The Joint Determinants of Managerial Ownership, Board Independence, and Firm Performance

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Abstract

We specify a simple structural model of the firm to isolate the economic determinants of key aspects of organization form in a value-maximizing contracting environment. Optimal firm size, managerial ownership, and board independence are jointly determined by exogenous parameters defining the productivity of physical assets, managerial input, inside director expertise, and outside director advising and monitoring. The model provides an equilibrium explanation for the cross-sectional relationships among managerial ownership, board structure, and firm performance observed in data. Using the model for policy analysis, our approach also explains the observed changes in compensation structure following new requirements for board independence.

JEL classification code: G32, G34, L29

Key words: Corporate Governance; Board Independence; Managerial Ownership; Structural Model

I. Introduction

This paper develops and empirically implements a structural model of the joint determinants of firm scale, board structure, firm performance, and managerial compensation contract. The economic decisions represented in the model are related to the advising and monitoring role of outside directors, the provision of firm- and industry-specific expertise by inside directors, a contractual solution to the standard moral hazard problem for managerial input, and definition of the boundaries of the firm as defined by investment. Using observed data on firm size, managerial pay-for-performance sensitivity, and board independence, we calibrate the model to estimate exogenous parameters that capture the productivity of physical assets, managerial input, inside director expertise, and outside director advising and monitoring. Variation of these productivity parameters across firms and through time, and the corresponding variation in optimal firm size and internal governance structure as represented by the model, all serve to characterize economic forces that are likely to generate the observed empirical relations among Tobin's Q, board independence, managerial ownership, and firm size.

To frame our approach, per Himmelberg (2002) and Coles, Daniel, and Naveen (2008), it is useful to think of corporate finance as concerned with a wide spectrum of organizational features, or "structure," and aspects of firm performance. Dimensions of structure include: managerial compensation; board and ownership structure; debt, investment, and dividend policy; leadership structure; anti-takeover protections; and product market strategy. Performance measures include accounting profit, stock returns, debt returns, and Tobin's Q. Regression experiments typically specify either performance as a function of structure or structure as a function of structure.

In the case of performance on structure, for example, various papers examine the association between firm performance and either managerial ownership or board independence. In both cases, the empirical results are mixed.[1] Similarly, a large number

[1] In the case of the former, Morck, Shleifer, and Vishny (1988) find a three-segment Z-shaped relation between Q and inside ownership, while McConnell and Servaes (1990) instead report an inverted-U relation between Q and fraction of common stocks owned by insiders. Numerous successors investigate the ownership-performance relation and, based on the large variation in results, Demsetz and Villalonga (2001, figure 1) express serious doubt as to whether there is any significant relation.

of studies examine the relation between performance and board independence but, again, with varying results.[2]

Experiments that regress structure on structure arise naturally from the notion that the firm is an incentive system (Holmstrom and Milgrom, 1991). Are two different mechanisms, managerial compensation and board composition, for example, substitutes or complements in “production”? Restated, if a relatively independent board fulfills the monitoring function, is it necessary to expose the management team to high pay-performance sensitivity? Again, the empirical evidence is mixed. Denis and Sarin (1999), Shivdasani and Yermack (1999), and Coles, Daniel, and Naveen (2008) estimate a negative relation between managerial ownership and the proportion of outsiders on the board, which suggests that they are substitutes in “production.” In contrast, Ryan and Wiggins (2004) and Davila and Penalva (2004) find a positive relation between insider ownership and the proportion of outsiders on the board.

There are several potential reasons for the wide variation across studies in results and conclusions. First, different papers rely on different samples that vary by time period, sample size, industry composition, firm size, and data sources. Second, when examining the relationship between firm performance and structure, the choices of control variables and instruments vary substantially across studies. Third, there may be no relation between firm structure and performance, but different studies deliver spurious (and contrasting) results because of model misspecification. Incorrect functional form, omitted variables, and causation problems can lead researchers to detect a relation when there is none present (e.g., see Demsetz and Lehn, 1985, and antecedents).

In this context, we pursue three objectives that represent our contributions to the literature. First, we isolate likely exogenous joint determinants of firm performance and value-maximizing organization form. Second, we reconcile widely varying empirical results and identify how characteristics of the contracting environment interact to determine firm structure and performance. Finally, we seek to assess quantitatively regulation and policy. In particular, we measure the effects on managerial compensation, firm size, and firm value of recently imposed restrictions on board independence.

[2] Among them, Yermack (1996) finds a negative relation between Q and board independence, Klein (1998) finds no relation, and Coles, Daniel and Naveen (2008) find a positive relation for some classes of firms.

Toward these goals, we work in the style of Coles, Lemmon and Meschke (hereafter CLM, 2006) to specify a simple structural model of the firm and calibrate that model to estimate exogenous parameters that capture the productivity of physical assets, managerial input, inside director expertise, and outside director advising and monitoring. In particular, we employ the principal-agent model of Holmstrom (1979) and Holmstrom and Milgrom (1987) but augment the production function, along with managerial input, to include firm scale and board structure. Our estimates of the productivity parameters are the values of those parameters that would give rise to observed managerial ownership, board independence, and firm scale as optimal choices in our model.

The estimated productivity parameters vary as might be expected across industries. For example, firms in the Metals and Mining, Utility, Gas, and Manufacturing industries have the highest productivity of physical assets relative to the productivity of human capital. Correspondingly, these firms exhibit high levels of investment in physical assets, low managerial ownership, and high board independence. In contrast, firms in the Apparel, Personal Business Services and Retail industries have the lowest relative productivity of physical assets relative to human capital, and are characterized by high levels of ownership and lower board independence.

Indeed, comparative statics analysis of our model shows that an increase in the productivity of physical assets has a large positive impact on investment in physical assets, leads to a significant reduction in managerial ownership, but has virtually no effect on optimal board composition. An increase in the productivity of managerial effort is associated with a large increase in CEO ownership and a modest reduction in board independence, while an increase in the productivity of advising/monitoring by outside directors causes reasonably large increases in optimal board independence and managerial ownership. Optimizing firm performance, as reflected in Tobin's Q, responds strongly to a change in the productivity of physical assets, but only weakly to the two productivity parameters that are related to human capital.

We go outside the model to examine whether our estimates of the exogenous productivity parameters have power to explain the nature of observed relations among managerial ownership, board composition, and firm performance. Using model-generated Tobin's Q, the model and variation in the productivity parameter estimates generate the familiar (McConnell and Servaes, 1990) hump-shaped relation between managerial ownership and firm performance. The model also produces a negative relation between model-generated Q and board independence that is similar to what appears in our sample using actual Q. We also consider whether managerial ownership and the proportion of outsiders on the board, both used to align managerial incentives, are substitutes or complements. In the model, they are complements in production. Nonetheless, because of how the productivity parameters are correlated in the cross-section, our analysis delivers the negative empirical relation between board composition and managerial ownership predicted by Hermalin (2005) and found in the data.

It is noteworthy that neither ownership nor the proportion of outsiders on the board has any explanatory power for firm performance after including simple functional forms of the three exogenous productivity parameters upon which we hypothesize that board independence and firm performance jointly depend. Approximately 17% (89%, 24%) of the variation in actual Tobin's Q (managerial ownership, board independence) can be explained by these productivity parameters alone. These results suggest that the productivity parameters specified in our model indeed capture some of the joint economic determinants of managerial ownership, board composition, firm size, and firm value.

Finally, we evaluate the effects of rules mandating changes in board independence that were imposed on firms following the Sarbanes Oxley act in 2002. Within the value maximizing equilibrium framework of our model, firms that are forced to change their board structures in order to comply with the rules readjust their compensation policy and firm scale in response. A mandated minimum of 50% outside directors implies, for the average newly constrained firm, a 7.0% decrease in optimal compensation and a 4.7% reduction in maximized shareholder value. The optimizing responses predicted by our model approximate the changes in compensation documented by Chhaochharia and Grinstein (2008). In our framework, however, the one-size-fits-all constraint forces some firms away from their optimal governance structure and reduces firm value. The use of our structural model in this setting highlights the potential unintended consequences of constraints on the contracting space and serves as a benchmark for further evaluating policy, regulatory reforms, and listing requirements.

Despite the empirical success of our approach, we doubt that our simple model encompasses all of the relevant economic determinants of managerial ownership, board structure, firm size, and firm value. Nonetheless, the construction of our model and its application to data provides an example of how a structural model of the firm can isolate important aspects of governance and quantify the economic significance of various incentive mechanisms. Our approach is consistent with recent calls by Zingales (2000), Hermalin and Weisbach (2003), and Himmelberg (2002), among others, for a quantitative theory of the firm that is empirically implementable and testable and that allows an assessment of the economic significance of various dimensions of the organization.

The reminder of our paper is organized as follows. Section II reviews the literature and summarizes the existing interpretations of the data. We present and analyze the model in Section III. Section IV describes our sample. Section V presents results on the estimated productivity parameters, evaluates variation of the estimates across industries, and provides comparative statics results. Section VI provides empirical evidence on board composition and managerial ownership as determinants of Q. Section VII discusses the association between board composition and managerial ownership. In Section VIII, we employ our model as a vehicle to examine, in an equilibrium setting, the economic consequences of recent board reforms. Section IX concludes.

II. Prior literature and modeling preliminaries

A. Performance on structure

Morck, Shleifer, and Vishny (1988, hereafter MSV) document a non-monotonic relation between Tobin's Q and managerial stock ownership. McConnell and Servaes (1990, MS) report an “inverted-U” or “hump-shaped” relation between Q and managerial ownership. One possible interpretation of the data is that shareholders maximize firm value if they can induce managers to own precisely the amount of stock associated with the peak of the performance-ownership relation. But then why would other combinations of managerial ownership and Q appear in the data?

One obvious possibility is that large transaction costs prevent a firm from moving to the optimum. Only when the distance away from the optimum at the top of the function is large will the benefits to shareholders of realigning ownership structure to the optimum exceed the transaction costs of doing so. An alternative interpretation, however, is that the inverted-U pattern represents a value-maximizing relationship between two endogenous variables. In this framework, if the empirical specification adequately captures the effects of all relevant exogenous variables, i.e. those structural parameters that drive both ownership and performance, that specification would be unlikely to detect any remaining association between the jointly-determined endogenous variables (Demsetz and Lehn, 1985, Hermalin, 2005, and CLM, 2006,). Thus, one challenge for those who operate in the equilibrium paradigm, in this particular empirical context or any other, is to specify and estimate a structural model of the firm. Doing so offers the potential for understanding how exogenous factors that capture the relevant economic forces associated with the contracting environment operate to give rise to a relation between managerial ownership and firm performance. Along these lines, in contrast to studies that view equity incentives as rent extraction by managers (e.g., Bebchuk, Fried, and Walker, 2002), Demsetz and Lehn (1985) and Himmelberg, Hubbard, and Palia (1999), among others, contend that managerial ownership levels are set on average at the optimal, value-maximizing level.

