Board Power, Board Information, and CEO Talent

Eitan Goldman[*]

February, 2012

Abstract

This paper develops a theory of board power when managers can be more talented and skilled than the board members who monitor them. The paper shows that board power can be helpful in eliminating over-investment by low talent managers, but that this comes at a cost of value destroying intervention by the board when the manager is highly talented. The paper highlights the importance of the interaction between board control and the board's incentive to become informed. Using the model we derive several implications on how board power impacts managerial turnover, managerial investment, and overall firm value. For example, we show that better governance, as measured by more powerful boards, can result in a lower sensitivity of turnover to negative market signals, in boards that discourage risky investments, and in lower overall firm value. The paper thus highlights some of the costs associated with awarding the board of directors with too much power.

[*] Indiana University, Bloomington Indiana, 47401, USA. Email: eigoldma@indiana.edu .
Part of this research was conducted while visiting at the Jerusalem School of Business at the Hebrew University. Thanks to the Lady Davis Foundation for its financial support.

1. Introduction

It has long been argued that an essential ingredient for a good corporate governance system is to have stronger boards that have more power and control. Stronger boards are better because they have a greater ability to mitigate and limit various forms of agency costs. This logic, for example, was at the heart of the Sarbanes Oxley legislation which forced companies to increase the number of independent directors in order to limit the control of the CEO over the company's board of directors.

Our goal in this paper is to construct a formal model of board power and derive from it some theoretical implications on how board power relates to managerial turnover decisions, how board power affects the likelihood of investing in risky innovative projects, and whether or not stronger boards always lead to better governance and higher firm value.

We analyze these issues in a setting where the manager of the firm can either be a low talent manager or a highly talented one. However, her talent level is, initially, not observed by either the board or the market. The manager is faced with a decision to invest in either a high risk innovative project or in a low risk "mundane" project where the agency problem stems from the fact that all managers, regardless of their type, want to invest in the innovative project (an over-investment problem). From the perspective of shareholders, however, only the highly talented manager should invest in the risky project and the low talent manager should invest in the mundane project. Thus, our model allows for the possibility that highly talented managers do not create agency costs.

The role of the board then is to try and learn about the manager's skill level and use its power to approve the high risk investment if it is made by a highly talented CEO and overturn the decision to invest in the innovative project if it is made by the low talent CEO. The board can also use noisy signals from the market to update its assessment of managerial talent and in some cases decide on pursuing a third option in which the board allows the manager to make the risky investment, but with closer board supervision over the project (which will impact the expected project cash flows).

We solve for the resulting equilibrium and analyze the costs and benefits of giving the board more power. The key tradeoff we identify is that giving the board power is beneficial to shareholders as it reduces over-investment by low talent managers as well

as it provides an incentive for the board to invest ex-ante in learning about the manager's true talent level. However, we also find that board power comes at a cost. When the board has the power over decisions, but is either uninformed or is only partially informed about the manager's true talent, then it may use its power and intervene in the running of the innovative project or it will force the manager to invest in the mundane project. Both of these actions will hamper the ability of the "superstar" CEO to maximize her potential from making the risky innovative investment and creating shareholder value.

Thus, our model highlights the cost of board power which stems from the fact that board power does not always come with board knowledge. A key point of our analysis is that CEOs are hired exactly because they are "superstars" who are uniquely skilled to make highly innovative investments. This is the reason why for these CEOs it is extremely costly when they are second-guessed and restricted by the decisions of a less talented board that is not skilled enough to make these investments on its own. The problem is that this well-meaning board may be unaware that their CEO is indeed truly talented. These boards may then, unintentionally, stand in the way of the superstar CEOs from fulfilling their high potential.

The model generates several implications regarding how board control should affect the likelihood of (efficient) innovation, managerial turnover, and firm value. First, investments in risky innovations are of great importance to the economic growth of firms. We show that greater board power can harm investment in innovation since powerful boards will tend to either overturn risky investments by highly talented CEO's or, at times, intervene in these projects resulting in lowered expected cash flows. While this is the direct effect of board power we also show that board power will increase the board's incentive to learn about the CEO's talent level and hence increase the likelihood that the efficient innovative investment will be made. The paper discusses the conditions under which this second indirect effect dominates the direct effect leading to an overall positive relation between board power and efficient innovation.

Second, our model has implications for how managerial turnover relates to measures of good corporate governance (i.e., board control). In particular, several empirical papers (e.g., Weisbach 1988, Denis et. al. 1997, and Huson et. al. 2001), argue that the lack of sensitivity of CEO dismissal to firm performance indicates which boards

exhibit bad governance. Our model demonstrates that this is only partially true. In our model, the board may or may not overturn the decision by the manager to invest in the high risk project. One can view the decision of the board to overturn the manager's investment choice as equivalent to replacing the manager. In this case we show that board power has two effects on whether or not the manager is replaced after observing a negative market signal.

The first direct effect of board power is that it increases the probability that the board will replace (overturn the manager's investment choice) the manager following negative market information. The second indirect effect is that higher ex-post board power also increases the board's ex-ante incentive to collect information on the talent level of the manager. Thus, board power increases the chance that the board will have private information about the manager's talent which in turn will decrease the likelihood that the board will respond to the noisy signal that the market provides. The paper then characterizes the conditions under which greater board power will result in boards that ignore a negative market signal.

Our model generates implications for when firm value increases with a strong board and when firm value falls if the board has too much power. For example, we find that board power increases firm value when the boards cost of producing information are low but it decreases firm value when boards are not skilled at gathering information. We also find that board power increases firm value when the information produced in the market is less noisy. Finally, we find that board power reduces firm value when the board's ability to help with the innovative investment is lower and when the talent pool of managers is of higher quality.

One immediate policy implication from our model concerns the theoretical assessment of the benefit of Sarbanes Oxley which legislated that all boards must have a majority of outside directors. The intent of the legislation was to give boards the power to make decisions, but as a consequence the legislation forced firms to search for new directors that were arguably less knowledgeable and less experienced at monitoring relative to incumbent directors. Our model would suggest that this is the exact combination that results in a decrease in firm value. Increasing the power of the board should be done in combination with an increase of the board's (average) talent level.

Recent literature motivating our work (e.g. Bebchuk 2005) noted that the control of the board over decisions is best even when board members are uninformed. We examine this argument more closely and show the conditions under which it is true.

Two related theoretical papers that also analyze the potential benefit of managerial control, but which use a different tradeoff then ours, are Adams and Ferreira (2007) and Harris and Raviv (2008). These papers use the cheap-talk model based on Crawford and Sobel (1982) to investigate a setting where both inside and outside board members have value relevant information. These papers analyze how board power affects the communication process between the board and the manager.

Adams and Ferreira (2007) consider a board that can both give advice and monitor and show that a friendly board can be better if it motivates the manager to share his private information with the board so that the board can then use this information and make better decisions. The paper concludes that powerful boards will be less able to learn about the manager's private information since the manager will fear the board will use that information to replace her. In contrast, our model shows that a more powerful board will have a stronger incentive to collect information about managerial type and that this may actually result in a lower likelihood of dismissal. Adams and Ferreira (2007) also find that friendly boards can lead to better investment, again due to greater sharing of information, but we find conditions under which friendly boards (i.e., powerful manager) lower the efficiency of investments. Thus, our model offers several alternative empirical predictions due to the fact that we study an alternative mechanism for the importance of board power.[1]

Harris and Raviv (2008) also consider the case where board input helps investments and analyze the optimality of having insiders on the board. Similar to Adams and Ferreira (2007) they find that insider control may be optimal because it allows for better use of the managers information. In addition, they find that insider control also provides greater incentives for outsiders to become informed.[2] This, again, is in contrast

[1] Note that Adams and Ferreira (2007) actually define board independence based on the board's marginal cost of monitoring. Thus, their results speak more to the skill of the board and less to its ability to control the manager's actions.

