1+\frac{1}{S}\right)\left(\Gamma'\Lambda\Gamma\right)^{-1}$$

, where S is the number of simulated data sets (here $S=10$), $\Lambda = N \times Cov\left(\hat{M}\right)$, $\Gamma = \underset{N\to\infty}{plim}\frac{\partial\hat{G}(\theta_0)}{\partial\theta'}$, $G(\theta)=\hat{M}-\frac{1}{S}\sum_{s=1}^{S}\hat{m}^s(\theta)$. The χ^2 identification test can be done using the following:

$$\frac{NS}{1+S}\hat{G}(\theta_0)'\Lambda^{-1}\hat{G}(\theta_0) \xrightarrow{d} \chi^2(\#moments-\#parameters)$$

Appendix D: Alternative Model Specification

This appendix reports estimation results for alternative specifications of equation (4). To address the concern that different kinds of directors may have different magnitudes of personal ties to the CEO, I allow the inside and outside directors to have different Bs. For the insiders, the strength of their personal ties to the CEO is represented by B_{ins}, which is drawn from a normal distribution with mean B_0 and variance σ_B^2. For the outsiders, the strength of their personal ties to the CEO is B_{out}, which is drawn from a normal distribution with mean B_1 and variance σ_B^2. The personal firing cost of the average directors takes the form of

$$personal=\left[B_{ins}\times(1-m)+B_{out}\times m\right]\times\eta, \tag{7}$$

where m is board independence and η is CEO ability. Estimating the correlation coefficient between B_{ins} and B_{out} presents a challenge since there is no moment that helps identify it. Instead of estimating such a parameter, I report results using different correlation coefficients

Table 11: Parameter Estimates

This table contains the optimal estimates of parameters under the alternative specification for Equation (4), which now takes the form of Equation (7). The data consists of 9,573 firm-year observations from S&P 1500 firms during 1998 and 2006. Parameters are estimated using Simulated Method of Moments (SMM) as described in Section 4. The first row reports estimates when B_0 and B_1 are not correlated, while the second row reports results when the correlation coefficient between B_0 and B_1 is 0.5.

Parameter	α_0	α_1	η_0	σ_η^2	σ_ϵ^2	B_0	B_1	σ_B^2
Cor(B_0, B_1)=0	0.0010	0.0016	0.0231	0.0061	0.0055	0.4022	0.3405	0.0008
Cor(B_0, B_1)=0.5	0.0010	0.0012	0.0182	0.0061	0.0055	0.3910	0.3508	0.0012

and show that model solutions do not change much when the correlation coefficient differs. Table 11 reports the optimal estimates of parameters while Table 12 reports the simulation results.

As can be seen from Table 12, there is a negative relation between board independence and CEO ability in general. And this relation is stronger when CEO ability is low but weak on average. Therefore, allowing insiders and outsiders to have different magnitudes of personal ties to the CEO does not materially change the qualitative prediction of the model. The main results still hold when Equation (4) is replaced by a more general functional form (Equation 7).

Table 12: Simulated Data Summary (Board Independence and Equity Value)

This table summarizes how board independence changes given CEOs with different characteristics. Simulated data are generated by the model described in Section 2, with Equation (4) replaced by Equation (7). Parameter values are listed in Table 11, with directors' equity holdings fixed at 3.87% (the sample median). I simulate 1,000 CEO spells for each (η, B_{ins}, B_{out}) pair and record the average outcome in this table. Each cell represents the average board independence within the CEO's tenure.

Panel A: Board Independence When $cor\left(B_{ins}, B_{out}\right) = 0$

		CEO Ability		
		$\eta_0 - \sigma_\eta$	η_0	$\eta_0 + \sigma_\eta$
B_{ins}, B_{out}	$B_0 - \sigma_B$, $B_1 - \sigma_B$	80%	69%	68%
	$B_0 - \sigma_B$, B_1	68%	56%	55%
	$B_0 - \sigma_B$, $B_1 + \sigma_B$	41%	40%	40%
	B_0, $B_1 - \sigma_B$	84%	77%	77%
	B_0, B_1	80%	69%	69%
	B_0, $B_1 + \sigma_B$	68%	56%	56%
	$B_0 + \sigma_B$, $B_1 - \sigma_B$	87%	82%	82%
	$B_0 + \sigma_B$, B_1	84%	77%	77%
	$B_0 + \sigma_B$, $B_1 + \sigma_B$	80%	69%	69%

Panel B: Board Independence When $cor\left(B_{ins}, B_{out}\right) = 0.5$

		CEO Ability		
		$\eta_0 - \sigma_\eta$	η_0	$\eta_0 + \sigma_\eta$
B_{ins}, B_{out}	$B_0 - \sigma_B$, $B_1 - \sigma_B$	77%	68%	67%
	$B_0 - \sigma_B$, B_1	51%	48%	48%
	$B_0 - \sigma_B$, $B_1 + \sigma_B$	25%	30%	30%
	B_0, $B_1 - \sigma_B$	87%	80%	80%
	B_0, B_1	82%	69%	69%
	B_0, $B_1 + \sigma_B$	52%	49%	48%
	$B_0 + \sigma_B$, $B_1 - \sigma_B$	90%	85%	85%
	$B_0 + \sigma_B$, B_1	87%	80%	80%
	$B_0 + \sigma_B$, $B_1 + \sigma_B$	77%	68%	67%