A similar style of argument can be made for the relationship between Tobin's Q and board composition. As with managerial ownership, the results vary. Weisbach (1988), Borokhovich, Parrino, and Trapani (1996), Brickley, Coles, and Terry (1994), Byrd and Hickman (1992), and Cotter, Shivdasani, and Zenner (1997) find that more-independent boards add value in some circumstances. Baysinger and Butler (1985), Hermalin and Weisbach (1991), and Bhagat and Black (2001), find no relation between the fraction of outside directors on the board and Tobin's Q. Yermack (1996) and Agrawal and Knoeber (1996) find a negative association between the fraction of outside directors and Tobin's Q, while Rosenstein and Wyatt (1997) and Klein (1998) find that insiders add value. Coles, Daniel, and Naveen (2008) find that the relationship between Q and board independence depends on R&D intensity. But even if there were agreement about the shape of the association, there would be disagreement over interpretation. What we believe, and provide some evidence for in this paper, is that the empirical association represents the locus of maxima of value-maximizing board structures, where the individual firm maxima vary in location according to exogenous factors, including differences in technology and the nature of the product market.

B. Structure on Structure

A natural question to ask from the perspective of shareholders when designing the structure of corporate governance is whether CEO pay-performance sensitivity and board independence are complements or substitutes in creating firm value. In general, the board of directors performs both advisory and monitoring functions. Monitoring can both directly affect the firm's cash flows and also reduce the noise in the signal used to evaluate the effort choice of the CEO. Directors, in an advisory capacity, may provide valuable and relevant knowledge that improves the productivity of CEO effort. A natural assumption is that inside directors, who have valuable firm and industry specific knowledge, have a comparative advantage in enhancing the productivity of CEO effort, while outside directors have a comparative advantage in monitoring. Along similar lines, viewing the firm as an incentive system, Holmstrom and Milgrom (1991) suggest that ownership of assets and worker freedom from direct control are complementary instruments for motivating workers. The bargaining framework in Hermalin and Weisbach (1998) argues that a risk-averse and successful CEO can bargain for both less board scrutiny and less pay-for-performance sensitivity. The interaction among these forces suggests a potentially complex relation between board structure and the incentives provided to the CEO.

Empirically, several papers, including Denis and Sarin (1999), Baker and Gompers (2003), Shivadasani and Yermack (1999), and Coles, Daniel and Naveen (2008), document a negative relationship between CEO ownership and board independence. In contrast, Core, Holthausen and Larcker (1999) find that the proportion of outside directors is significantly positively related to the amount of performance-based pay given to the CEO. Ryan and Wiggins (2004) and Davila and Penalva (2004) find a positive relation between insider ownership and the proportion of outsiders on the board.

C. The economic determinants of managerial ownership and board independence

What ingredients would a model of board structure, managerial compensation, and firm performance contain? The prior literature provides some guidance. Many studies focus on the information asymmetry between insiders and outsiders. Demsetz and Lehn

(1985) suggest that required levels of managerial equity ownership are related to firm size and monitoring difficulty. They argue that there is an optimal firm size and optimal level of managerial ownership given the firm's factor input and product markets.

Harris and Raviv (2004) present a model for optimal board control, in which decision delegation, the optimal number of outsiders, and resulting profits are functions of the importance of insiders' and outsiders' information and the extent of agency problems. Their model assumes that outside directors are monitors and inside directors are information providers. Hermalin (2005) explains a number of trends in corporate governance with the proposition that the intensity with which the board monitors management is increasing in board independence. In particular, his model predicts that board independence and CEO compensation should co-vary inversely in the cross-section but positively in time-series data. Adams and Ferreira (2005) show that, when it is important for the CEO to share information with the board of directors, shareholders may optimally choose a less independent or friendlier board. Raheja (2005) argues that optimal board size and composition are functions of director and firm characteristics when the board is responsible for monitoring projects and CEO succession. In that model, the optimal board structure is determined by the tradeoff between maximizing the incentive for insiders to reveal their private information and minimizing the costs of outsiders to verify and reject inferior projects. Empirically, Boone et al. (2004) suggest that board size and independence reflect a trade-off between the firm-specific benefits of monitoring and the costs of such monitoring.

Thus, we include in our model three natural components. One is the standard agency problem, from which arises strong intuition about the conditions under which the agent's (manager's) compensation should be exposed to firm performance through ownership and the managerial compensation contract. Second, we include the investment decision. Firm size is a crude representation of boundaries of the firm. Moreover, firm size affects the contracting problem insofar as managerial input is combined with fixed assets. In addition, firm size affects the sharing of risk among shareholders and managers. Third, our model recognizes the dual role of the board of directors in providing both advisory and monitoring services and the natural relative advantages that inside versus independent directors have in providing these services. We integrate these features in our structural model of the firm.

III. Model

Our model is based on the standard principal-agent problem (e.g., Holmstrom, 1979). In particular, the principal chooses the size of the firm as well as the internal corporate governance structure. Governance is comprised of effective ownership (the compensation scheme) of the manager and the fraction of outsiders on the board (the advising/monitoring scheme).

In our model, shareholders choose the composition of the board, as well as the manager's compensation contract and the optimal scale of the firm to maximize firm value. By choosing board composition and managerial compensation *ex ante*, shareholders pre-commit to the governance structure. While it is standard to think of shareholders choosing the corporate control mechanisms, perhaps it is more familiar to think of managers choosing investment. To the extent that investment is observable, however, it is equivalent to place the decision rights over investment with shareholders.

Firm cash flow is generated by the following production function:

$$\tilde{f} = pI^{y}((1-m)g)^{z}m^{t} + I^{x}(\tilde{\varepsilon}+\tilde{v}) \qquad (1)$$

where I is the level of investment or assets, g is the manager's effort and m is the proportion of outsiders on the board (so $1-m$ is the proportion of insiders). Assets I can include property, plant, and equipment as well as other intangible assets. Managerial input, director monitoring and advising, and firm investment interact in the Cobb-Douglas production function, $pI^{y}((1-m)g)^{z}m^{t}$.

The productivity parameter $y \in (0,1)$ determines the productivity of physical assets. Parameter $z \in (0,1)$ determines the productivity of managerial input or effort (g). Managerial input is combined with the proportion of inside directors on the board $(1-m)$ to represent synergy between managerial effort and the firm- and industry-specific expertise of inside directors. Such expertise should enhance the productivity of managerial input. Parameter $t \in (0,1)$ determines the direct effect of outside director advising and monitoring on cash flows. Outside directors provide advice, expertise, and monitoring pertaining to strategy, managerial performance, financing, product markets, succession, industry, and legal, accounting, regulatory and political issues, etc.[3] Production is scaled by $p > 1$, which can be interpreted as the standard Cobb-Douglas scale parameter times a profit margin net of all input costs other than managerial compensation and the cost of initial investment. For simplicity, we do not explicitly include board costs.

The disturbance term has two independent components. $\varepsilon \sim N(0, \sigma^2)$ is idiosyncratic firm risk, perhaps from a technology shock. $\nu \sim N(0, (1-m)^2)$ represents other cash flow variability. This second term can also be interpreted as the information gap between insiders and outsiders (Harris and Raviv, 2004). Costly monitoring by outsiders on the board can reduce this variability in part through cooperation and communication among insiders and outsiders (Holmstrom and Tirole, 1993). Cash flow risk is scaled by a function of investment, I^x, where $x > 0$. We think it reasonable to assume that an additive cash flow shock depends on the size of the asset base (firm size).

Taken as a whole, we include board independence in the reduced-form production function and signal extraction technology to represent the avenues through which inside and outside directors affect value. In our formulation it is clear that there is a tradeoff between the advising and monitoring provided by outside directors and the firm-specific human capital of inside directors. Inside directors make managerial effort more productive. On the other hand, outside directors have general knowledge (e.g., about financial or legal issues) relevant to firm decisions and also provide monitoring services.[4]

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[3] See Coles, Daniel, and Naveen (2008). They affirm the conventional wisdom that greater board independence allows for more effective monitoring and improves firm performance. Along these lines, various studies have documented that non-management directors on the board affect important tasks, including hiring and firing of the CEO (Weisbach, 1988; Borokhovich, Parrino, and Trapani, 1996), adoption of anti-takeover devices (Brickley, Coles, and Terry, 1994), and negotiating takeover premiums (Byrd and Hickman, 1992; Cotter, Shivdasani, and Zenner, 1997).

[4] Note that expected cash flow $E(\tilde{f})$ is not always an increasing function of the proportion of outside directors (m). In the absence of the contracting problem, the sign of $\partial E(\tilde{f}) / \partial m$ depends on the relative importance of insiders' firm-specific information and outsiders' non-firm-specific expertise. $\partial E(\tilde{f}) / \partial m > 0$ if and only if $z / t > (1-m)/m$. Of course, optimal board independence (m) will exceed that which directly maximizes $E(\tilde{f})$. The reason is that more outsiders also implies more intense monitoring, which leads to lower cash flow variability ($\text{var}(\tilde{f}) = I^{2x}(\sigma^2 + (1-m)^2)$, with

The manager's utility function is:

$$U(\tilde{w}, g) = -e^{[-r(\tilde{w} - C(g))]} \qquad (2)$$

where $\tilde{w}$ is the uncertain wage, $C(g)$ is the money equivalent cost of effort, and r is a parameter determining the degree of risk aversion.[5] For convenience, we let the cost of effort be linear, $C(g) = g$, and define the manager's reservation utility constraint as $E[U] \geq -e^{-r(0)} = -1$.

Expected utility is:

$$E[U(\tilde{w}, g)] = -e^{[-r(E(\tilde{w}) - \frac{r}{2}\sigma^2(\tilde{w}) - C(g)]} \qquad (3)$$

Following Holmstrom and Milgrom (1987) (also see Hellwig and Schmidt, 2002), the optimal contract that specifies the manager's claim is linear in the observable outcome and is given by:

$$\varphi(\tilde{f}) = \tilde{w} = \alpha + \delta \tilde{f} \qquad (4)$$

Thus, maximizing expected managerial utility is equivalent to maximizing the certainty equivalent of the manager, given by:

$$\alpha + \delta p I^y ((1-m)g)^z m^t - \frac{r}{2}\delta^2 I^{2x}(\sigma^2 + (1-m)^2) - g \qquad (5)$$

Solving the first-order condition for the optimal effort level, g, yields:

$$g^* = ((1-m)^z m^t z \delta p I^y)^{\frac{1}{1-z}} \qquad (6)$$

which is increasing in ownership (or slope of the effective compensation scheme, $\varphi'(\tilde{f}) = \delta$), scaled margin ($p$), investment ($I$), and parameters that determine the marginal productivity of managerial effort (z), outside director input (t), and investment (y). Given the tradeoffs between the costs and benefits of outside versus inside directors, optimal effort is not monotonic in the proportion of outsiders on the board.

Expected total surplus is given by:

$\partial \operatorname{var}(\tilde{f}) / \partial m < 0$) and better inference and risk-sharing in the contracting problem, which then feeds back to generate higher expected cash flow.