[2] In related work Harris and Raviv (2010), build on the work of Aghion and Tirole (1997) and explore the issues of formal versus real authority in a setting where shareholders can delegate decision power to management.

to our result that giving manager (i.e., insiders) more power always increases the board's incentive to become informed. [3]

In sum, our model analyzes an alternative channel through which managerial power affects the economic environment. While the above two papers suggest that managerial power will increase the communication of information between the manager and its board, and hence will be more valuable when managerial information is important, we highlight the opposite situation in which managerial power will discourage the board from collecting information because the board will be less able to use this information ex-post. In our model the board does not need the manager's information in order to assess managerial type. We also stress the importance of managerial talent in allocating power to a board that is of lower ability. Finally, our model offers detailed predictions on how board power affects the board's responsiveness to negative (noisy) market information. In addition, we show the conditions under which board power increases the likelihood of observing investments in risky innovative projects.[4]

Our paper also considers explicitly the importance of managerial talent and the skill level of the board. We allow for the possibility that talented managers do not cause agency problems but that low talent managers do. Boards then may make "mistakes" by exerting power and getting involved in the investment decisions of a very talented manager. Thus, the talent level of both the CEO and the board are a central feature of our model. In our model setup we aim to highlight a slightly different view of the traditional agency model which was based on the view that all managers will harm shareholder value if left to invest on their own.

The rest of the paper is organized as follows: In section 2 we describe the model. Section 3 discusses the equilibrium and derives the main results of the paper. Section 4 concludes.

2. Model

The model starts with a firm that has a manager who is in charge of making an investment decision. The manager is supervised by a board of directors. The manager is

[3] This aspect of our paper relates to Burkart Gromb and Panunzi (1997) who showed how monitoring by a large shareholder discourages the manager from making firm specific investments. Burkart Gromb and Panunzi (1997), however, do not consider the question of the optimal allocation of control.

[4] There is also a related literature looking at the dynamics of board power (e.g., Hermalin and Weisbach 1998) and at the determinants of board member characteristics (e.g., Raheja, 2005).

characterized by her talent level, or her type, and this reflects her ability to select a good innovative investment. The manager of the firm comes from the general pool of managers which has a talent distribution with a proportion α of managers that are high types, T_H , and a proportion $1-\alpha$ of managers that are low types, T_L .

2.1 Investment

The manager of the firm faces the choice of either investing in a "mundane" project which has a certain return of R or in an innovative project with a risky return of either zero or $\pi_i T_j$ where $j=\{H,L\}$ reflects the manager's type and $i=\{H,L,B\}$ reflects the impact on cash flows of whoever has control (i.e., either the high talent manager, the low talent manager, or the board). The risky innovative project has an ex-ante probability of success of 0.5 and a 0.5 probability of failing and providing zero cash flows.[5]

We make the following assumption about the expected payoffs of the two projects.

Assumption 1: Project payoffs satisfy, $\frac{\pi_H T_H}{2} > R > \frac{\pi_L T_L}{2}$.

Assumption 1 implies that the innovative investment is better than the mundane investment if it is managed by the high talent manager. In contrast, if the CEO is a low talent CEO then the munane investment dominates the innovative project.

In addition to generating cash flows we assume that each project offers the manager with private benefits. In particular, we assume that the manager gets a private benefit of $B>0$ if she invests in the innovative project and a private benefit of zero if she invests in the mundane project. We further assume that these private benefits are sufficiently high so that any manager would prefer to invest in the high risk innovative

[5] We consider our risky investment as an innovation in the sense that it is risky relative to the mundane project, its success requires the input of a high talent CEO, and its payoff is in the long-term and cannot be used to solve the agency problem. For a more explicit model of innovation see, for example, Holmstrom (1989) and Manso (2011).

investment over the mundane one. Therefore, the agency problem facing the board is a standard over-investment problem.

2.1.1 Board Intervention

The board may also impact the cash flow from the risky projects if it decides that it is in the best interest of shareholders that the board becomes more involved with the implementation and the day to day running of the innovative investment. We assume that the ability of the board to affect the expected cash flows from the risky project is higher than that of the low talent manager but lower than that of the high talent manager. Hence, board intervention will be suboptimal at times and optimal at other times. In particular, we make the following assumption.

Assumption 2: $\frac{\pi_B T_H}{2} < \frac{\pi_H T_H}{2}$ and $\frac{\pi_L T_L}{2} < \frac{\pi_B T_L}{2} < R$

The impact of board intervention on expected cash flows is modeled through the parameter π_B which replaces π_H in the case of the highly talented manager and π_L in the case of the low talent manager. The economic interpretation of Assumption 2 is that when the board intervenes in the innovative project that is managed by a highly talented manager it ends up lowering the expected cash flows from the project while intervening in the decisions of the low talent manager who invests in the innovative project will increase expected cash flows.

Note that, we Assumption 2 also states it is always better to invest in the mundane project if the manager is a low talent manager and regardless of whether or not the board helps with the innovative project by supervising the manager's decisions.

2.2 Information

The board is initially uninformed about the talent level of the manager. If the board was fully informed and if the board had control over decisions then it would allow the high talent manager to invest in the risky project and require that the low talent manager invest in the mundane project (Assumption 1).

However, in the case where the board is uninformed and does not possess any new information about the talent level of the manager the board considers an investment in the risky project to have an expected cash flow equal to $\alpha \frac{\pi_H T_H}{2} + (1-\alpha) \frac{\pi_L T_L}{2}$. This needs to be compared with the cash flow from the mundane investment, R .

The basic tension in the model is that a fully informed board prefers to allow the high talent manager to invest in the innovative project and prefers that the low talent manager invest in the mundane project. The uninformed board, in contrast, may prefer that the manager invest in the mundane project if it makes an assessment that there is a sufficiently high probability that the manager is a low talent one. Hence, collecting information about the manager's type is valuable as this may reduce the potential cost of over-investment.[6]

After the manager works at the firm and the board sees her in action the board decides on an effort level e which determines the probability that it will be able to learn the manager's true type. We assume that with probability e the board becomes fully informed about the manager's talent level and that with probability $1-e$ the board learns nothing. The cost of becoming informed is, $C(e) = \frac{1}{2} ce^2$.

The role of the board in our model is to collect information and approve or reject managerial investment ideas and, at times, to become actively involved with the implementation of these investment decisions.

The information environment is also characterized by an additional signal that is produced in the market place once the manager announces his intension to make the innovative investment (but before it is finally approved or dismissed by the board). This information can be used by the board if it helps in making a better investment decision. We assume that after the board collects its information the market generates an additional signal which is a noisy indication of whether or not the manager is a high talent CEO. One can think of this market signal as the stock price response to announcements made

[6] As mentioned, we abstract from any consideration of the optimal contract by implicitly assuming that the private benefits from investing in the risky projects are very high. Recent models that focus on optimal contracts to limit over-investment include, for example, Almazan and Suarez (2003),and Inderst and Mueller(2010).

by the CEO to undertake the innovative project.[7] In particular, we assume that the market observes a signal $S = \{High, Low\}$ with the following structure,

$$\left\{\begin{array}{l} \text{If manager talent is } T_H \text{ market observes high signal with probability } P_H \\ \qquad\qquad\qquad\qquad \text{market observes low signal with probability 1-}P_H \\ \text{If manager talent is } T_L \text{ market observes high signal with probability } P_L \\ \qquad\qquad\qquad\qquad \text{market observes low signal with probability 1-}P_L \end{array}\right\}$$

Assumption 3: The market signals are informative implying that, $P_H > P_L$.