[5] Generally, we focus on the case in which the manager has CARA, that is *r(w) = r*, a constant. Nonetheless, our model can be implemented using an approximation of CRRA similar to that employed by CLM (2006). CLM specify $r(w_o) = r / w_o \gamma$, where w_o represents accumulated wealth of the manager. Empirically, CLM use m = max{$5,000,000, 6(0.28)(ln(assets))}. As do we, CLM find that the results using CRRA are quite similar to those based on CARA.

$$S = E\{[\tilde{f}] - E[\varphi(\tilde{f})] - I\} + \{E[\varphi(\tilde{f})] - \frac{r}{2}\delta^2 I^{2x}(\sigma^2 + (1-m)^2) - g\} \qquad (7)$$

The shareholders' maximization problem is

$$\max_{I,\delta,m}\{S = pI^y((1-m)g)^z m^t - I - \frac{r}{2}\delta^2 I^{2x}(\sigma^2 + (1-m)^2) - g\} \qquad (8)$$

$$s.t. \quad g = g^* \qquad (9)$$

$$\alpha + \delta pI^y((1-m)g)^z m^t - \frac{r}{2}\delta^2 I^{2x}(\sigma^2 + (1-m)^2) - g \geq 0 \qquad (10)$$

$$S \geq 0 \qquad (11)$$

Equation (9) is the manager's incentive compatibility constraint (IC) arising from (6). Equations (10) and (11) are the manager's and shareholders' individual rationality constraints (IR), respectively. The corresponding first-order conditions for the principal's choice of ownership δ, board independence, m, and assets, I, are represented as:

$$\begin{cases} \left.\frac{\partial S}{\partial I}\right|_{I=I^*} = 0 \\ \left.\frac{\partial S}{\partial \delta}\right|_{\delta=\delta^*} = 0 \\ \left.\frac{\partial S}{\partial m}\right|_{m=m^*} = 0 \end{cases} \qquad (12)$$

Supposing all inequality constraints hold, sufficient conditions for any maximum are that the principal minors of the matrix of second cross partial derivatives alternate in sign at that critical point (or the Hessian matrix is negative semi-definite). We eliminate all other maxima in favor of the global maximum. Holding x, r, σ^2, and p constant, the input and output of the above system of equations are:

$$(y,z,t) \rightarrow (I^*, \delta^*, m^*) \qquad (13)$$

Optimal ownership, board composition, and investment, denoted by δ^*, m^* and I^*, arise from exogenous productivity parameters *y*, *z*, and *t*. Finally, the optimal fixed component of compensation, denoted by α^*, is given by substitution in the manager's reservation utility constraint (10).

Despite the simplicity of the model, solving for the maximum is nontrivial. Accordingly, we use numerical methods to solve and verify the conditions for a global maximum. For any combination of the parameters, we can provide $\delta^* = \delta^*(z, y, t, x, r, \sigma, p)$, $m^* = m^*(z, y, t, x, r, \sigma, p)$ and $I^* = I^*(z, y, t, x, r, \sigma, p)$. Reversing the calculation, the functions are numerically invertible for restrictions that reduce the dimensionality of the parameter space to three. In our case, we fix x, r, σ, and p, and then allow y, z and t to vary so as to fit (I^*, δ^*, m^*) to data. In particular, we take δ^* to be effective CEO ownership, m^* to be the proportion of outsiders on the board, and I^* to be firm total assets, and then calculate the combination of y, z and t that would give rise to observed CEO ownership, board composition, and firm total asset as optimal choices in the model. That is, we take (I^*, δ^*, m^*) as given and solve the first-order conditions (12) (making sure the SOCs are satisfied) for (y, z, t). To enable solving (12), we obtain x and r from other studies, estimate σ from a cross-sectional regression, and obtain p for each industry by calibration. In this way, we estimate the parameters y, z and t for each firm-year observation on the triple (I^*, δ^*, m^*).

Our one-period model provides a natural definition for Tobin's Q. Model--generated Q^* equals maximized surplus, S^*, plus optimal initial investment, I^*, plus the random shock, all scaled by optimal initial investment, or:

$$Q^* = \frac{S^* + I^* + I^{*x}(\tilde{\varepsilon} + \tilde{v})}{I^*} \tag{14}$$

Model-generated Q^* arises endogenously from value-maximizing choices of corporate governance and firm investment, the exogenous parameters, utility-maximizing managerial input, expected cash flow $E[\tilde{f}^*] = E[p(I^*)^y((1-m^*)g^*)^z(m^*)^t + (I^*)^x(\tilde{\varepsilon} + \tilde{v})]$ and CEO pay $E[\varphi^*(\tilde{f}^*)] = E[\alpha^* + \delta^*\tilde{f}^*]$, and the realized random disturbance. Expected model generated Q^*, written as EQ^*, is Q^* with the random shock set equal to zero.

IV. Sample Collection and Characteristics

We use the 2003 version of the Execucomp database, covering the years 1993 through 2003. Execucomp provides data on salary, bonus, and total compensation for the top five executives, though we consider only those who are identified as CEOs. For each firm-year we compute the sensitivity of CEO wealth to changes in shareholder wealth (the effective ownership share or pay-performance sensitivity of the CEO). In computing our measure of pay-performance sensitivity (δ^*), we include the effects of the CEO's direct stock ownership, restricted stock, and existing and newly granted stock options.[6]

We obtain board data from the merger of Compact Disclosure for the years 1993-2000 and IRRC for the years 1999-2003. Compact Disclosure gives the name of the company, CUSIP, name, age and designations of both the officers and the directors of the firm. Compact Disclosure obtains these data from the proxy statement filed by the company. If the proxy date is not indicated we cannot align the data, in which case we exclude the observation. We cross-check Compact Disclosure information with the proxy statements directly (using LEXIS-NEXIS) for a substantial portion of the data. One problem with Compact Disclosure is that it identifies only whether the director is an officer of the firm and cannot differentiate among the various types of "affiliated" or "gray" directors. IRRC provides more detailed information on affiliation of directors. Ideally, we would like to use the proportion of truly independent outsiders as our proxy for the board's advising/monitoring intensity, since affiliated directors are not generally viewed as effective monitors due to conflicts of interest (Klein, 1998; Booth and Deli, 1996). Because of the nature of the data, however, we use the proportion of nonexecutive directors for m^* when performing the analysis.[7]

Financial data come from Compustat. We use data on the book value of total assets to represent firm size I^*. To measure firm performance we use Tobin's Q, computed as the book value of total assets minus the book value of equity plus the market value of

[6] For direct stock ownership and restricted stock, the pay-performance sensitivity is computed as the number of shares of stock held by the CEO divided by the number of shares outstanding. For stock options, we follow Yermack (1995) and compute the pay-performance sensitivity arising from stock options as the option delta from the Black-Scholes option-pricing model (the change in the value of the stock option for a one dollar change in the stock price) multiplied by the ratio of the number of shares granted to total shares outstanding. We compute option deltas separately for new option grants and existing options, following Core and Guay (2002). For newly granted options we assume a maturity of seven years because executive stock options are generally exercised early (Carpenter, 1998; Huddart and Lang, 1996; Bizjak, Bettis, and Lemmon, 2003). For existing options, we assume that unexercisable options (those that are not vested) have a maturity of six years and that exercisable options (vested) have a maturity of four years. The risk free rate and volatility estimates for each firm year are given in Execucomp.

[7] Fortunately, the correlation between the two datasets during the two overlapping years (1999 and 2000) is 0.9775. We repeat some of our analysis using data only for the two overlapping years (so as to use only the IRRC data on the proportion of independent outside directors). The results are similar.

equity all divided by total assets. We also collect a number of other firm characteristics that have been used in other studies as follows. Research and development expenditures and advertising expenses, both scaled by total assets, measure asset intangibility and growth opportunities. Following Bizjak, Brickley and Coles (1993), we set missing values of R&D and advertising expense to zero. Book leverage is calculated as long-term debt divided by total assets. Return on assets is calculated as net income, subtracting interest and depreciation, scaled by book assets. Firms are classified by industry based on the Fama-French 30 industry classification. Stock return data come from the Center for Research in Security Prices (CRSP).

Summary statistics for our sample of 8,512 firm-year observations are reported in Table 1.[8] As shown in Panel A, the mean effective ownership share of the CEO is 2.97%, indicating that CEO wealth increases about three cents for every dollar increase in shareholder wealth. The standard deviation of the effective CEO ownership is 5.67%. The median board has 10 members, with roughly 2 insiders and 8 outsiders (including affiliated directors). These figures are similar to those in recent studies.[9]

Book assets averages $13,301 million, with a range from $21 million to $1,264,032 million (Citigroup in year 2003). Sales average $5,839 million and range from $0.099 million to $245,308 million (Exxon Mobil in 2003). Firm age is defined as the number of years since the firm first appears on Compustat. Average firm age is 31 years. Leverage averages 0.197, and the average R&D and advertising expense scaled by total assets are 0.024 and 0.011, respectively. Finally, average Tobin's Q for firms in the sample is 1.92. The 90th percentile is 3.32 and the 10th percentile is 1.02.

[8] We start with 8582 firm-year observations. There are 70 firm-year observations we could not identify as a global maximum, which brings down the actual number of observations used in this paper to 8512.

[9] For example, managerial ownership in our sample is comparable to that in Shivdasani and Yermack (1999), which is based on a sample of Fortune 500 firms. Bhagat and Black (2001) report a median board size of 11 members with 3 insiders using data for the year 1991. Huson, Parrino, and Starks (2001) find that in their sample, for the period 1989-1994, the median board size is 12, with median insider fraction of 0.21. Yermack (1996) finds that over the period 1984-1991, the median sample firm has 12 board members with an insider fraction of 0.33. Coles, Daniel, and Naveen (2008), based on the period 1992-2001, find medians of 10, 2, and 8 for board size, number of inside directors, and number of outside directors.

V. Empirical Implementation

A. Estimates of the exogenous productivity parameters

To identify the model, we fix σ at 0.333 and r at 4. Risk aversion of $r = 4$ is taken from Haubrich (1994).[10] Our estimate for σ is based on the median annualized volatility of monthly stock returns for all firms in our data. To obtain an estimate of the scale parameter, x, we follow the methodology in CLM (2006). In particular, we regress $\ln(\sigma^e)$ on ln(*I*), where I is total book assets of the firm. For each firm, cash flow volatility (σ^e) is calculated as the standard deviation of the time series of monthly total dollar stock returns (from CRSP) over the 48 months preceding the observation year. We exclude firm-year observations with fewer than 24 months of prior return data. Our point estimate of x is almost exactly 0.5, and x reliably falls between 0.4 and 0.6. The point estimate $x = 0.5$ represents decreasing risk, as measured by standard deviation, per unit of firm scale. Perhaps larger firms operate in more lines of business and are more diversified and less risky per dollar invested in fixed assets. Margin times the Cobb-Douglas scale/unit parameter, p , is calibrated at the Fama-French 30 industry level to match the first moment of model-generated Q^* to that of actual Tobin's *Q*.