The market signals can potentially help the board make a decision about the best investment choice. If the board's investigation reveals the true type of the manager then the board does not need the information that is revealed in the market. If the board's investigation leads to no information then the board can use the market's noisy signal to potentially make a better decision.[8]

2.2.1 Investment Based on Market Information

Given the market signal we can now determine what would be the best investment decision for shareholders. To see this we first define the following conditional probabilities:

Definition 1: *Define by ξ_H the probability that the manager is of high type after observing a high market signal and define by ξ_L the probability that the manager is of low type after observing a low market signal.*

Bayes rule implies that,

[7] For papers looking at the informational role of stock prices see, for example, Dow and Gorton (1997), Goldman (2004), and Goldstein and Guembel (2008).
[8] Although in our model the board is either fully informed or uninformed relative to the market the results would follow through if we allow for a board that receives a signal that is less noisy than that of the market.

$$\xi_H = \frac{\alpha P_H}{\alpha P_H + (1-\alpha)P_L} \text{ and, } \xi_L = \frac{(1-\alpha)(1-P_L)}{\alpha(1-P_H) + (1-\alpha)(1-P_L)}.$$

Thus, a high market signal will increase the liklihood that the manager is a high type and a low market signal will increase the liklihood that the manager is of low type.

In order for market signals to be of interest we assume that the uninformed board will use these signals in a way that changes its actions. Assumption 4 and Assumption 5 below characterizes this case.

Assumption 4: *Following a low market signal we have that* $\xi_L \frac{\pi_L T_L}{2} + (1-\xi_L)\frac{\pi_H T_H}{2} < R$ *and that* $\xi_L \frac{\pi_B T_L}{2} + (1-\xi_L)\frac{\pi_B T_H}{2} < R$.

Assumption 5: *Following a high market signal we have that,*
$\xi_H \frac{\pi_B T_H}{2} + (1-\xi_H)\frac{\pi_B T_L}{2} > \max\{R,\ \xi_H \frac{\pi_H T_H}{2} + (1-\xi_H)\frac{\pi_L T_L}{2}\}$.

Assumption 4 states that a the best decision for anyone who has no private information about the talent level of the manager and which observes a negative signal from the market ($S = Low$) is to follow the markets view and invest in the mundane project. The assumption simply guarantees that a negative market signal is sufficiently important in that the update that the manager is of low talent is large and leads to a decision to invest in the safe project. Thus, the assumption allows us to focus on the more interesting case in which negative market signals are informative and have an impact on board actions.

Similarly, Assumption 5 states that following a positive market signal our upated estimates that the manager is a high talent manager are sufficient to cause us to prefer the risky investment project. Thus, it too implies that an uninformed board will view a high signal from the market as important and meaningful. Assumption 5, however, also states that with the remaining uncertainty about the talent of the manager the best course of action is to be more cautious. This is achieved by proceeding with the innovative investment, but at the same time increasing the board's involvement with the project.

This assumption is required in order for the board's talent level to play a role in the model.[9] In other words, if we believe that board intervention is never optimal then we would look at a model where,

$$\xi_H \frac{\pi_B T_H}{2} + (1-\xi_H)\frac{\pi_B T_L}{2} < \xi_H \frac{\pi_H T_H}{2} + (1-\xi_H)\frac{\pi_L T_L}{2}.$$

More generaly, our model trys to capture a broad range of possiblities for the impact of the board on the value of the firm both through voting on the investments suggested by the manager and through more direct involvment with the firm at times of uncertainty about the quality of the manager. Focusing on this parameter space is the more interesting and richer setting to analyze. It is easy to verify that many of these assumptions can be justfied as long as $\pi_H > \pi_B > \pi_L$, $0 >> \pi_L$, and as long as α is not too low.

2.3 Governance

The governance of the company is defined based on the parameter g which represents the probability that the power to make the investment decision is at the hands of the board of directors. Recall that the agency problem is that the manager always wants to invest in the innovative project, and that the objective of the board of directors is always to maximize shareholder value. Therefore, with probability g the manager has to get approval from the board for her choice of the investment project while with probability $1-g$ the manager has control over the board which allows her to invest as she sees fit.

The definition of governance in our model can be interpreted as measuring the ability of the board to reject an investment made by the manager any time that the board believes this investment will be a negative net present value investment. One can also

[9] A more general approach would include a continuous distribution for the market signal based on the manager's true talent level. In this case we would have three regions: a high region in which the best actions is to invest in risky project with no intervention, a middle region in which it is best to invest in the risky project with intervention, and a low region in which it is best to invest in the safe project. For simplicity we focus on the two region case which generates all the main results but with less notation.

interpret a rejection of the project offered by the manager as a decision to replace the manager. Therefore, we can later analyze how governance affects the probability that a manager will be replaced.

Finally, we assume that the governance system is in place prior to the decision by the board to invest in learning about manager type and prior to the investment decision.

2.4 Sequence of Events

The sequence of events in the model is depicted in Figure 1. Initially, a firm decides on the level of governance (setting the firm's charter). Then the firm and its board hire a manager whose type is unknown. Once hired, the board collects "on the job" information about the manager and about his level of talent. The manager then makes an announcement about his proposed project which is followed by a market signal (response to this announcement) that provides a noisy assessment of what the market thinks is the talent level of the manager. At this point the investment decision is made according to whoever has control. If the board has the power to decide then it either approves or rejects the investment decision of the manager and either becomes actively involved in the project or not. If the manager has the power to decide then he will always invest in the innovative project. Finally, once investments are made cash flows are realized and the firm is liquidated.

3. Equilibrium

In this section we solve for the equilibrium of the model and discuss the main results of the paper. The equilibrium is defined by the optimal choice of the investment project and intervention policy according to who is in control, an optimal choice of effort in collecting information by the board, and the optimal ex-ante choice of governance that maximizes firm value.

As is customary in these models we solve for the equilibrium by going back in time. We first decide on the ex-post best investment decision. We then solve for the optimal level of effort by the board when taking these future investment decisions into account. Finally, we solve for the ex-ante level of board control (i.e., firm governance) that maximizes the expected value of the firm.

3.1 Ex-Post Investment Choice

In this section we explore the ex-post investment decision by looking at each state of nature separately. The state of nature is defined by whether the board is informed or not, whether the board has power or not, and whether the market signal is high or low. Figure 2 summarizes the investment choices discussed below. For convenience the investment choice is presented separately for the high type and low type managers.

3.1.1 Manager is High Type, T_H

If the manager is of type T_H then an informed board with the power to approve the project will always allow the manager to invest in the innovative project, regardless of whether the market's noisy signal is high or low. This is because the innovative project that is managed by the high talent manager is best for shareholders and because the information that the board has is more precise then the noisy information provided by the market signal.

In the case where the board has power but when it's investigations where not successful, leaving the board uninformed, the board will rely on the information that is provided by the market. In this case if the board observes a negative market signal it will compare the following three expected cash flows:

$$R,\ \xi_L \frac{\pi_B T_L}{2} + (1-\xi_L)\frac{\pi_B T_H}{2} \text{ ,and } \xi_L \frac{\pi_L T_L}{2} + (1-\xi_L)\frac{\pi_H T_H}{2}$$

The first cash flow is the cash flow obtained from investing in the mundane project. The second expected cash flow will be achieved by investing in the innovative project after updating upward the assessment that the manager is a low type and after deciding to intervene in the running of the project. The third cash flow is obtained from investing in the innovative project and letting the manager run it by herself. Because, we assume market signals are important (Assumption 4), the optimal investment decision the board makes in this case is to invest in the mundane project.