For each firm-year observation in the sample, as described above, for $x = 0.5$, $r = 4$, σ as above, and p as calibrated across 30 industries, we use numerical techniques to find the values of y, z and t that match effective CEO ownership, board independence, and total assets (δ^*, m^* and I^*) in the data. Based on the estimated values of y, z and t, observed δ^*, m^* and I^*, as well as (x, r, σ, p) and simulated cash flow shocks, we calculate the value of *Q* predicted by the model. Model-generated *Q** is defined in equation (14). To calculate the additive shock, for each firm year observation we draw a randomly generated values of ε from $N(0, \sigma^2)$ and ν from $N(0, (1-m^*)^2)$, sum the two, and multiply by the square root of total assets ($(I^*)^{.5}(\varepsilon + \nu)$).

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[10] The assumption that risk aversion does not vary across managers and firms is consistent with the choice to exclude adverse selection from the model. Instead, our modeling strategy focuses on differences in contract form, board structure, and firm size being driven by variation in production opportunities rather than by differences in managerial preferences.

Panel B of Table 1 presents summary statistics for the estimated productivity parameters derived from solving the model to match the data. The mean value of y is 0.583 and the median value is 0.608. The mean (median) value of z is 0.289×10^{-2} (0.0044×10^{-2}). The mean and median values of t are 0.291×10^{-2} and 0.0102×10^{-2}, resp.

B. Comparative statics

One significant benefit of fitting a structural model to data is the ability to gauge the economic significance of the underlying structural parameters as determinants of organization form and performance. Table 2 presents a comparative statics analysis of the effect of changing parameters $(z, y, t, x, r, \sigma, p)$ on the optimizing choice of investment, managerial ownership, and board composition, as well as firm performance. Because δ^*, m^*, I^*, and Q^* are highly nonlinear in the structural parameters, we calculate optimal ownership, board composition and firm size for a benchmark level of the parameter plus and minus a perturbation in that parameter and then calculate the percentage changes in δ^*, m^*, I^* and Q^*. In all calculations, we use the industry median values of the exogenous parameters $(z, y, t, x, r, \sigma, p)$ as the benchmark levels. We calculate the average across industries of the change in the variable of interest.

Table 2 reports that a 10% increase in *z*, which increases the marginal productivity of managerial effort, implies an increase of 4.85% in the optimal ownership level of the CEO and a 1.41% decrease in board independence. A 10% increase in *t*, which increases the marginal productivity of outside director input, implies an increase of 1.53% in the optimal proportion of outsiders on the board. Increasing *y* by 10%, which increases the marginal productivity of investment, induces a large 335.74% increase in the optimal investment scale, a 3.83% decrease in the optimal ownership level of the manager, and a 0.38% decrease on board independence. Neither *z* nor *t* has much effect on firm performance Q^*. In contrast, a 10% increase in the value of *y* (and corresponding increase in investment) induces a relatively large decrease (8.99%) in Q^*.

Consistent with the basic predictions of the standard principal-agent model, an increase in σ, which determines the volatility of cash flows, reduces the optimal level of managerial ownership. Interestingly, an increase in cash flow risk, reduces the optimal proportion of outsiders. An increase in *x*, which determines the extent to which scale affects cash flow volatility, decreases ownership but has very little effect on Q^*, investment, and the proportion of outsiders on the board. Increases in managerial risk aversion are negatively related to the optimal level of CEO ownership. An increase in risk aversion, however, has only negligible effects on investment, board composition and firm performance. All else equal, an increase in scaled profit margin (p) increases the optimal ownership of the manager and the size of the firm, but has negligible effects on board composition and Q^*. When the values of the parameters are decreased by 10% from their benchmark levels, the changes in the endogenous variables have the opposite signs, yet are somewhat different in magnitude, reflecting the nonlinearities in the model.

These results illustrate how heterogeneity in the contracting environment across firms can give rise to a wide array of optimal governance structures across firms and across time. Importantly, we are also able to provide evidence on the economic significance of different governance arrangements. These figures go some distance toward satisfying the call by Zingales (2000) and others for a quantitative theory of the firm that is empirically implementable and testable and that allows an assessment of the economic significance of various dimensions of the organization.

C. Estimated parameters by industry

To provide a further assessment of the model, Table 3 reports median values of the estimated structural parameters, y, z and t, endogenous insider ownership, board composition and investment (i.e., δ^*, m^* and I^*), and Q^*, across industries, and shows that our estimates of the productivity of managerial effort, outside director advising and monitoring, and physical assets all appear to vary in a "reasonable" and plausible way across industries. The parameter y, a measure of the importance of physical capital in the production process, is high in a broad spectrum of industries, ranging from Utilities, Textile, Steel and Manufacturing. Both managerial effort and inside director expertise are most productive in Restaurants and Hotels, Apparel and Transportation. Outside directors are relatively important in Apparel, Transportation and Financials.[11] It is also interesting to point out that industries with a high value for the productivity of physical assets normally carry a low value for the other two parameters measuring the productivity of

[11] See the survey of Murphy (1999) for evidence of similar variation in pay-performance sensitivity across industries.

human capital. Physical assets are most important relative to human capital (the ratio of y over the product of z and t) in Metal and Mining, Utilities and Business Suppliers.

D. Correlations: exogenous parameters, endogenous choices, and other variables

Finally, Table 4 reports correlation coefficients between the estimated productivity parameters and a number of other variables that have been used either as control variables or firm performance measures in other research. Though we focus the discussion on the Pearson correlations, for completeness we also present the Spearman rank correlations. The correlation between y and z is -0.08 (significant at the 1% level). The negative correlation between y and z is consistent with the previously documented negative relation between effective CEO ownership (wealth to performance sensitivity) and firm size. Indeed, the correlation between ownership and total assets in our data is also negative and significant, indicating that CEOs in larger firms have smaller ownership shares. The correlation between y and t is -0.05 (significant at the 1% level). The negative relationship between y and t suggests that larger firms should also have a smaller proportion of insiders on the board. This relation is confirmed in our data by the positive correlation between total assets and the proportion of outsiders. It is also consistent with the results in Coles, Daniel, and Naveen (2008), who argue that larger firms are more complex and will therefore have more independent directors.

The correlation between z and t is 0.70 (significant at the 1% level). Can this positive relationship between z and t mean that the board will optimally have more outsiders when the CEO has higher effective ownership (higher sensitivity of wealth of performance)? The comparative statics suggest that the positive effect of an increase in z on optimal ownership will bolster the same effect of an increase in t. In contrast, changes in z and t have opposite effects on board independence, and in some cases the negative effect of an increase in z on board independence can more than offset the increase in the optimal proportion of outsiders from an increase in t. It is through this channel that differences in firm characteristics (represented by differences in the productivity parameters) drive the observed relationship between ownership and board independence to be negative in the data.

Note that, in some sense, effective ownership and board independence are "complements" in production. To be specific, for $\delta \leq \delta^*$, $m \leq m^*$, and $I \leq I^*$, it can be shown that the second cross-partial derivatives of expected surplus in δ and m are positive.[12] Thus, an increase in board independence increases the marginal impact of effective ownership on expected surplus. Holding scale constant, maximizing expected surplus is the same as maximizing firm value, so effective ownership and board independence are complements in production in the conventional sense for usage of those governance mechanisms below the optimal values.

Nonetheless, it is important to point out that it is variation in the exogenous productivity parameters, not the shape of the "production function," that define the contracting environment that drives the relationship between the two endogenous choices of ownership and board independence. Indeed, optimizing choices of ownership and board structure will place the firm at the *top* of the objective function. Thus, it is the variation in the location of that maximal point across firms and over time that gives rise to the ultimate relation between ownership and board independence in the data. More precisely, it is the co-variation in the productivity parameters that drives the negative relation between jointly-determined δ^* and m^* in the cross-section.

Within our model, the optimal choices of ownership and board structure are jointly determined along with firm performance. If our model is a poor representation of the forces operating in the firm, then the characteristics of model-generated Q^* will not match the data. On the other hand, if our model captures some of the important economic determinants of the structure of the firm, then Q^* derived from the productivity parameter estimates, should be consistent with the data.

The mean of actual Tobin's Q in our sample is 1.9, the same as the mean of model-generated Q^*. The standard deviation of actual Q (Q^*) is 1.56 (0.84). Actual Q has larger variation than model-generated Q^*. One reason is that additional or latent factors outside our model are likely to influence realized firm performance. Nonetheless, Table 4 shows that the Pearson (Spearman) correlation coefficients between Q^* and actual Q are 0.32 (0.47), and both are significant at the 1% level.

Finally, Table 4 also shows that both actual Q and model-generated Q^* are correlated in a similar manner to variables outside of the model. Both are positively related to CEO ownership, R&D expenditures, and return on assets. Both actual Q and

[12] There is no analytical solution for this partial derivative. We use a numerical approach and the data.

model-generated *Q** are negatively related with total assets, sales, leverage, and firm age. The negative relationship between firm performance and firm scale is due to the decreasing returns to scale in the Cobb-Douglas production function. In terms of board structure, board size is negatively related to both actual *Q* and model-generated *Q**, which indicates that smaller boards tend to be associated with higher firm valuations (as in Yermack, 1996). The proportion of outsiders also is negatively related to both actual *Q* and model-generated *Q**. In short, model-generated *Q** has the same relationship with most firm characteristics as actual *Q* does, suggesting that our model is successful in capturing some of the primary economic factors that jointly determine board independence, CEO ownership, firm size, and firm performance.

VI. Results for Performance on Structure

Table 5, Panel A, examines the relationship between firm performance and governance structure in a regression framework. When we regress actual *Q* on ownership and the square of ownership (Model 1), we see the commonly reported result of an "inverted-U" or "hump-shaped" association between ownership and Tobin's *Q* (e.g., McConnell and Servaes, 1990). The coefficient estimate on the CEO's ownership share is 3.765 (p-value < 0.01), and the coefficient estimate on the squared ownership of the CEO is -7.707 (p-value < 0.05). The ratio of the coefficient estimate of the linear term to that of the squared term is 0.49, which corresponds to a maximum *Q* at CEO ownership of about 24.5%.[13] We replace actual *Q* with model-generated *Q** in Model 4. The hump shape persists, with the maximum occurring at a similar level. One established interpretation of this finding is that the incentive effects associated with higher ownership are strong for low to medium levels of ownership, but that entrenchment effects become dominant at high levels of CEO ownership (Stulz 1988). An alternative interpretation, consistent with the model herein (and CLM, 2006), is that these results can also arise as the outcome of value maximizing choices of organizational form driven by the underlying exogenous characteristics of the firm as represented by *y*, *z*, and *t*.

[13] CLM (2006) report a figure of 20% CEO effective ownership to reach maximum *Q*. The maximum based on the result in McConnell and Servaes (1990) occurs at about 37.5% ownership for the larger group of officers and directors.

Model 2 regresses actual *Q* on the level of board independence and shows that *Q* is inversely related to board independence. This is similar to results reported in Yermack (1996) and Agrawal and Knoeber (1996). The result is somewhat counterintuitive relative to the conventional wisdom, which suggests that independent directors provide better monitoring compared to inside directors, but can be explained within the context of our model by the fact that firms with high productivity of CEO effort (and therefore high values of Tobin's *Q*) optimally choose less independent boards. Model 5 shows that similar results hold when actual *Q* is replaced with model-generated *Q**. Finally, Models 3 and 6 show that both ownership and board independence remain statistically significantly associated with firm performance when both are included in the regression. Moreover, as the estimated coefficients indicate, the model produces simulated results that are similar to those in the data.

These simple specifications with no control variables essentially ignore what we know from the model. We now exploit the structural model to evaluate further the results in Table 5. Within the model, optimal ownership, board structure and firm performance are all endogenously determined as value-maximizing choices by the exogenous productivity parameters *z*, *y*, and *t*, that define the contracting environment. In the context of our model, a properly specified empirical test should not detect any significant relationship between *Q* and the corporate governance variables once we control adequately for the exogenous parameters. Table 6, model 1 reports regression that include a relatively parsimonious set of nonlinear functions of *z*, *t* and *y* to control for the structural determinants of *Q**. Note that we do not know the exact functional form to use because the model is not solvable in closed form.

The adjusted R^2 from Model 1 in Table 6 is equal to 17%, which is dramatically (34 times) higher than the R^2 for Model 1 in Table 5. Model 2 shows that regression including the governance variables and the estimated productivity parameters drives out the relations between *Q* and ownership and board structure documented in Table 5. None of the coefficients on δ, δ^2, and m are significant. Models 3 and 4 use model-generated *Q** as the dependent variable. As expected the R^2 of the regressions in both models are very high because *z*, *y*, and *t* are by definition the correct explanatory variables and because the noise from the random shocks to *Q** that we induce appears to be modest. Also, as expected within our equilibrium context, adding nonlinear functions of the exogenous productivity parameters, z, y, and t to the regressions drives out the effects of ownership and board independence in explaining firm performance.

The evidence in this section suggests that the model does a reasonable job explaining performance, board independence, and ownership. The explanatory power of effective ownership and board independence, using either model generated Q^* or actual Q, are either eliminated or reduced substantially by the inclusion of the exogenous variables suggested by our structural model.[14]

VII. Results for Structure on Structure

The evidence on the relation between CEO pay-for-performance sensitivity and board independence is mixed. Denis and Sarin (1999), Baker and Gompers (2003), Shivadasani and Yermack (1999), and Coles, Daniel and Naveen (2008), document a negative relationship between CEO ownership and board independence. In contrast, Core, Holthausen and Larcker (1999) find that the proportion of outside directors is significantly positively related to the amount of performance-based pay given to the CEO. Ryan and Wiggins (2004) and Davila and Penalva (2004) find a positive relation between insider ownership and the proportion of outsiders on the board. Our model suggests that CEO ownership and board independence are determined by the exogenous productivity parameters. Variation across firms and over time in these parameters could lead to either a positive or negative relationship between value-maximizing CEO ownership and board independence. What guidance does our model provide?

Note that an increase in the productivity of outside director advising/monitoring (t), as Table 2 indicates, implies an increase in ownership and an increase in board independence. Thus, holding the other two productivity parameters, y and z, constant, there will be a positive relation between ownership and board independence. Ownership and board independence, however, will move in the opposite direction if we

[14] We do not suggest that other forces are unimportant. In contrast, it is quite likely that factors other that z, y and t (and p, r, x, and σ) also affect investment, managerial ownership and board structure. Such variables may include takeover and anti-takeover provisions, exchange rates, monetary and fiscal policy, government regulation, taxes etc. Our model can be nested within a model that includes additional such factors, in which case formal statistical tests of their explanatory power would be simple to perform. This is a logical next step.

hold y and t constant and let z vary across firms. In contrast, if the productivity of physical assets (y) increases while t and z are held constant, there is a decrease in both ownership and board independence. In other words, depending on how the three productivity parameters move across firms and industries, the model can generate either a positive or negative relation between ownership and board independence. If parameter z moves to a larger extent in the cross section than parameter t, or if parameter y moves in the opposite direction from z or t, then we would expect ownership to be negatively related to board independence. Indeed, as indicated in Table 4, both z and t are negatively correlated with y and, correspondingly, board independence and ownership are negatively correlated in the data.

Table 5, Panel B, reports the results from regressing ownership on independence and vice versa, both with and without controlling for "growth opportunities" as represented by actual Q and model-generated Q^*. The estimated coefficients on independence (m^*) and CEO effective ownership (δ^*) are significantly negative in all six specifications, suggesting that these two incentive mechanisms are substitutes in value creation. Including growth opportunities has little effect on these coefficients, though it is interesting that the sign on growth opportunities is positive when the dependent variable is effective ownership and negative when the dependent variable is board independence.

Table 7 reports regressions similar to those in Table 6. The specifications test whether simple functional forms of the three productivity parameters can explain the negative relation in Table 5 between ownership and board independence in structure-on-structure regressions. In this comparison, because Table 7 does not control for gowth opportunities, focus on Models 1 and 4 of Panel B in Table 5.

In Table 7, the dependent variable is ownership in Model 1 and 2 and board independence in Model 3 and 4. Per Models 1 and 3, it turns out again that using simple functional forms of three productivity parameters can explain 89% and 24% variation in ownership and board independence, respectively. Notice that the lower R^2 in Model 3 is likely to reflect the fact that board independence does not vary too much in the sample. The null hypothesis arising from our model is that once we control for the productivity parameters, variation in ownership should not be associated with variation in board independence. The evidence in Models 2 and 4 supports this hypothesis. When ownership is the dependent variable in Model 2, the coefficient on board independence is negative but insignificant. We obtain a similar result when we regress board independence on ownership in Model 4. In comparison to Models 1 and 4 in Panel B of Table 5, the productivity parameters extracted from the contracting model have power to explain the joint determination of optimal board independence and CEO ownership.

The results in Section VI and Section VII warrant additional comment. In actual data the econometrician does not observe the exogenous productivity parameters. Instead, existing studies employ numerous proxy variables, such as industry, R&D, etc. to control for differences in the underlying contracting environment. Nevertheless, model specification issues arise both from the unobservability of the underlying exogenous parameters and from the fact that the relation between ownership and board independence is a nonlinear function of these exogenous variables. Absent a properly specified model, it is easy to generate spurious relationships between various governance and performance variables that are not causal. By specifying a structural model and extracting estimates of the underlying exogenous parameters we are able both to avoid some of these issues and to identify some of the likely primary economic determinants of governance structure.

VIII. Policy Analysis—The Case of Board Reforms

In this section we use our model to analyze the consequences of restrictions on the contract space for governance and firm value. In doing so, we provide additional perspective on our conclusions above and also highlight the advantages of our structural approach for understanding the implications of regulation for corporate governance.

In response to recent corporate governance failures, the US Congress, through the Sarbanes-Oxley Act of 2002, and major stock exchanges, through listing requirements, established new restrictions on the structure and operation of boards. One purpose of recent changes in exchange listing requirements, for example, is to strengthen governance practices of listed companies by increasing the role and authority of independent directors. For instance, since late 2003 the NYSE and NASDAQ have required that a majority of board members on a board be independent. Again viewing the firm is an incentive system

(Holmstrom and Milgrom, 1991), in addition to the direct, intended effects of this requirement, the question arises as to the effects of a minimum for board independence on other governance choices. When various incentive alignment mechanisms are determined in combination, how does a restriction on one mechanism influence optimizing choice of another?

Chhaochharia and Grinstein (2008, CG hereafter) examine the effects of the various new requirements for board structure and procedure on executive compensation. Using a difference-in-difference approach, they find a significant decrease in CEO compensation for firms that were more affected by these requirements compared with firms that were less affected. The effect is economically large -- according to their estimates, CEO compensation in the affected firms declines by around 17% following the reforms. They identify minimum board independence as the relevant restriction and lower bonuses and stock option grants as the reason for lower compensation.

CG (2008) note that one possible interpretation of these results, per Jensen (1993) and likely reflecting the intent of the rules, is that an increase in board independence decreases the power of management over directors, reduces rent extraction (e.g., through lower "excessive" compensation), and increases shareholder value. Of course, our model provides an alternative interpretation. A one-size-fits-all restriction or regulatory reform forces newly constrained firms away from their preferred board structure and causes them to readjust the usage of other governance mechanisms in response. We use our model to assess the whether the changes in compensation that would be generated within a value-maximizing framework are consistent with those documented by CG (2008).

For comparability to CG (2008), we use compensation data and director information in year 2000 and 2001 as the pre-SOX period, and data for years 2004 and 2005 as the post-SOX period. While the listing requirements on board independence were not formally adopted until 2003 and implemented in 2004, it is likely that it was well-understood by most firms at the passage of SOX that such restrictions would be imposed. Accordingly, we partition time by pre-SOX and post-SOX, even though SOX itself imposed no minimum for board independence. We include in the analysis only firms that existed in both periods so as to avoid any structural changes in the sample composition due to entries and exits. We obtain total assets, effective CEO ownership (including options), and the proportion of insiders on the board (as defined by IRRC). We average firm-year observations at the firm level in pre- and post-SOX periods.

To evaluate the effects of the restriction on board independence we follow a two-step procedure. We first extract the productivity parameters (*y*, *z*, *t*) using pre-SOX firm size, CEO ownership and board independence as optimal choices in our model. The process is the same as described in Section 2. We assign these estimates of the productivity parameters to the same firm in the post-SOX period. The second step is to generate predictions of post-SOX firm size and CEO ownership from the model that are consistent with post-SOX board structure and the parameter estimates generated in the first step. In particular, we obtain post-SOX optimal firm size and CEO ownership by maximizing the total surplus in equation (7) with respect to I and δ, given estimated (*y*, *z*, *t*), observed post-SOX board independence, and the other exogenous parameters. That is, we solve the first two of the FOCs in (12), having inserted $(z, y, t, x, r, \sigma, p)$ and observed m, which presumably is optimal m^* for unconstrained firms and is suboptimal $m^c \geq 1/2 > m^*$ for those constrained by the minimum independence requirement. This yields $(I,\delta) = (I^*, \delta^*)$ (or at least $(I,\delta) \approx (I^*, \delta^*)$ if the parameters are only approximately stationary) when board independence is unconstrained and $(I,\delta) = (I^c, \delta^c) \neq (I^*, \delta^*)$ when board independence is constrained by the minimum away from the optimum. Notation for decision variables and performance for unconstrained versus constrained firms varies in similar manner by superscript: for example, α^*, g^*, $\tilde{f}^*$, $\varphi^*(\tilde{f}^*)$, and Q^* versus α^c, g^c, $\tilde{f}^c$, $\varphi^c(\tilde{f}^c)$ and Q^c, respectively. The final sample size is 1,132 firms as the model fails to provide a solution for 2 firms.

We compare these estimates of (I,δ) and level of expected CEO compensation $E[\varphi(\tilde{f})]$ to the results in CG (2008). Following CG (2008), we designate as non-compliant firms that do not have a majority of independent directors on the board in year 2002. We find 936 compliant (unconstrained) firms and 196 non-compliant (constrained) firms. The proportion of non-compliant firms in our sample is 17%, the same as reported in CG (2008) for their data in 2002.