In the case when the board is uninformed, has power, and observes a positive market signal it will compare the following three alternatives expected cash flows:

$$R,\ \xi_H \frac{\pi_B T_H}{2} + (1-\xi_H)\frac{\pi_B T_L}{2} \text{ ,and } \xi_H \frac{\pi_H T_H}{2} + (1-\xi_H)\frac{\pi_L T_L}{2}$$

Based on our assumption that the positive market signal is sufficiently informative to impact the actions of the board (Assumption 5) a positive market signal will lead the board to update upward its estimation that the manager is indeed a high talent manager which will imply that mundane investment is suboptimal. The remaining decision faced by the board is whether or not to allow the manager to invest on her own or whether the board should become more involved in the investment process given the remaining uncertainty about the quality of the manager in charge. Because, there is a sufficiently large concern that a low type manager will generate low cash flows in this project it is optimal for the board to allow the innovative investment but also play an active role in the process so as to limit the downside risk.

Finally, in the case where the manager has control, and regardless of the information that the board has, the manager will choose to invest in the risky innovative project. Note, that in this case it is also the optimal choice from the perspective of the board and of its shareholders.

3.1.2 Manager is Low Type, T_L

If manager is of type T_L then an informed board that has power will always require the manager to invest in the mundane project regardless of what is the noisy market signal. If the board is informed but does not have power then the manager will select (inefficiently) to invest in the innovative project.

For all the possible outcomes in the states in which the board is uninformed the investment decisions will be similar to the set of decisions analyzed above for the high type manager. This is because the uninformed board cannot distinguish whether the manager is indeed a high type or a low type and hence must make the same action

independent of the manager's true type. As mentions, Figure 2 summarizes the above discussion.

3.2 Endogenous Information

Given these ex-post investment decisions the board has to choose ex-ante what is the optimal investment to make in collecting information. The board will then choose an effort level, e, that maximizes the following,

$$\max_{e} \ \alpha\Pi_H + (1-\alpha)\Pi_L - C(e) \tag{1}$$

Where, $\Pi_H = e\frac{\pi_H T_H}{2} + (1-e)(1-g)\frac{\pi_H T_H}{2} + (1-e)g[P_H \frac{\pi_B T_H}{2} + (1-P_H)R]$, (2)

and

$$\Pi_L = egR + e(1-g)\frac{\pi_L T_L}{2} + (1-e)(1-g)\frac{\pi_L T_L}{2} + (1-e)g[P_L \frac{\pi_B T_L}{2} + (1-P_L)R]. \tag{3}$$

The above profit function reflects the two inefficiencies that come about in the model. The first is that the manager always wants to invest in the innovative project even if this is not optimal for shareholders. This will create inefficiencies when the manager is a low talent manager and when the board (informed or uninformed) has no power. This will also create an inefficiency, but to a lesser extent, when the board is uninformed and has power.

The second inefficiency arises when the manager is a high talent manager. In this case the inefficient investment will occur when the board is uninformed but has power. Being unsure about the manager's true type the board will then act based on the market signal: either completely forbidding the manager from investing in the innovative project (if the market signal is low) or investing in the innovative project but also intervening with internal decisions (if the market signal is high). Either of these decisions will limit the high ability manager and will hamper her ability to produce the highest profits possible. Note, however, that although this action will lower firm value, it is still the board's best choice given its (lack of) information

One example for this type of inefficiency would be the situation in which the board hired someone like, say, the late Steve Jobs to run the firm, but was unsure whether or not he was indeed a genius. Any intervention by the board in the decisions made by this manager will limit the profitability of the innovative project due to the fact that the talent level of the manager was in fact much higher than that of the board. Intervention, of course would be the right decision by the board since the board may be concerned that the manager is a low talent manager who is leading the firm in a potentially dangerous path.

Lemma 1 *The optimal information collection effort by the board of directors is given by the following,*

$$e^* = \frac{g}{c}\{\alpha[\frac{\pi_H T_H}{2} - (P_H \frac{\pi_B T_H}{2} + (1-P_H)R)] + (1-\alpha)[P_L(R - \frac{\pi_B T_L}{2})]\} \quad (4)$$

Lemma 2 *The board's incentive to become informed about managerial talent increases with board power, and with the expected cash flows generated by a high type manager, but decreases with the board' ability to impact cash flows and with the probability that the market signal is informative about the high talent manager. Finally, information collection increases with the proportion of high talent managers,* α *, if and only if* $\pi_B < \bar{\pi}$ *, where* $\bar{\pi} \equiv \frac{\pi_H T_H - 2R(1-P_H+P_L)}{P_H T_H - P_L T_L}$.

Lemma 1 describes the optimal investment in information production by the board of directors. The board decided on how much information to collect based on its power, the availability of the noisy information from the market, and the inefficiencies created from being uninformed.

In Lemma 2 we describe some of the basic comparative static results concerning the incentive of the board to become. First, Lemma 1 and Lemma 2 show that the board's incentive to become informed increases with the governance of the firm (i.e., with board power), g . This result is due to the fact that the board's information is only useful if the board has power to use it while its information has no value if the board ends up with no power to decide on which investment to make. Therefore, a board that expects to have power will have a higher incentive to learn about what should be the right course

of action. Note, that this result is in sharp contrast to Adams and Ferreira (2007) and Harris and Raviv (2008) who argue that higher board power will result in less informative decisions because a powerful board will discourage the manager from sharing her information.

Second, the two lemma's show that the board collects more information if the cash flows generated by a high talent manager are higher, but that the board collects less information if the board's ability to increase cash flows is higher. The intuition for these results is that becoming informed helps the board to avoid limiting a high talent manager. As the cash flows generated by this manager increase the benefit of becoming informed increases as well. However, when the board is uninformed it will sometimes decide to supervise the manager and thus impact cash flows. As the cash flows generated through board intervention go up the need to become informed is reduced. Thus, the option of a talented board to oversee operations lowers its incentive to monitor ex-ante.

Third, effort to collect information decreases with the probabilities that the market signal will reveal that a high type manager is indeed high, P_H, but increases with the probability that a market signal will be high when the manager is actually a low type, P_L. The intuition for these results is that both a higher probability P_H or a lower probability of P_L imply that the information that the market provides is less noisy. Hence, because the board has to exert costly effort to collect its own information it will have a lower incentive to do that if it cans obtain more accurate information from market prices.

Finally, the incentive for the board to collect information increases with the percentage of high types in the population, α, if and only if the board's ability to oversee the risky project, π_B is sufficiently low**.** The intuition is that the cost of having an uninformed board occurs both when the manager is highly talented (in which case the board might hinder his freedom to generate profits) and when the manager is a low type (in which case an uninformed board would let him invest in the innovative project and supervise). When the value of board supervision is high it reduces the need for the board to be informed (as just explained) but this need is reduced more for a high talent manager relative to a low talent one (note that cash flows are π_B times T_j).

3.3 Investment in The risky Innovative Project

One benefit of explicitly modeling the impact of board power on the board's incentive to become informed is that we can now analyze the relation between board power and the firm's incentive to invest in the risky innovative project.[10]

Definition 2: Let Q be the probability that a firm invests in the innovative project. Then,

$$Q \equiv 1 - g\{(1-\alpha)e^{*} + (1-e^{*})[(1-\alpha)(1-P_L) + \alpha(1-P_H)]\} \tag{5}$$

Investment in long-term risky projects is a key ingredient of any profitable company. From Equation (5) we can see that board power, g, has a direct negative effect on the likelihood of making these investments as $\frac{\partial Q}{\partial g} < 0$. The reason for this is that the board will try to limit investment in innovative projects only to those cases where the board is sufficiently certain that the innovative investments are being made by the highly talented manager.

However, as can be seen from Equation 4, board power also has an indirect effect on Q through its impact on the board's incentive to collect information. In particular, board power increases the incentive of the board to become informed which may result in more innovative activity. Lemma 3 below characterizes the condition under which a more informed board will increase investments in the innovative project.

Lemma 3: *A higher investment in information collection will increase the probability that the firm will invest in the innovative project if and only if the following condition is satisfied,*

$$\frac{P_L}{1-P_H} < \frac{\alpha}{1-\alpha} \tag{6}$$

Lemma 3 shows that the indirect effect of board power may actually result in more powerful boards increasing innovation rather than decreasing it. This can happen because

[10]Edmans (2009) and Goldman and Strobl (2012) also analyze the firms incentive to innovate or invest in long-term projects in a setting where managers are myopic. They focus on the impact that large shareholders have on these investment decisions.

a more powerful board will also (endogenously) become more informed about the manager's talent. The condition for this state is described in Lemma 3.

Intuitively, a more informed board (due to greater board power) will lead to higher likelihood of innovation if the probability that the manager is a low type $(1-\alpha)$, and hence will not be allowed to innovate if board is informed, is lower than the probability that the markets signal will be low $(\alpha(1-P_H)+(1-\alpha)(1-P_L))$, and hence an uninformed board will reject the innovation. The condition in Equation (6) is necessary and sufficient for this to be the case.

Our model argues that a powerful board discourages innovation because it takes away the discretion that a manager needs in order to make innovative investments. However, we also show that board power may increase innovation since it leads the board to put more effort to become informed about the manager's talent level.[11] Note, however that the lemma above considers total innovation which can be both bad for shareholders and good for them. Below we consider the impact of board power on *efficient* innovation investment; that is innovation that maximizes shareholder value.

Definition 3: Let Z be the probability that a firm invests in the innovative project when this is the optimal investment for shareholders. Then,

$$Z \equiv \alpha - \alpha(1-e^*)g \tag{7}$$

Efficient innovation can only occur when the firm is managed by a high talent manager. In this case the only time innovation is stopped is when the board has power but is uninformed about the talent of the manager. In that situation the board will rely on the market signal to either intervene in the managers running of the innovative investment

[11] We focus here on the probability of innovation. Our results generalize to a model where the invested amount is chosen as part of the maximization problem. Namely, if we let the amount invested in innovation be endogenously determined we can show that the board power has a negative direct effect on innovation but a positive indirect effect through the incentive of the board to become informed. Thus, talented managers who face strong boards will optimally avoid making innovative investments for fear that the board will not be able to understand the hidden long-term value in these projects. This will be true unless the board is sufficiently informed. The model with endogenous investment level, however, complicates the analysis without adding much intuition.

(following a high market signal) or simply reject the innovative investment in favor of the mundane project (following a low signal from the market).

From Equation (7) above we see that a board with more power will actually lower the likelihood that the efficient innovative investment will be made as $\frac{\partial Z}{\partial g} < 0$. This happens because a powerful board helps in reducing inefficient investment when the manager is a low type but at the cost of sometimes hurting innovation when the manager is a very talented one. The analysis becomes more interesting once we consider the fact that the board also optimally chooses how much effort to put into becoming informed. It is clear that $\frac{\partial Z}{\partial e} > 0$ which means that a more informed board will increase efficient innovation. Lemma 4 below characterizes what is the total impact of governance on efficient innovation.

Lemma 4: *A more powerful board will result in an increase in efficient innovation if and only if the probability that the board is informed is sufficiently large.*

The intuition behind this result is that a governance system that gives power to the board over the CEO will only increase efficient investment in innovative projects if board power is also accompanies with the board being highly informed about the quality of the manager at the helm. In other words, an uninformed board that has power is actually very detrimental to innovation.

More broadly, we can interpret the result in Lemma 4 as indicating that strong board governance will lead to higher investment in innovation for large values of e^* and will lead to lower levels of innovation if e^* is low. Thus, the empirical implication of the lemma is that any parameter that increases e^* will increase the probability that we are in a regime where governance and innovation are positively correlated. Corollary 1 below summarizes some comparative static results that lead to specific empirical implications.

Corollary 1: *Board power increases efficient investment in innovation whenever it is less costly for the board to become informed (lower c), whenever the markets information is less reliable (lower P_H and higher P_L), and whenever the talent difference*

between the board and the high talent CEO is greater (higher value of π_H and T_H but lower value of π_B.

3.4 Turnover Following Negative Market Signal

Our model considers whether or not the manager's decision to invest in the innovative project is overturned by the board of directors. If we assume that overturning the manager's decision is akin to firing the manager then we can analyze how board governance impacts turnover decisions.

It will be especially instructive to follow the empirical literature (e.g., Weisbach 1988) which has used CEO turnover events in order to measure what a good governance board should look like. In particular, this literature has focused on how responsive is the board to negative signals from the market. The interpretation of boards that are not responsive to negative market signals is that these boards exhibit bad corporate governance. For example, if the turnover to (negative) market signal has a lower responsiveness for large boards then we must conclude that large boards are not good for shareholder governance.

To analyze the relation between governance and how responsive the board is to negative market signals we first define the following measure.

Definition 4: *Let RESP be the probability that we observe a negative market signal followed by a firm investing in the mundane project. Then we have,*

$$RESP \equiv \frac{\text{Prob } \{\text{Invest in } R \mid S = Low\}}{\text{Prob}\{S = Low\}}$$

A calculation of the probabilities of the relevant outcomes from Figure 1 yields the following result,

$$RESP \equiv g\,\frac{\alpha(1-e^{*})(1-P_H)+(1-\alpha)(1-P_L)}{\alpha(1-P_H)+(1-\alpha)(1-P_L)} \qquad (8)$$

From Equation 8 we can see that the direct effect of better governance (higher g) on the board's responsiveness to a bad market signal is positive as $\frac{\partial RESP}{\partial g} > 0$. This is indeed what has motivated the empirical literature, which investigated CEO turnover events, to conclude that better governance should manifest in a higher sensitivity of turnover to stock price declines.

What we want to emphasize is an additional channel through which governance impacts turnover. From Equation 8 we can also observe that, $\frac{\partial RESP}{\partial e} < 0$. Thus, a more informed board will actually be less responsive to negative market signals. The intuition here is that a more informed board will have better information than the market about the manager's skill level and hence will have less use for the markets information. More generally, an informed board will put less weight on any (new) market information regarding the quality of the manager. This will imply that the board will be less likely to replace the manager after a bad market signal. When the amount of information collected by the board is allowed to be endogenous we argue that better governance (as indicated by a board with more power) may lead boards to ignore negative market signals. The lemma below describes when this will occur.

Lemma 5: *Boards with more control will not always exhibit a higher probability of replacing the manager following a negative market signal. Stronger boards will be associated with a higher value of $RESP$ if and only if the equilibrium level of information collected by the board is sufficiently low as indicated by,*

$$e^* \leq \frac{1+\frac{(1-\alpha)(1-P_L)}{\alpha(1-P_H)}}{2} \tag{9}$$

Corollary 2: *If the percentage of high talent managers, α, is sufficiently high, $\alpha > \frac{(1-\alpha)(1-P_L)}{1-P_H}$, then the relation between board power and RESP will be negative when the cost of collecting information, c, is sufficiently low, when board power, g, is sufficiently high, and when cash flows generated by the high talent manager, $\pi_H T_H$, are sufficiently high.*

Lemma 5 indicates that more powerful boards will be more responsive to market information only if their privately collected information is weak. Corollary 2 describes some specific scenarios when this will be the case. For example, the board will be less informed if it has high costs of collecting information, if it expects to have little power, or if the cost of limiting the investment of a high talent manager is low.