Given the linear contract in our model, total compensation, $\varphi(\tilde{f}) = \alpha + \delta\tilde{f}$, is the sum of base salary and performance-based compensation. We obtain base salary from the model by assuming that the participation constraint is binding and solving for the manager's reservation utility. The expected value of the performance-based compensation is the level of CEO ownership multiplied by expected firm cash flows from (1). Firm size and effective CEO ownership in the pre-SOX period come from Execucomp. We obtain board independence in both the pre- and post-SOX periods from the IRRC. Recall, however, that we simulate the post-SOX values of compensation, ownership and firm size as value maximizing choices from the model.

Table 8 presents summary statistics from our simulation. Panel A provides summary statistics for the entire sample. Average total compensation increased from \$6.964 million in the pre-SOX period to \$7.47 million in the post-SOX period. Average base salary increased from \$2.154 million to \$2.318 million. Average effective CEO ownership increased from 0.033 to 0.035 and the corresponding value of performance-based compensation increased from an average of \$4.81 million to \$5.152 million. Consistent with the mandates of the reforms, board independence increases from 64% to 70%. Average firm size decreased from \$13.7 billion to \$13.0 billion.

Panel B partitions the sample into compliant and non-compliant subsamples. The increase in board independence in the full sample is driven by non-compliant firms, with average independence increasing from 37% pre-SOX to 53% post-Sox. In contrast to the figures for the full sample and compliant subsample, CEO compensation *decreased* following board reforms.. For non-compliant firms, total compensation decreased from \$10.102 million to \$9.398 million. The performance-based component dropped from \$7.298 million to \$6.634 million as CEO effective ownership dropped from δ^* = 0.059 to δ^c = 0.055. Furthermore, for newly constrained firms managerial effort decreases on average in response to the change in board independence.

In our model these effects are simple to explain. The ratio of managerial productivity (*z*) to outsider director productivity (*t*) for non-complaint firms is three times higher than the ratio for compliant firms. Hence, for non-compliant firms, inside director expertise is much more important to firm production than outside director advising and monitoring. As these firms are forced away from their preferred board structures by the minimum independence requirement, they decrease the pay-performance sensitivity of the manager's contract. Moreover, newly constrained firm size declines on average from \$13.1 billion to \$12.3 billion (versus a significantly less severe decline from \$13.8 to \$13.2 billion for unconstrained firms) as a less-effective combination of governance attributes $(\delta^c, m^c) \neq (\delta^*, m^*)$ implies lower returns to investment. All of these effects combine to decrease expected cash flow from \$386 million to \$368 million, a 4.7% loss in value to shareholders. The offsetting effects of a less-effective governance package and smaller firm size (when production is Cobb-Douglas) are manifested in smaller average $Q^c < Q^*$ for constrained firms and no change in Q for unconstrained firms.

Panel A of Table 9 presents the univariate analysis for the change in the natural log of total compensation from pre–SOX period to the post-SOX period for both compliant and non-compliant firms. The last row of the table reports the t-statistics and Wilcoxon rank sum tests for the differences in means and medians, respectively. Like the results documented in CG (2008), both tests suggest that the decline in total compensation from the pre-SOX period to the post-SOX period is significantly more negative for non-compliant firms compared to compliant firms.

Panel B in the table presents the results from the following regression specification over the balanced panel of 1132 firms.

Log(total compensation) = Post-SOX + Non-compliant + Post-SOX*Non-Compliant + Sales*Pre-SOX + Sales*Post-SOX + ROA*Pre-SOX + ROA*Post-SOX + Returns*Pre-SOX + Returns*Post-SOX + Tenure

Post-SOX is a dummy variable that equals one if the observation is from the years 2004 or 2005, and zero otherwise. Pre-SOX is a dummy variable that equals to one if the observation is from the years 2000 or 2001, and zero otherwise. Non-compliant is a dummy variable that equals one if the firm did not have a majority of independent directors on the board in the year 2002, and zero otherwise. To account for other firm characteristics related to compensation, we also include the natural log of company sales.

In Panel B, using a difference-in-difference multivariate analysis, we examine the impact of board reform on model-genearated managerial compensation, firm's expected cashflows or output and Tobin's Q*, as in model 1, 2 and 3, respectively. The coefficient of the interaction dummy Post-SOX and Non-compliant in model 1 is -0.121 and significant. It indicates a drop in the compensation of CEOs in newly constrained firms that is larger by 12.1%, relative to complying firms. In Model 2 we replace dependent variable with natural log of expected cashflows as in Eq. (1). The coefficient estimate for the interaction term is consistent with univariate result that constrained firms produce less output as a consequence of increasing board independence. Finally, in our framework, the minimum independence constraint represents a net cost to shareholders as firms are precluded from implementing optimal governance. That is what exactly model 3 indicates when we have model-generated Tobin's Q* as our measure for firm value.

The analysis in this section provides three main conclusions. First, we cast considerable doubt on the proposition that a decline in compensation following the increase in board independence arises from decreased power of management over directors and reduced "excessive" compensation. Instead, the reason for the decrease in compensation plausibly is a rational response to constraint on board independence. Second, per just above, our analysis highlights the inferential difficulties of assessing the costs and benefits associated with regulatory reform. Third, our analysis illustrates how a structural approach can be employed to assess the implications and efficacy of policy changes.

IX. Conclusion

We specify a simple structural model of the firm and calibrate the model to data to obtain estimates of three exogenous parameters that determine the productivity of physical assets, managerial input, inside director expertise, and outside director advising and monitoring. Our model augments the principal-agent model of Holmstrom (1979) and Holmstrom and Milgrom (1987) with investment, managerial ownership and board structure decisions. We estimate the productivity parameters that would give rise to the observed levels of ownership, the proportion of outsiders on the board, and investment as optimal choices in our model.

Our estimates of the productivity parameters vary as expected across industries. Physical assets and human capital play different roles in different industries, which lead to various designs of CEO compensation and board structure in practice. Furthermore, we provide comparative statics results that allow us to gauge the economic significance of the underlying structural parameters as determinants of optimal organization form.

Having estimated the structural parameters from the data, we test whether our estimates of the exogenous productivity parameters have power to explain managerial ownership, board composition, and firm performance. Using model-generated Tobin's Q, the model generates the familiar (McConnell and Servaes, 1990) hump-shaped relation between managerial ownership and firm performance. The model also produces a negative relation between model-generated Q^* and board independence that is similar to what appears in our sample using actual Q. When including simple functional forms of the three productivity parameters, neither ownership nor the proportion of outsiders on the board has any explanatory power for firm performance.

Our model also explains the negative relation between managerial ownership and board independence that often appears in the data. The estimated parameters governing the productivity of managerial effort and outside director advising are correlated in such a way that their effects on value-maximizing board independence and managerial ownership give rise to the negative relation between ownership and board independence that is reported in various studies. Controlling in the regression for simple functional forms of the productivity parameters subsumes the explanatory power of board independence. These results on structure on structure, combined with those on performance and structure, suggest that the productivity parameters specified by our model represent some of the joint economic determinants of managerial ownership, board composition, and Tobin's Q.

At the center of our analysis, we examine the extent to which changes in the productivity of physical assets, managerial input, inside director expertise, and outside director monitoring and advising affect optimal managerial ownership and board independence, as well as firm performance. That is, our model represents part of a quantitative theory of the firm that is empirically implementable and testable and that allows an assessment of the economic significance of various dimensions of the organization.

Despite the empirical success of our approach, however, we doubt that our model encompasses all of the relevant economic determinants for managerial ownership and structure of board. Nonetheless, our augmented principal-agent model does provide one possible equilibrium explanation for the relation between performance and various internal governance structures, as well as the interaction among these internal governance structures. Such equilibrium arises from endogenous value-maximizing choices of optimal organizational form, rather than from transaction costs or other market frictions.

Finally, we apply our model to analyze the effects of recent board reforms on compensation policy. Our model replicates the observed drop in compensation associated with changes in board structure but suggests a different interpretation from that espoused by corporate governance activists. Following passage of the Sarbanes-Oxley Act in 2002, a mandated minimum of 50% outside directors implies, for the average newly constrained firm, a 7.0% decrease in optimal compensation and a 4.7% reduction in maximized shareholder value. Our analysis isolates some of the potential costs of one-size-fits-all regulation.

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Table 1: Summary Statistics

The total sample consists of 8512 firm-year observations from 1993-2003. Effective CEO ownership is computed as the fractional direct stock ownership of the CEO plus the effective fractional ownership arising from the CEO's stock option holdings. Firm age is calculated as the years since the firm has been added to Compustat. Leverage is the ratio of long-term debt to total book assets. R&D and advertising expenses are all scaled by total book assets. Tobin's Q is computed as the book value of assets less the book value of equity plus the market value of equity all divided by the book value of assets. ROA is net income, subtracting interest and depreciation, divided by total assets. Board data are from Compact Disclosure and IRRC. Board size is the number of directors on the board. Board independence is defined as the proportion of outside directors who are not the employees of the firm. Panel B presents the parameter calibration results from the model in Section III. y governs the productivity of physical assets, z governs the productivity of managerial effort, and t is the governs productivity of outside director input. Q^* is model-generated Tobin's Q using (14).

Variable	Mean	Median	Std Dev	10 Percentile	90 Percentile
Panel A (firm characteristics)					
Effective CEO Ownership	0.0297	0.0107	0.0567	0.0021	0.0736
Board Independence	0.7361	0.7778	0.1536	0.5	0.9
Board size	10.3005	10	3.1176	7	14
Tobin's Q	1.9200	1.4262	1.5606	1.0200	3.3210
Assets ($millions)	13301.24	2323.79	50020.15	391.1	26220
Sales ($millions)	5838.68	1903.61	13601.32	386.344	13544
Leverage	0.1971	0.1860	0.1526	0.0029	0.3878
Firm age (years)	31.2550	32	15.8738	11	53
R&D	0.0244	0	0.0531	0	0.0846
Advertising	0.0111	0	0.0333	0	0.0382
ROA	0.1353	0.1323	0.0979	0.0313	0.2387
Panel B (model estimates)					
y	0.5830	0.6081	0.1644	0.3509	0.7827
z ($\times 10^2$)	0.2891	0.0044	1.5501	0.0002	0.2704
t ($\times 10^2$)	0.2909	0.0102	1.6684	0.0004	0.3125
Q^*	1.9154	1.6383	0.8432	1.2770	2.8485

Table 2: Comparative Statics

This table presents the comparative static results for optimal CEO effective ownership (δ^*), investment (I^*), board independence (m^*) and expected model-generated Tobin's Q ($EQ*$). The benchmark values for the exogenous parameters, as well as the three choice variables, are the median values in each industry. The table reports the average across all firms of the percentage change based on the 10% increase or decrease in one of the exogenous parameters. Changes in one parameter hold the other parameters constant.