A more general interpretation of our findings is that boards that decide to ignore negative market signals could be good boards that have very strong (endogenous) priors about the quality of the manager.

3.5 Firm Value

Recall that the agency problem is that all managers want to invest in the risky project but that the first best investment is for the high talent manager to invest in the innovative risky project and for the low talent manager to invest in the mundane project. If we could achieve this investment scheme we would observe a firm value of,

$$V^{FB} = \alpha \frac{\pi_H T_H}{2} + (1-\alpha)R \tag{10}$$

Because of the over-investment agency problem the board of directors can increase firm value by collecting information and intervening whenever it finds out that the manager is indeed a low type. This comes at the cost of collecting information, at the cost of making a mistaken decision when not fully informed, and at the cost of not having the power to change a bad decision by the manager. The above costs and benefits result in the following expression for the value of the firm under the equilibrium actions,

$$\mathrm{V(g},\alpha,...) = \alpha\Pi_H(e^*) + (1-\alpha)\Pi_L(e^*) - C(e^*) \tag{11}$$

Where Π_H and Π_L are the expected profits under a high type manager and a low type manager respectively, as defined in Equations 2 and 3.

Lemma 6: *The board power that maximizes firm value is at one of the two extremes. It is optimal to either give the board maximum power,* $g^* = 1$*, or give the manager full power,* $g^* = 0$.

As Lemma 6 indicates firm value is maximized either when the board has full power or when the manager has full power. It is first helpful to look at the first order condition,

$$\begin{aligned}\frac{dV}{dg} &= \alpha(1-e^*)\{(P_H\,\frac{\pi_B T_H}{2} + (1-P_H)R - \frac{\pi_H T_H}{2}\} \\ &+ (1-\alpha)\{e^*(R - \frac{\pi_L T_L}{2}) + (1-e^*)[P_L\,\frac{\pi_B T_L}{2} + (1-P_L)R - \frac{\pi_L T_L}{2}]\}\end{aligned} \tag{12}$$

The first term is negative while the second term is positive which is consistent with the intuition that board power is beneficial to shareholder value if the manager ends up being of low quality (probability $1-\alpha$) but is detrimental to shareholder value if the manager is a talented "super star" who will be held up by the mediocre board (probability α).

To derive some comparative statics on when board power is beneficial to shareholders we need to compare the value of the firm when $g^* = 1$ to its value when $g^* = 0$. Substituting for the value of $e^*(g)$ for the two values of board power we get the following:

$$V(g^* = 0) = \alpha\,\frac{\pi_H T_H}{2} + (1-\alpha)\,\frac{\pi_L T_L}{2} \tag{13}$$

and

$$\begin{aligned}V(g^* = 1) = \alpha\{e^*\big|_{g=1}\,\frac{\pi_H T_H}{2} + (1-e^*\big|_{g=1})[P_H\,\frac{\pi_B T_H}{2} + (1-P_H)R]\} + \\ + (1-\alpha)[e^*\big|_{g=1}\,R + (1-e^*\big|_{g=1})[P_L\,\frac{\pi_B T_L}{2} + (1-P_L)R]\} - C(e^*\big|_{g=1})\end{aligned} \tag{14}$$

Equation 13 shows the value of the firm under full manager power. In this case the board optimally decides to collect no information about the manager and hence this is the "no information" case. Here we see that the loss of value arises due to the low talent manager investing in the inefficient innovative project.

Equation 14 shows the value of the firm when the full power over decisions is given to the board of directors. This can be termed the "high information" case because this is the case in which the board optimally collects the maximum possible information about the manager. Here, the loss of value (relative to the first best) arises because the board incurs a cost of collecting information and because the effort to learn about the manager's skill level does not always result in full information to the board.

We now define the variable Δ as

$$\Delta \equiv V(g^* = 1) - V(g^* = 0) \tag{15}$$

This is simply the difference in firm value between the case of high board power and low board power. In the lemma below we analyze under what conditions this difference becomes larger and under what conditions it becomes smaller. Since Δ can be either positive or negative we can interpret any variable that increase (decreases) Δ as increasing the states of nature where board (manager) power is optimal.

Lemma 7: *The difference in firm value between a firm with a powerful board and a firm with a weak board, Δ, is:*

i) *Decreasing in π_H, and in π_L.*

ii) *Increasing with the board's ability to generate cash flows, π_B, and with the board's ability to produce information, (low c).*

iii) *Increasing with the accuracy of information generated by the market, as measured by a higher P_H and a lower P_L.*

iv) *Decreasing with the fraction of managers who are of high talent, α.*

Board power is better for shareholders when the cash flows generated by the high and low talent manager who invests in the innovative risky project are higher. The reason is that a more powerful board is more likely to step in and either reject the innovative investment altogether or intervene in the operation of the innovative project and limit the impact of the manager on cash flows. Thus, when these cash flows are expected to be higher it is less valuable to give the board ex ante power.

On the other hand, when the board has greater ability to generate cash flows (ii) then it is more beneficial to allocate power to the board and away from the manager. This

is because board intervention is less detrimental to cash flows if the manager is high talent and more beneficial if the manager is low talent.

The accuracy of market signals is also a key factor in determining the impact of board control on firm value (iii). The implication from our model is that when market information is more accurate the benefit of allocating the board with power increases. The cost of giving the board power is that the board may end up relying on market information in order to make the best investment decision. Hence, the more accurate is the information from the market the higher is the value created by the board. Note that in the extreme case where market information is fully accurate about managerial type we get back to the first best value of the firm under, $g^* = 1$.

Finally, the lemma shows that as the talent pool of managers becomes better it is more valuable to reduce the power of the board. The reason is that the cost of allocating power to the board is in the fact that an uninformed board with power will tend to intervene too much and lower the value created by a high talent CEO. Thus, as the likelihood that the CEO is indeed a superstar increases allocating control away from the CEO becomes more costly. It is interesting to note that several papers looking at the trend in CEO compensation have argued that this trend can be explained by an increase in the talent of the top CEO's (e.g. Murphy and Zabojnik 2004, Kaplan and Rauh 2010). Our model would then argue that this is exactly the time to reduce board power rather than increase it (unless the talent pool of the board is also on the rise).

4. Conclusion

In this paper we highlight the costs and benefits of allocating control to the board. We show that allocating more power to the board induces the board to become more informed and hence improves on the decision made by the board. However, we also show that board control may come at a cost in those situations when the board is not sufficiently informed and must rely on noisy market information.

We characterize under what conditions board power is preferred over managerial power as well as what we can learn about the relation between board control and managerial turnover and between board control and efficient investment in risky innovations.

Figure 1: Sequence of Events

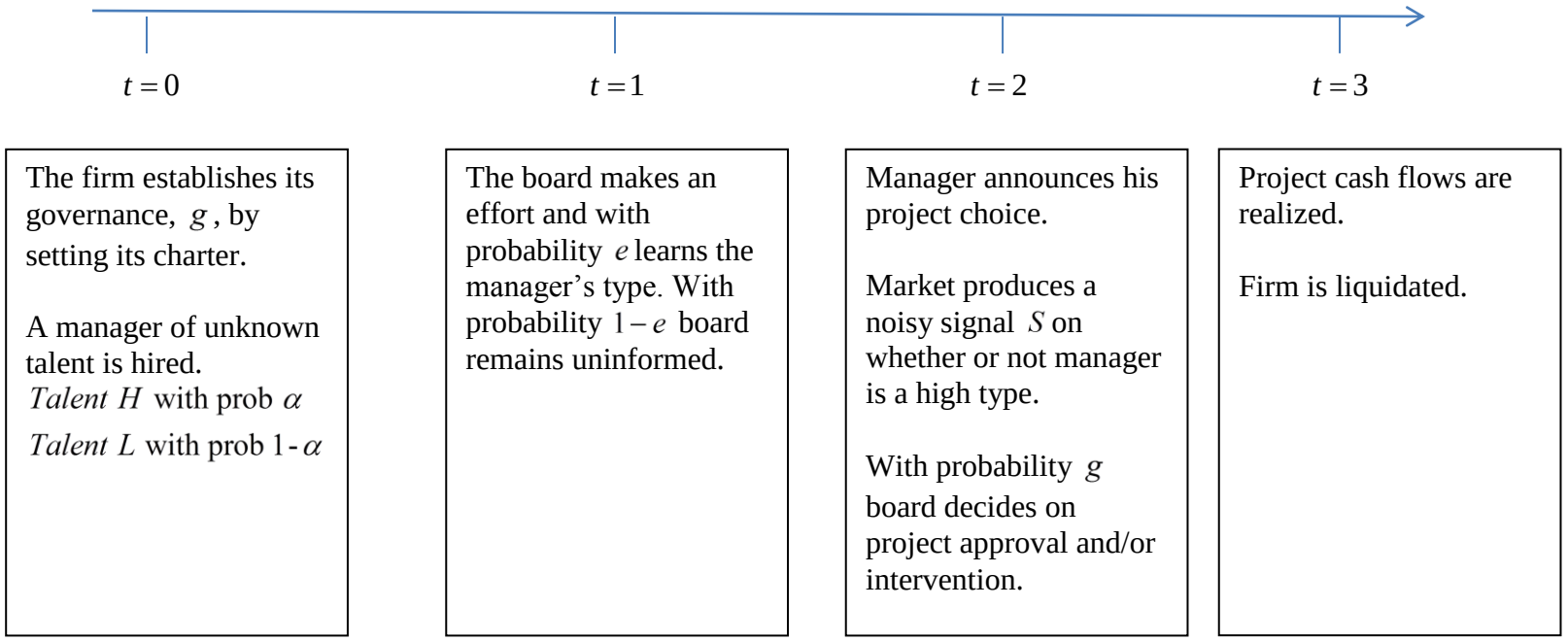

Figure 2: Investment Decision following market information

				Expected Cash flows
Manager Type **High**				
	Board informed	Has Power	Market Signal High	$\frac{\pi_H T_H}{2}$
			Market Signal Low	$\frac{\pi_H T_H}{2}$
		No Power	Market Signal High	$\frac{\pi_H T_H}{2}$
			Market Signal Low	$\frac{\pi_H T_H}{2}$
	Board Uninformed	Has Power	Market Signal High	$\alpha\frac{\pi_B T_H}{2}+(1-\alpha)\frac{\pi_B T_L}{2}$
			Market Signal Low	R
		No Power	Market Signal High	$\frac{\pi_H T_H}{2}$
			Market Signal Low	$\frac{\pi_H T_H}{2}$
Manager Type **Low**				
	Board informed	Has Power	Market Signal High	R
			Market Signal Low	R
		No Power	Market Signal High	$\frac{\pi_L T_L}{2}$
			Market Signal Low	$\frac{\pi_L T_L}{2}$
	Board Uninformed	Has Power	Market Signal High	$\alpha\frac{\pi_B T_H}{2}+(1-\alpha)\frac{\pi_B T_L}{2}$
			Market Signal Low	R
		No Power	Market Signal High	$\frac{\pi_L T_L}{2}$
			Market Signal Low	$\frac{\pi_L T_L}{2}$

References

Adam and Ferreira, 2007, A theory of Friendly Boards, *Journal of Finance*

Aghion, and Tirole, 1997, Formal and Real Authority in Organizations, *Journal of Political Economics.*

Almazan, A., and J. Suarez, 2003, Entrenchment and Severance Pay in Optimal Governance Structures. *Journal of Finance* 58:519–48.

Bebchuk, L.A. , 2005, "The Case for Increasing Shareholder Power," *Harvard Law Review 118*, 835-914.

Burkhart, M., D, Gromb and F., Panunzi, 1997, "Large Shareholders, Monitoring, and the Value of the Firm," *Quarterly Journal of Economics 112*, 3, August, 693-728.

Crawford, V. P. and J. Sobel, 1982, Strategic Information Transmission, *Econometrica*, 50, 1431-1451

Denis, D., J., D. K. Denis, and A., Sarin, 1997, Ownership structure and top executive turnover, *Journal of Financial Economics* 45, 193-222.

Dow, J. and Gorton, G. 1997, Stock Market Efficiency and Economic Efficiency: Is there a Connection?, *Journal of Finance*, 52, 1087–1129.

Edmans, A., 2009, Blockholder Trading, Market Efficiency, and Managerial Myopia, *Journal of Finance*.

Goldman, E., The Impact of Stock Market Information Production on Internal Resource Allocation", *Journal of Financial Economics*, 2004, 71, 143-167

Goldman and Strobl, 2012, Large Shareholder Trading and the Complexity of Corporate Investments , *Journal of Financial Intermediation , forthcoming*.

Goldstein and Guembel, 2008, Manipulation and the Allocational Role of Prices, *Review of Economic Studies*, vol. 75(1), pp. 133-164.

Harris, M., and A., Raviv, 2008, A Theory of Board Control and Size, Review *of Financial Studies*. 21(4): 1797-1832

Harris, M., and A., Raviv, 2010, Control of Corporate Decisions: Shareholders vs. Management, Review *of Financial Studies*. 23(11): 4115-4147

Hermalin, B. E. and M. S. Weisbach, 1998, "Endogenously Chosen Boards of Directors and Their Monitoring of the CEO," *American Economic Review*, 88, 96-118.

Holmstrom, B., 1989, Agency Costs and Innovation, *Journal of Economic Behavior and Organization* 12, 305–327.

Huson, Mark R., Robert Parrino, and Laura T. Starks, 2001, Internal Monitoring Mechanisms and CEO Turnover: A Long Term Perspective. *Journal of Finance* 56, 2265-2297.

Inderst, Roman, and Holger Mueller, 2010, CEO replacement under private information, *Review of Financial Studies*, 23, 2935–2969.

Kaplan, S., and Rauh, J., 2010, Wall Street and Main Street: What Contributes to the Rise in the Highest Incomes? *Review of Financial Studies*, (23), 1004-1050.

Manso, Gustavo, 2011, Motivating Innovation, *Journal of Finance, forthcoming.*

Murphy and Ján Zábojník, 2004, CEO Pay and Appointments: A Market-Based Explanation for Recent Trends, *The American Economic Review* Vol. 94, No. 2, 192-196

Raheja, C., 2005. Determinants of board size and composition: a theory of corporate boards. *Journal of Financial and Quantitative Analysis* 40, 283-306.

Weisbach, 1988, Outside Directors and CEO Turnover, *Journal of Financial Economics*.

Appendix

Proof of Lemma 1: From the maximization problem in Equation 1 and the expected profits in Equation 2 and Equation 3 we see that profits are linear in effort while the cost of effort is convex. Thus, the first order condition characterizes a maximum which can be computed from solving this first order condition.