Percent changes for a 10% increases in parameter

	baseline	z	y	t	x	r	p	σ
Investment (I^*)	3307.61	-0.85	335.74	-0.84	-0.85	-0.84	25.55	-0.84
Ownership (δ^*)	0.01144	4.85	-3.83	3.18	-30.56	-3.09	1.61	-5.70
Independence (m^*)	0.76889	-1.41	-0.38	1.53	0.11	0.08	0.08	-0.87
$EQ*$	1.99815	0.11	-8.99	0.11	0.11	0.11	0.11	0.11

Percent changes for a 10% decreases in parameter

	baseline	z	y	t	x	r	p	σ
Investment (I^*)	3307.61	-0.83	-63.56	-0.84	-0.84	-0.84	-22.78	-0.84
Ownership (δ^*)	0.01144	-1.92	7.07	-0.17	48.77	7.06	1.61	10.20
Independence (m^*)	0.76889	1.69	0.07	-1.57	0.03	0.07	0.08	1.15
$EQ*$	1.99815	0.11	11.24	0.11	0.11	0.11	0.11	0.11

Table 3: Summary Statistics by Industry

This table presents summary statistics for estimated parameters, actual (and optimized) values of choice variables, and actual and model-generated (simulated) performance by industry. The 30 industry definition is based on Ken French's classification available from his website. N is the number of firms in each industry. p is the profit margin or unit cost and is fixed for all firms in the same industry. Otherwise, median value is reported for each parameter within the industry. z and t are scaled by 10^2. Q and Q^* are actual and model-generated Tobin's Q, respectively. Ownership (Own.) and investment (Inv.) are the median value of CEO effective ownership and total book assets. Independence (Indep.) is the proportion of outside directors on the board. The standard deviation of Q (Q^*) is calculated within each of the 30 industry groups.

Industry name	**n**	***p***	**Inv. (*I*)**	***y***	**Own. (δ)**	***z*($\times 10^2$)**	**Indep. (*m*)**	**t($\times 10^2$)**	***Q***	***Q****	**std(*Q*)**	**std(*Q**)**
Precious Metals and Metal Mining	52	33	2619.87	0.5940	0.011	0.0118	0.82	0.0215	1.69	1.69	0.71	0.14
Utilities	529	5	10342.69	0.8321	0.007	0.0552	0.81	0.0258	1.19	1.20	0.15	0.03
Business Supplies and containers	268	17	5338.7	0.6808	0.014	0.0316	0.77	0.0531	1.47	1.48	0.59	0.11
Others	100	47	31739.15	0.5946	0.015	0.0234	0.81	0.0729	1.70	1.70	0.61	0.20
Petroleum and Natural Gas	349	24	11731.2	0.6605	0.016	0.0673	0.74	0.0678	1.52	1.52	0.43	0.13
Products and Machinery	349	35	3430.56	0.5811	0.019	0.0543	0.79	0.0893	1.74	1.74	0.88	0.19
Electrical Equipment	109	50	2594.66	0.5352	0.026	0.0998	0.74	0.1244	1.90	1.90	1.54	0.32
Communications	179	126	30791.17	0.5457	0.017	0.1371	0.73	0.1484	1.85	1.86	0.78	0.23
Chemicals	316	32	4837.1	0.6543	0.018	0.1226	0.78	0.2038	1.66	1.54	0.60	0.11
Healthcare	576	351	5213.56	0.3397	0.030	0.1294	0.73	0.1224	3.36	3.36	2.36	1.67
Wholesale	333	13	3010.08	0.6935	0.028	0.1686	0.73	0.3045	1.45	1.44	0.68	0.09
Textiles	60	4	1232.97	0.8272	0.030	0.3866	0.66	0.2489	1.22	1.21	0.39	0.03
Business Equipment	815	208	4403.17	0.3869	0.031	0.2372	0.73	0.2006	2.73	2.73	2.69	0.68
Consumer Goods	182	107	4488.21	0.4616	0.034	0.3422	0.73	0.1767	2.24	2.24	1.21	0.43
Financials	1194	15	53118.23	0.7443	0.026	0.2584	0.75	0.3859	1.34	1.34	0.91	0.08
Printing and Publishing	174	68	2760.84	0.5208	0.034	0.2381	0.76	0.2982	1.93	1.93	0.86	0.18
Automobiles and Trucks	214	16	22070.66	0.6869	0.029	0.3825	0.74	0.2464	1.46	1.46	0.67	0.12
Aircraft, ships and Railroad	87	29	11316.54	0.6519	0.029	0.3984	0.77	0.2668	1.54	1.54	0.45	0.11
Recreation	108	68	4864.1	0.5279	0.041	0.2755	0.69	0.3354	1.91	1.91	2.35	0.20
Restaurants, Hotels and Motels	152	42	2707.62	0.5416	0.044	0.4627	0.64	0.2317	1.87	1.86	0.83	0.21
Steel Works	238	7	3103.21	0.7677	0.026	0.4160	0.75	0.3969	1.31	1.30	0.57	0.05
Food, Beer, Liquor and Tobacco Product	287	204	8642.8	0.4356	0.042	0.4060	0.71	0.3467	2.39	2.39	1.55	0.56
Construction	299	19	2811.04	0.6491	0.039	0.4480	0.73	0.5165	1.54	1.54	0.69	0.11
Retails	578	87	5185.08	0.4938	0.042	0.4477	0.68	0.4500	2.06	2.06	1.26	0.29
Personal and Business Services	588	189	4317.91	0.3809	0.046	0.4224	0.68	0.4354	2.77	2.77	2.19	0.79
Apparel	130	22	1223.84	0.5957	0.066	1.2299	0.67	0.9186	1.68	1.67	0.98	0.15
Transportation	246	16	6528.71	0.6807	0.051	1.2601	0.74	1.0296	1.46	1.46	0.66	0.10

Table 4: Pearson/Spearman Correlation Matrix

Pearson correlations are above the diagonal and Spearman rank-correlation are below the diagonal. The table presents correlations among three four classes of variables: productivity parameters estimated from the model (y,z,t); actual values of decision variables that are value-maximizing in the model (effective ownership, firm size, and board independence); actual and model-generated firm performance (Q and Q^*); and firm characteristics and choices that are outside of the model (sales, leverage, firm age, R&D intensity, and ROA). See Table 1 for variable definitions. Unless otherwise specified (italic), all correlations are significant at the 10% level.

	y	z	t	Ownership	Indep.	Board size	Assets	Actual Q	Q^*	Sales	Leverage	Firm age	R&D	ROA
y		-0.080	-0.046	-0.214	0.205	0.434	0.241	-0.367	-0.855	0.200	0.175	0.340	-0.468	-0.184
z	-0.245		0.701	0.818	-0.255	-0.111	-0.038	*0.016*	0.044	-0.048	-0.040	-0.086	-0.033	*0.017*
t	-0.169	0.893		0.717	-0.045	-0.091	-0.033	*0.003*	*0.016*	-0.043	-0.023	-0.064	-0.043	*-0.005*
Ownership	-0.333	0.983	0.934		-0.296	-0.238	-0.091	0.051	0.175	-0.123	-0.072	*-0.221*	*-0.012*	0.013
Indep.	0.210	-0.402	*0.003*	-0.297		0.213	0.054	-0.065	-0.158	0.077	0.068	0.265	*0.001*	-0.047
Board size	0.437	-0.418	-0.341	-0.446	0.236		0.295	-0.147	-0.372	0.286	*0.012*	0.361	-0.219	-0.077
Assets	0.581	-0.466	-0.391	-0.511	0.236	0.600		-0.077	-0.160	0.529	-0.044	0.073	-0.076	-0.138
Actual Q	-0.473	-0.035	-0.078	*0.004*	-0.087	-0.133	-0.180		0.315	*0.000*	-0.208	-0.132	0.360	0.374
Q^*	-0.998	0.232	0.157	0.319	-0.200	-0.433	-0.578	0.472		-0.171	-0.169	-0.306	0.564	-0.038
Sales	0.409	-0.442	-0.377	-0.475	0.204	0.517	0.820	-0.022	-0.405		*-0.003*	0.231	-0.049	*0.007*
Leverage	0.204	-0.060	-0.024	-0.075	0.094	0.086	0.113	-0.243	-0.201	0.123		0.129	-0.188	-0.062
Firm age	0.309	-0.415	-0.323	*-0.422*	0.261	0.419	0.364	-0.071	-0.305	0.446	0.176		-0.142	0.060
R&D	-0.432	-0.077	-0.058	*-0.014*	0.047	-0.194	-0.176	0.384	0.435	-0.102	0.123	0.446		-0.158
ROA	-0.332	-0.028	-0.054	-0.010	-0.054	-0.088	-0.240	0.625	0.332	0.043	-0.055	0.058	0.150	

Table 5: Pooled OLS Regression for Actual *Q* and Modeled *Q**

This table contains pooled OLS regressions of *Q* on the ownership share of CEO, the squared ownership share of CEO, the board independence. CEO effective ownership ($\delta = \delta^*$) is computed as the fractional direct stock ownership of the CEO plus the effective factional ownership arising from the CEO's stock option holdings. Board Independence ($m = m^*$) is measured by the fractions of outsiders on the board. In model 1-3, the dependent variable is the actual Tobin's *Q*. In model 4-6, the dependent variable is the model-generated *Q**. The numbers in parentheses are robust standard errors, clustered at the firm level. *,**,*** indicates significance at the 10%, 5%, and 1% levels, respectively.

Panel A: Performance on Structure

Dependent Variable:	Actual *Q*			Modeled *Q**		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Intercept	1.840***	2.408***	2.225***	1.7987***	2.554***	2.243***
	(0.042)	(0.145)	(1.459)	(0.022)	(0.088)	(0.089)
Ownership (δ^*)	3.765***		3.007**	5.072***		4.184***
	(1.426)		(1.459)	(0.914)		(0.905)
$(\delta^*)^2$	-7.707**		-6.521*	-8.048**		-6.656**
	(3.391)		(3.366)	(3.173)		(3.064)
Independence (m^*)		-0.663***	-0.499***		-0.868***	-0.577***
		(0.188)	(0.188)		(0.112)	(0.111)
Adjusted R^2	0.005	0.004	0.007	0.038	0.025	0.048

Panel B: Structure on Structure

Dependent Variable:	Ownership (δ^*)			Independence (m^*)		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Intercept	0.110***	0.106***	0.088***	0.760***	0.769***	0.796***
	(0.008)	(0.008)	(0.008)	(0.003)	(0.005)	(0.008)
Ownership (δ^*)				-0.804***	-0.800***	-0.751***
				(0.063)	(0.064)	(0.063)
Independence (m^*)	-0.109***	-0.106***	-0.102***			
	(0.009)	(0.009)	(0.009)			
Q		0.001			-0.005***	
		(0.001)			(0.002)	
Modeled *Q**			0.009***			-0.020***
			(0.002)			(0.004)
Adjusted R^2	0.088	0.087	0.105	0.088	0.089	0.099

Table 6: Non-linear OLS Regression for Performance on Structure

This table contains non-linear OLS regression of actual Q and model-generated Q^* on CEO effective ownership $\delta = \delta^*$ and board independence $m = m^*$ and simple functional forms of the exogenous parameters estimated from the model. The numbers in parentheses are robust standard errors, clustered at the firm level. *,**,*** indicate significance at the 10%, 5%, and 1% levels, respectively.

Dependent	Actual Q		Modeled Q^*	
	Model 1	Model 2	Model 3	Model 4
Intercept	-4.682	-5.354	-0.171	-0.113
	(4.126)	(4.248)	(0.106)	(0.088)
Ownership (δ^*)		1.594		-0.034
		(1.818)		(0.031)
$(\delta^*)^2$		-20.787		2.012
		(20.575)		(1.501)
Independence (m^*)		-0.033		0.001
		(0.172)		(0.003)
y	17.619**	18.597**	0.278	0.187
	(8.217)	(8.401)	(0.195)	(0.166)
z	14.056	16.019	-3.468***	-3.047***
	(10.492)	(37.336)	(0.649)	(0.481)
t	13.834	29.578	-0.748*	-2.547***
	(14.538)	(26.331)	(0.399)	(0.758)
y^2	-14.139***	-14.516***	0.141	-0.096
	(5.247)	(5.315)	(0.117)	(0.101)
z^2	23.251	22.401	0.305	0.637
	(30.698)	(42.584)	(1.001)	(0.859)
t^2	6.673	-1.723	0.309*	1.508***
	(18.968)	(11.092)	(0.175)	(0.429)
$1/y$	0.835	0.955	1.036***	1.023***
	(0.762)	(0.784)	(0.021)	(0.018)
$1/z$	0.001	0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)
$1/t$	0.001	0.001	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
$1/y^2$	-0.021	-0.028	-0.001	-0.001
	(0.041)	(0.041)	(0.001)	(0.001)
$1/z^2$	-0.001	-0.001	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
$1/t^2$	-0.001	-0.001	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
yz	27.109	-4.044	2.237**	1.052**
	(18.133)	(28.078)	(0.949)	(0.491)
yt	-22.312	-36.941	1.206*	2.699***
	(22.766)	(33.385)	(0.638)	(0.903)
zt	-40.510	-12.684	-1.192*	-3.966**
	(54.887)	(34.546)	(0.678)	(1.669)
$1/yz$	0.001	0.001	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
$1/yt$	0.001	0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)
$1/zt$	0.001	0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Industry Dummy	yes	yes	yes	yes
Adjusted R^2	0.177	0.178	0.999	0.999

Table 7: Non-linear OLS Regression for Structure on Structure

This table contains non-linear OLS regression of CEO effective ownership $\delta = \delta^*$ on board independence $m = m^*$ or vice versa, both with control variables and exogenous parameters. The numbers in parentheses are robust standard errors, clustered at the firm level. *,**,*** indicate significance at the 10%, 5%, and 1% levels, respectively.

Dependent	Ownership (δ^*)	Ownership (δ^*)	Independence (m^*)	Independence (m^*)
	Model 1	Model 2	Model 3	Model 4
Intercept	0.087*	0.108**	0.928***	1.024 ***
	(0.048)	(0.048)	(0.321)	(0.317)
Ownership (δ^*)				-1.099
				(0.722)
Independence (m^*)		-0.022		
		(0.025)		
y	-0.072	-0.096	-1.115*	-1.194*
	(0.095)	(0.093)	(0.647)	(0.639)
z	4.938***	4.736***	-9.359***	-3.931***
	(0.445)	(0.456)	(0.938)	(1.009)
t	2.423***	2.541***	5.485***	8.148***
	(0.663)	(0.686)	(1.189)	(1.919)
y^2	-0.025	-0.001	1.141***	1.114**
	(0.061)	(0.059)	(0.429)	(0.423)
z^2	-11.101***	-10.355***	34.506***	22.303***
	(1.379)	(1.352)	(3.581)	(2.877)
t^2	-2.810***	-2.906***	-4.441***	-7.531***
	(0.706)	(0.716)	(1.305)	(1.753)
$1/y$	0.006	0.004	-0.099*	-0.093
	(0.009)	(0.009)	(0.060)	(0.059)
$1/z$	-0.001	-0.001	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
$1/t$	0.001	0.001	-0.001***	-0.001***
	(0.001)	(0.001)	(0.001)	(0.001)
$1/y^2$	-0.001	-0.001	0.001*	0.005*
	(0.001)	(0.001)	(0.001)	(0.003)
$1/z^2$	0.001***	0.001***	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)
$1/t^2$	0.001***	0.001***	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)
yz	-2.391***	-2.401***	-0.465	-3.094*
	(0.687)	(0.692)	(1.644)	(1.837)
yt	-0.831	-0.813	0.832	-0.081
	(1.085)	(1.113)	(2.102)	(3.013)
zt	-0.796	-1.161	-16.889***	-17.765***
	(2.244)	(2.218)	(4.159)	(4.129)
$1/yz$	-0.001	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)
$1/yt$	-0.001	-0.001	0.001***	0.001***
	(0.001)	(0.001)	(0.001)	(0.001)
$1/zt$	-0.001***	-0.001***	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Industry Dummy	yes	yes	yes	yes
Adjusted R^2	0.891	0.893	0.244	0.262

Table 8: Summary Statistics for SOX Analysis

This table shows simulated CEO effective compensation, managerial effort, firm size, board independence, and firm performance for the post-SOX period using model parameters estimated in the pre-SOX period. The sample consist of 1132 firms exist in both pre-SOX period, which is year 2000 and 2001 and post-SOX period, which is year 2004 and 2005. Decision variables are freely optimized for firms that are compliant pre-SOX with the 50% minimum constraint on board independence. For firms that are constrained pre-SOX, board independence is set equal to the post-SOX level and then the remaining decision variables (CEO compensation and firm size) are simulated as constrained optima. Panel A provides summary statistics for all sample firms in both pre-SOX and post-SOX period. Base salary (α^*) is the optimal fixed component of compensation by setting the manager's reservation utility constraint binding. Performance-contingent compensation is CEO effective ownership (δ^*) multiplied by expected cash flows ($E(f^*)$) in Eq (1). Total compensation is the sum of base salary and option-based compensation according to Eq. (4). CEO risk premium and effort (g^*) are given by (5) and (6), respectively. Panel B separates the firms into pre-SOX compliant and non-compliant groups. Firms in the non-complaint group did not have a majority of independent directors in the year 2002. We report the mean (median).

Panel A: Summary Statistics

	Pre-SOX (2000-2001)	Post-SOX (2004-2005)
Base Salary ($MM)	2.154	2.318
	(0.480)	(0.496)
Option-based Compensation ($MM)	4.810	5.152
	(0.481)	(0.502)
Total Compensation ($MM)	6.964	7.470
	(1.130)	(1.152)
Board Independence (m)	0.641	0.701
	(0.667)	(0.721)
CEO ownership (δ^*)	0.033	0.035
	(0.013)	(0.013)
Total Assets	13685.51	13046.32
	(1887.65)	(1859.56)
Model-generated Q*	2.077	2.039
	(1.443)	(1.754)
Expected Cashflows ($MM)	459.369	455.920
	(36.710)	(36.690)
Risk Premium	0.093	0.067
	(0.001)	(0.001)
Managerial Effort (g*)	5.713	4.389
	(0.003)	(0.003)

Panel B: Summary Statistics by Compliant and Non-Compliant firms

	Compliance Firms		Non-Compliance Firms	
	Pre-SOX	Post-SOX	Pre-SOX	Post-SOX
Base Salary ($MM)	2.018	2.224	2.804	2.763
	(0.444)	(0.481)	(0.712)	(0.705)
Option-based Compensation ($MM)	4.286	4.842	7.298	6.634
	(0.461)	(0.481)	(0.555)	(0.536)
Total Compensation (TC) ($MM)	6.304	7.066	10.102	9.398
	(1.034)	(1.078)	(1.626)	(1.579)
Board Independence (m)	0.696	0.737	0.371	0.528
	(0.697)	(0.750)	(0.385)	(0.536)
CEO ownership (δ^*)	0.028	0.031	0.059	0.055
	(0.011)	(0.012)	(0.024)	(0.025)
Total Assets	13806.14	13206.01	13102.81	12283.70
	(2064.48)	(2029.74)	(1321.73)	(1302.58)
Model-generated Q*	2.018	2.006	2.364	2.197
	(1.412)	(1.723)	(1.622)	(1.859)
Expected Cashflows (ECF) ($MM)	474.656	474.353	386.364	367.891
	(42.553)	(42.532)	(20.485)	(20.451)
Risk Premium	0.052	0.052	0.292	0.140
	(0.001)	(0.001)	(0.007)	(0.005)
Managerial Effort (g*)	2.098	2.267	22.887	14.523
	(0.002)	(0.002)	(0.036)	(0.036)
y	0.564		0.519	
	(0.579)		(0.530)	
z ($*10^2$)	0.243		1.356	
	(0.006)		(0.055)	
t ($*10^2$)	0.224		0.327	
	(0.008)		(0.007)	

Table 9: Regression Results for Policy Analysis

This sample consists of a balanced panel of 1132 firms that exist in both pre-SOX and post-SOX period. Post-SOX is a dummy variable that equals to one if the observation is in year 2004 and 2005 and zero otherwise. Pre-SOX is a dummy variable that equals to one if the observation is in year 2000 and 2001 and zero otherwise. Non-compliant is a dummy variable that equals to one if the firm did not have a majority of independent directors on the board in the year 2002 and zero otherwise. Sales is the natural log of company sales. Panel A shows the univariate analysis for change in natural log of total compensation from post-SOX period to pre-SOX period for both complaint firms and non-compliant firms. The last row reports the t-statistics for parametric test for the difference in mean and z-score for Wilcoxon rank sum test for the difference in median. Panel B shows the panel regression. The dependent variable in model 1 is the natural log of total compensation. The dependent variable in model 2 is the natural log of expected cashflows (ECF) in Eq (1). The dependent variable in model 3 is the model generated Tobin's Q*. The numbers in parentheses are robust standard errors, clustered at the firm level. *,**,*** indicates significance at the 10%, 5%, and 1% levels, respectively.

Panel A: Univariate Test

	Mean	Median
Change in Log(total compensation) for Compliant Firms	0.057	0.045
Change in Log(total compensation) for Non-Compliant Firms	-0.015	-0.035
Difference in Difference (Non-Compliant - Complaint)	-0.072	-0.080
T-stats (Z-score)	-4.96	-5.58

Panel B: Multivariate Regression

Dependent Variable:	Log(TC)	Log(ECF)	Q*
	Model 1	Model 2	Model 3
Intercept	-0.078	-3.231***	4.486***
	(0.053)	(0.255)	(0.211)
Post-SOX	0.078	0.456*	-0.026
	(0.138)	(0.232)	(0.082)
Non-Compliant	0.343***	-0.300***	0.091
	(0.126)	(0.105)	(0.066)
Post-SOX*Non-Compliant	-0.121***	-0.114***	-0.033**
	(0.023)	(0.035)	(0.013)
Sales*Pre-SOX	0.475***	0.951***	-0.327***
	(0.032)	(0.034)	(0.026)
Sales*Post-SOX	0.459***	0.865***	-0.314***
	(0.033)	(0.046)	(0.028)
N	2264	2264	2264
Adjusted R^2	0.193	0.486	0.304