Proof of lemma 2: Given the value of e^* in Equation 4 we can see that, $\frac{de^*}{dg} = \frac{1}{c}\{\alpha[\frac{\pi_H T_H}{2} - (P_H \frac{\pi_B T_H}{2} + (1-P_H)R)] + (1-\alpha)[P_L(R - \frac{\pi_B T_L}{2})]\}$ which is positive as long as $e^* > 0$. It is also straight forward to verify that $\frac{de^*}{d\pi_H} = \frac{g}{c}\alpha\frac{T_H}{2}$ which, again, is positive, and that $\frac{de^*}{d\pi_B} = -\frac{g}{c}\alpha\frac{T_H}{2}P_H$ which is negative.

A more accurate market signal is obtained when P_H is higher and when P_L is lower. Since, $\frac{de^*}{dP_H} = \frac{g}{c}\alpha[-\frac{\pi_B T_H}{2} + R]$ and since we know that the mundane project is worse then the innovative project run by a high type even with board intervention then the derivative is negative. Similarly, we have that, $\frac{de^*}{dP_L} = \frac{g}{c}(1-\alpha)[R - \frac{\pi_B T_L}{2}]$ which is positive because the mundane project is preferred whenever the manager is a low talent.

Finally, we have that $\frac{de^*}{d\alpha} = \frac{g}{c}\{\frac{\pi_H T_H}{2} - P_H\frac{\pi_B T_H}{2} - (1-P_H)R - P_L R + P_L\frac{\pi_B T_L}{2})\}$. This can be rearranged as $\frac{de^*}{d\alpha} = \frac{\pi_B}{2}(P_L T_L - P_H T_H) + (\frac{\pi_H T_H}{2} - R) + (P_H - P_L)R$. The first term is negative while the last two terms are positive which suggests that the whole derivative is positive as long as π_B is sufficiently small.

Proof of Lemma 3: Based on Equation 5 we see that a more informed board will increase innovation when, $\frac{dQ}{de} = -g\{(1-\alpha) - [(1-\alpha)(1-P_L) + \alpha(1-P_H)]\}$ is positive. This occurs if and only if $\frac{\alpha}{1-\alpha} > \frac{P_L}{1-P_H}$.

Proof of Lemma 4: Taking the derivative of the probability of efficient innovation with respect to board power we have that,

$$\frac{dZ}{dg} = \frac{\partial Z}{\partial g} + \frac{\partial Z}{\partial e}\frac{de}{dg}\bigg|_{e=e^*} = \alpha[g\frac{de}{dg}\bigg|_{e=e^*} - (1-e^*)]$$

But from the equilibrium value of effort we can see that,

$$g\left.\frac{de}{dg}\right|_{e=e^*} = e^*$$

And hence,

$$\frac{dZ}{dg} \geq 0 \Leftrightarrow \alpha[e^* - (1-e^*)] \geq 0 \Leftrightarrow e^* \geq \frac{1}{2}.$$

Proof of Lemma 5: From Equation 8 we have that,

$$\frac{dRESP}{dg} = \frac{1}{[\alpha(1-P_H)+(1-\alpha)(1-P_L)]^2}\{\alpha(1-e^*)(1-P_H)+(1-\alpha)(1-P_L) - g\alpha(1-P_H)\frac{de^*}{dg}\}.$$

Using the fact that $g\frac{de^*}{dg} = e^*$ we can focus on the term in the numerator to yield,

$Sign[\frac{dRESP}{dg}] = Sign\{(1-2e^*)\alpha(1-P_H)+(1-\alpha)(1-P_L)\}$ which is negative if and only if the equilibrium effort level is sufficiently high, as indicated by the condition in the lemma.

Proof of Lemma 6: From the first order condition,

$$\frac{dV}{dg} = \frac{\partial V}{\partial g} + \left.\frac{\partial V}{\partial e}\frac{de}{dg}\right|_{e=e^*}.$$

Note that based on the envelope theorem the second term equals to zero at $e = e^*$. This yields a first order condition of,

$$\frac{dV}{dg} = \alpha(1-e^*)\{(P_H\frac{\pi_B T_H}{2} + (1-P_H)R - \frac{\pi_H T_H}{2}\}$$

$$+(1-\alpha)\{e^*(R - \frac{\pi_L T_L}{2}) + (1-e^*)[P_L\frac{\pi_B T_L}{2} + (1-P_L)R - \frac{\pi_L T_L}{2}]\}$$

Since e^* is linearly increasing in g we have that,

$$\frac{d^2V}{d^2g} = \frac{de^*}{dg}[-\alpha\{P_H\frac{\pi_B T_H}{2} + (1-P_H)R - \frac{\pi_H T_H}{2}\} + (1-\alpha)P_L\{R - \frac{\pi_B T_L}{2}\}].$$

It is easy to verify that the second order condition is positive. This means that the highest value of the firm is achieved on the boundary, either when full power is given to the board or when full power is given to the manager.

Proof of Lemma 7: First note that for any variable, x, we have that,

$\frac{d\Delta}{dx} = \frac{\partial\Delta}{\partial x} + \left.\frac{\partial\Delta}{\partial e}\right|_{e=e^*}\frac{de^*}{dx}$ but due to the envelope theorem we know that $\left.\frac{\partial\Delta}{\partial e}\right|_{e=e^*} = 0$, so that we only need to consider the partial derivative with respect to x.

Thus, $\frac{d\Delta}{d\pi_H} = \frac{\alpha T_H}{2}(e^*\big|_{g=1} - 1) < 0$ this proves (i). We also can see that,

$\frac{d\Delta}{d\pi_B} = \frac{\alpha T_H}{2}(1 - e^*\big|_{g=1})[\alpha\frac{P_H T_H}{2} + (1-\alpha)\frac{P_L T_L}{2}] > 0$, and that $\frac{d\Delta}{dc} = -e^*\big|_{g=1} < 0$ which proves point (ii). Looking at the impact of market information we see that,

$\frac{d\Delta}{dP_H} = (1 - e^*\big|_{g=1})\alpha[\frac{\pi_B T_H}{2} - R] > 0$ which is positive because the innovative project with board intervention with a high talent manager generates higher cash flows than the mundane project, and $\frac{d\Delta}{dP_L} = (e^*\big|_{g=1} - 1)(1-\alpha)[R - \frac{\pi_B T_L}{2}] < 0$ which is negative because board intervention with a low talent manager running the innovative project generates lower value than the mundane project. Finally, we have that

$$\frac{d\Delta}{d\alpha} = e^*\{\frac{\pi_H T_H}{2} - R\} + (1-e^*)\{[P_H\frac{\pi_B T_H}{2} + (1-P_H)R] - [P_L\frac{\pi_B T_L}{2} + (1-P_L)R]\} -$$
$$-(\frac{\pi_H T_H - \pi_L T_L}{2})$$

Note that the first two terms (in the curly brackets) are an average with weights e^* and $1-e^*$. Thus to show that this average is less than $\frac{\pi_H T_H - \pi_L T_L}{2}$ we can show that each term in the average is lower. Since $\frac{\pi_L T_L}{2} < R$ then $\frac{\pi_H T_H - \pi_L T_L}{2} > \frac{\pi_H T_H}{2} - R$ and we are done with the first term. Now $P_H\frac{\pi_B T_H}{2} + (1-P_H)R$ is an average of two terms that are both smaller than $\frac{\pi_H T_H}{2}$ and $P_L\frac{\pi_B T_L}{2} + (1-P_L)R$ is an average of two terms that are both larger than $\frac{\pi_L T_L}{2}$. Thus the difference $[P_H\frac{\pi_B T_H}{2} + (1-P_H)R] - [P_L\frac{\pi_B T_L}{2} + (1-P_L)R]$ has to be smaller than the difference $\frac{\pi_H T_H - \pi_L T_L}{2}$ and the proof is complete.